



RESEARCH ARTICLE

Growth and Survival of *Clarias batrachus* with Associated Macroinvertebrate Dynamics in Integrated Rice – Fish Fields and Conventional Ponds in Lakhimpur, Assam, India

Bipul Saikia*

Senior Assistant Professor, Department of Zoology, North Lakhimpur University, Lakhimpur, Assam, India

Received: 10 Mar 2026

Revised: 17 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Bipul Saikia

Senior Assistant Professor,
Department of Zoology,
North Lakhimpur University,
Lakhimpur, Assam, India
E.Mail: bipul.saikia1@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

A two-year field study (2022-2023) on growth and survival of *Clarias batrachus* with associated macroinvertebrate dynamics in integrated rice–fish fields and conventional ponds was conducted in Lakhimpur district of Assam. Both the systems were maintained under similar stocking density and feeding conditions. Approximately 24 kg of hatchery-produced fingerlings (about 2000 individuals; $\sim 2 \text{ m}^{-2}$), with an initial length of 8-9 cm and mean weight of about 12 g, were stocked. Fish reared in the rice–fish system consistently exhibited better growth and survival compared to those in conventional pond system. At harvest, the average length and weight of fish in the integrated rice–fish fields were 28.78 ± 0.53 cm and 180.75 ± 3.55 g, whereas pond-reared fish attained 26.12 ± 1.93 cm and 174.33 ± 1.63 g. Survival was also higher in the rice–fish system (76.4%) compared to the pond system (68.5%). Macroinvertebrate density was comparatively higher in the rice-field ecosystem. Correlation analysis indicated a moderate negative relationship between macroinvertebrate abundance and fish weight in the rice system, while a clear negative association was witnessed in the pond system. The study recorded higher survival of *Clarias batrachus* in the integrated rice-field system, where macroinvertebrate density was also higher than the pond system.

Keywords: *Clarias batrachus* , rice–fish integration, macroinvertebrates, supplementary feeding, fish survival



**Bipul Saikia**

INTRODUCTION

The Asian catfish *Clarias batrachus* (Linnaeus, 1758) is a well-known freshwater food fish valued for its considerable nutritional benefits. It is rich in protein and iron and contains comparatively low fat [1, 2]. Although it is not regularly listed among commonly consumed fish in daily diets, mainly due to its higher market price, it is often preferred for its health benefits, especially during illness and post-operative recovery. Despite its importance in both nutrition and the local economy, wild populations of this species have decreased in many regions because of habitat degradation, pollution, and overexploitation [3–5]. While hatchery-based seed production has improved the availability of fingerlings, identifying suitable and sustainable grow-out systems remains essential to maintain production and reduce pressure on wild stocks [6, 7]. Anthropogenic activities have considerably altered aquatic habitats, including the drainage of natural ponds, conversion of wetlands, and modification of low-lying landscapes, thereby reducing the availability of suitable environments for indigenous fish species [8, 9]. Furthermore, seasonal drying of wetlands and complete drainage during harvesting periods often lead to the reduction of remaining fish populations and brood stock [10, 11]. Changes in environmental conditions, especially fluctuations in temperature and water availability, can impose stress on native fish species and influence their survival. However, rice-field ecosystems, particularly those associated with deep-water rice cultivation, tend to retain shallow and relatively stable water conditions.

The presence of vegetation in such systems may provide shelter and refuge, thereby supporting fish survival [12]. Rice–fish integrated farming systems are now increasingly recognized as productive and sustainable agroecosystems where crop and fish production are carried out at the same period of time within the same area. These systems usually harbor a wide-range of aquatic macroinvertebrates, including insect groups such as Hemiptera, Coleoptera, Diptera, and Odonata, along with other benthic organisms. Many of these organisms act as natural food for insectivorous fish and contribute significantly to overall productivity [13, 14]. Such naturally available food resources may reduce reliance on external feed inputs and enhance both the growth and survival of fish. In addition to natural food availability, supplementary feeding remains an important factor influencing the growth of *Clarias batrachus* under culture conditions. Feeds prepared from locally using ingredients like rice bran, fish meal, molluscan shell powder, and silkworm pupae are often used by farmers because they are nutritionally adequate and cost-effective [15–17].

However, the relative contribution of natural food organisms and supplementary feed, whether influence independently or together, to fish growth in integrated rice–fish system in compared to conventional pond culture was not well defined. Although rice–fish integrated culture is practiced in certain parts of Assam, there is still a lack of well documented comparative studies evaluating the growth and survival performance of *Clarias batrachus* under similar management conditions in integrated rice–fish system and conventional pond culture system. In addition, there is scanty information on the role of naturally occurring macroinvertebrate communities, including paddy pest, and their influence on fish growth and survival. Therefore, the present study was designed to assess the growth performance, survival rate, and biomass accumulation of hatchery produced *Clarias batrachus* reared in integrated rice fish field and conventional pond systems under comparable stocking densities and feeding conditions. Furthermore, the study also investigates the distribution of aquatic macroinvertebrates in both the systems and examines their possible relationship with fish growth parameters and survival.

MATERIALS AND METHODS

Study Area and Experimental Design

The study was conducted during 2022–2023 at Madhukalya Aquatic Farm, Seajuli (27.342953°N, 94.125703°E), located in the Lakhimpur district of Assam, India. The experimental rice field comprised a low-lying, waterlogged area with



**Bipul Saikia**

scattered open-water patches. The area covers for fish culture was about 3 bigha (≈ 0.4 ha), and water depth varied between 30 and 50 cm throughout the culture period. Nearby earthen ponds within the same farm served as the comparison system and experienced similar agro-climatic conditions. A parallel comparative approach was followed to assess two culture systems: an integrated rice–fish field (System A) and a conventional earthen pond (System B). Both systems were managed under similar conditions to reduce experimental variation. Fingerlings from the same batch were stocked in each system, and uniform stocking density, feeding schedule, and monitoring procedures were maintained.

Fish Stocking and Feeding

Healthy early-stage fingerlings of *Clarias batrachus* (mean length 8–9 cm; average weight ≈ 12 g) were collected from hatchery sources. Before stocking, the fingerlings were carefully graded to maintain uniform size. A total of approximately 24 kg of hatchery-produced fingerlings (≈ 2000 individuals; $\sim 2\text{m}^{-2}$) were stocked in each system, following recommended low density stocking practice [18, 19]. Supplementary fish feed were prepared using locally available ingredients, including rice bran (35%), fish meal (25%), silkworm pupae meal (25%), molluscan meal (10%), and rice flour (5%) used as a binder [20, 21]. Feeding was carried out at about 4% of the estimated standing biomass per week, in accordance with low-input culture practices [22]. The standing biomass was estimated at regular interval through gill net sampling, based on the average body weight and the estimated number of surviving fish. The calculated weekly fish feed amount was equally divided into two portions and applied twice a week in shallow feeding areas to enhance feed utilization and minimize wastage.

Growth Monitoring and harvest

Mean length and weight of fish with standard deviation was measured on a monthly basis using gill net of mesh sizes 1.5 to 3.5 cm. During each sampling, catch per unit effort (CPUE; fish net⁻¹) was also recorded. Fish survival was assessed monthly at regular interval during the study periods. At the end of culture period, when water accumulated in deeper section of paddy field and nearby water bodies, the fish samples were collected using drag nets followed by partial removal of water from the source.

Macroinvertebrates sampling and identification

Aquatic macroinvertebrates were collected monthly from both the rearing fields from July to November in each study years. For quantitative analysis, a one square meter quadrat placed randomly within each habitat and the aquatic vegetation within the quadrat was disturbed gently to dislodge the organisms. A D-frame net with a mesh size of 500 μm was then used to collect the organisms, following established aquatic biomonitoring procedures [23, 24] as well as commonly adopted methods in rice-field environments. Identification was performed up to the lowest possible taxonomic level using standard identification keys [25–28]. Macroinvertebrate density was quantified as individual per m^2 .

Statistical analysis

Mean values with standard deviation related to fish growth and macroinvertebrates abundance were calculated separately for each year and also for combined dataset. Two-way analysis of variance (ANOVA) were applied to analyze the effect of sampling months and culture system (rice–fish field and pond) on the fish and macroinvertebrates parameters, considering both factors as fixed effects. Pearson's correlation was also performed to understand the relationship between macroinvertebrates abundance and fish growth parameters within each culture systems. Differences in total harvest parameters of fish between two culture systems were evaluated with sample *t* tests. Statistical significance was determined at $p < 0.05$, and all statistical analysis were done using IBM SPSS statistics (version 25).



**Bipul Saikia****Ethical considerations**

Fish handling and sampling were performed with minimal stress, and the fish were released back to their respective habitats after measuring parameters. The final harvesting was performed by farm owners following routine aquaculture practices.

RESULTS

The *Clarias batrachus* was increased steadily in size and weight in both the culture systems during 2022 and 2023, with higher observed values in integrated rice-fish field (System A) compared to the pond (System B). Fish growth shown slightly better in 2022. The month, July showed a mean length of 11.01 ± 0.84 cm in System A and 10.98 ± 0.72 cm in System B. At the time of harvest, fish in system A attained a mean length of 28.68 ± 0.51 cm and weight about 179.20 ± 3.68 g, whereas the System B showed the value of 25.94 ± 2.29 cm in length and 173.56 ± 1.82 g in weight. The month September was reported with medium growth parameter; recorded a length of 22.67 ± 1.78 cm in System A and 21.16 ± 2.94 cm in System B (Table 1). A similar growth line was observed in 2023. *Clarias batrachus* measured 12.15 ± 0.76 cm in System A and 11.9 ± 0.25 cm in System B during month of July, 2023. This increasing pattern continued over the subsequent month of the year, climaxing at harvest with mean values of 28.88 ± 0.56 cm in length and 182.29 ± 2.80 g in weight in system A. The system B showed 26.29 ± 1.61 cm of length and 175.10 ± 0.98 g in weight (Table 2).

Catch per Unit Effort (CPUE):

Catch per unit (CPUE) showed a gradual decline in both systems over the culture period, although CPUE quantify consistently higher in the rice-fish field. In 2022, CPUE decreased from 9.9 ± 1.52 to 8.0 ± 2.67 fish net⁻¹ in System A and from 9.7 ± 2.00 to 6.6 ± 2.95 fish net⁻¹ in System B. A comparable trend was observed in 2023, where CPUE declined from 9.8 ± 1.87 to 8.0 ± 4.99 fish net⁻¹ in System A and from 9.2 ± 1.55 to 7.2 ± 3.43 fish net⁻¹ in System B (Tables 1 and 2).

Pooled Harvest Performance and Survival

The pooled data from both years clearly indicated that *Clarias batrachus* performed better in the integrated rice-fish system. Mean harvest length and weight were higher in System A (28.78 ± 0.53 cm; 180.75 ± 3.55 g) compared to System B (26.12 ± 1.93 cm; 174.33 ± 1.63 g), and these differences were statistically significant ($p < 0.05$). Survival rate also followed a similar trend, with higher survival recorded in System A (76.4%) than in System B (68.5%) (Table 3).

Macroinvertebrate Abundance and Distribution

Macroinvertebrate density differed between the two systems, with consistently higher abundance recorded in the rice-fish field (Table 4). Two-way ANOVA revealed a significant effect of culture system ($p < 0.01$) and year ($p < 0.05$), whereas the interaction between these factors was not significant ($p > 0.05$). Within the prey-predator assemblage of the rice-field ecosystem, paddy pest species such as *Nilaparvata lugens*, *Dicladispa armigera*, *Scirpophaga incertulas*, *Cnaphalocrocis medinalis*, and *Spodoptera amauritia* were found only in the rice-fish field (Table 4). The pooled mean ($\pm$ SD) of macroinvertebrate density for 2022–2023 was higher in the rice-fish system compared to the pond system. Among the recorded taxa, *Scirpophaga incertulas*, *Dicladispa armigera*, *Nilaparvata lugens*, and *Hydrometra* sp. were the most abundant, with higher densities in the rice-fish field. In contrast, the pond system was dominated by *Ranatra* sp., *Laccotrephes ruber*, and *Baetis fuscatus*, with *Ranatra* sp. and *Laccotrephes ruber* occurring at relatively higher densities in the pond than in the rice-fish field (Fig. 1). Macroinvertebrates belonging to major taxonomic groups such as Odonata, Hemiptera, Coleoptera, Diptera, and Gastropoda were present in both systems, but their overall densities were higher in the rice-fish field (Fig. 2).



**Bipul Saikia****Association between Macroinvertebrates and Fish Growth**

Pearson correlation analysis showed a negative relationship between macroinvertebrate density and fish harvest weight in both systems. In the rice–fish field, the correlation was moderate and not statistically significant ($r = -0.47$, $p > 0.05$). In contrast, the pond system exhibited a stronger and statistically significant negative correlation ($r = -0.66$, $p < 0.05$).

DISCUSSION

The results obtained during the present study indicate that the integrated rice–fish system offers a more favorable environment for the rearing of *Clarias batrachus* when compared with the conventional pond system. Fish reared in rice fields consistently showed better growth, higher survival rates, and improved catch efficiency during the two successive culture cycles. These results explained that, beyond supplementary feeding, environmental conditions and ecological interactions play an important role in influencing fish performance, which is in support of earlier studies on rice–fish ecosystems [22, 29]. As both systems were given with similar feeding inputs, the differences seen are likely related to variations in natural food availability and habitat conditions. The improved growth observed in the rice–fish system appears to be closely linked to the higher natural productivity of the paddy ecosystem. The significantly greater abundance of macroinvertebrates recorded in the rice–fish field (Fig. 1; Table 4) indicates the availability of a diverse range of natural food organisms, including insect larvae and benthic fauna. These organisms likely complemented the supplementary feed and contributed to enhanced nutrient intake and growth [13, 30]. The farm-based supplementary feed also provided a balanced diet, supporting normal growth and maintaining the overall health of fish in both systems. In contrast, the comparatively lower biological diversity in the pond system may have limited the contribution of natural food resources to fish growth [31].

The higher macroinvertebrate abundance in the integrated system also reflects the structurally complex nature of the rice-field habitat. The presence of vegetation, shallow water, and varied microhabitats creates multiple ecological niches and allows continuous input of organic matter. Such conditions are likely to support sustained production of invertebrates, thereby strengthening the trophic base for fish growth and survival [32, 33]. The exclusive occurrence of rice-associated insect taxa in the rice–fish field, as presented in Table 4, further emphasizes the ecological characteristics of the paddy environment. These insects, including several important rice pests, may serve as an additional food source for *Clarias batrachus*. This indicates the possibility of trophic interactions between fish and pest populations, which may contribute to a certain degree of natural regulation within the system [34]. Although gut content of fishes were not examined in this study, the presence of such prey organisms suggests a potential role of fish in controlling pest populations in rice-based agro-ecosystems. The observed negative relationship between macroinvertebrate abundance and fish growth in both systems may be explained by predator–prey dynamics. In the pond system, the stronger negative correlation suggests that increased fish biomass may result in greater consumption of available macroinvertebrates, leading to a decline in their abundance. On the other hand, the weaker relationship in the rice–fish system may be due to continuous replenishment and regeneration of macroinvertebrate populations, which helps maintain their availability despite predation pressure [32]. However, this relationship should be interpreted with caution, as correlation does not necessarily indicate direct causation and may also be influenced by other environmental factors. The higher survival of *Clarias batrachus* observed in the rice–fish system (Table 3) may be attributed to the presence of vegetation and structurally diverse habitats that provide shelter and reduce environmental stress. The shallow and heterogeneous conditions of the rice field likely enhance habitat suitability and improve fish retention compared to pond environments. These factors collectively promote better adaptation and survival of *Clarias batrachus* under integrated culture conditions [35]. The interactive role of macroinvertebrates in integrated fish-rice field also suggest that improve fish growth parameters is not only because of supplementary diet but is positively influenced by natural productivity and ecological interaction within the system.



**Bipul Saikia**

CONCLUSIONS

Integrated rice-fish farming for this nutritious fish species can be considered a practical and sustainable approach, particularly in deep water rice ecosystems. On the other hand, this study provides baseline information in to Indian cat fish production, macroinvertebrates dynamics, and even biological pest management within such integrated system.

ACKNOWLEDGEMENTS

The author expresses deep gratitude to Prof.D N Das, Department of Zoology, Rajiv Gandhi University, for his valuable suggestions and guidance throughout the course of this study. The author is also highly thankful to Mr. Bikul Goswami for providing the opportunity to conduct the experiment on his farm, as well as for his assistance and support during the study. The author gratefully acknowledges the faculty members of the department of Zoology, North Lakhimpur University, for their help and support.

REFERENCES

1. Chand BK, Dubey SK, Trivedi RK, Beg MM, Das UK, Ghosh SK. Dose optimisation of the synthetic reproductive hormone WOVA-FH for induced breeding of *Clarias batrachus* (Linnaeus, 1758). ZoolEcol 2015; 25 (4):365–72.
2. Devi LS, Devi AI. Nutritional values of *Clarias batrachus* (Linnaeus, 1758), walking catfish. J AdvZool 2023; 44:1–5.
3. Dey A. Catfish *Clarias batrachus* , a threatened species needs to be conserved for sustainability of life: A review. In: Revisiting strategies for sustainable development. Vol. 2. 2022. p. 66–70.
4. Sharma B, Khatoon A, Jaiswal M. Freshwater fish biodiversity of Indrapuri Dam, Rohtas, Bihar. J Fish Res 2023;7 (6):177.
5. Talwar PK, Jhingran AG. Inland fishes of India and adjacent countries. Vol. 2. New Delhi: CRC Press; 1991.
6. Sasmal S, Das D, Khaparde M, Thakur A. Growth and production of desimagur (*Clarias batrachus*) under fresh water biofloc system. Uttar Pradesh J Zool 2024;45 (23):84–87.
7. Zafar MA, Hasan MZ, Ali MM. Growth and production performance of Vietnamese koi (*Anabas testudineus*) with magur (*Clarias batrachus*) at different stocking densities. Asian-Australas J BiosciBiotechnol 2017;2 (3):226–27.
8. Maurya PK, Shubham G, Majhi SK. Factors posing threat to the endangered catfish *Clariasmagur* and strategies for conservation. Environ Ecol 2018;36 (3):749–54.
9. Kalita B, Chakraborty A, Dey A. Present status of fish population, abundance, and anthropogenic stressors affecting ichthyofaunal diversity in DeeporBeel, Assam, India. Biol Forum Int J 2025;17 (2):1–13.
10. Nahar S, Rahman MH, Islam MS, Alam MA, Lupa ST, Amin A, et al. Fish biodiversity at haor wetland of Bangladesh: A comprehensive review. Int J Aquac Fish Sci 2025;11(1):001–09.
11. Welcomme RL. Inland fisheries: ecology and management. Oxford: FAO and Blackwell Science; 2001.
12. Roger PA. Biology and management of the floodwater ecosystem in rice fields. Manila: International Rice Research Institute; 1996.
13. Halwart M. Biodiversity and nutrition in rice-based aquatic ecosystems. J Food Compos Anal 2006;19 (6–7):747–51.
14. Vromant N. Combining fish and rice production. CABI Rev 2008; 3:1–10.
15. Vishnu SS, Anand Prasad P, Lavanya CH, Mamatha D, Thriveni K, Meshram SN. Review on silkworm pupal meal as a protein source in aquatic animal nutrition as a replacement of fish meal. Uttar Pradesh J Zool 2024;45 (20):1–16.
16. Paulraj R. Aquaculture feed. MPEDA Handbook No. 10. Cochin: Marine Products Export Development Authority; 1993.





Bipul Saikia

17. Tacon AGJ. Standard methods for the nutrition and feeding of farmed fish and shrimp. Rome: FAO; 1991.
18. Bombeo RF, Fermin AC, Tan-Fermin JD. Nursery rearing of the Asian catfish *Clarias macrocephalus* at different stocking densities in cages suspended in tanks and ponds. *Aquac Res* 2002; 33(13):1031–36.
19. Aktar MRA, Hossain MDH. Effect of stocking density on growth, survival and production of *Clarias batrachus* fry in nursery hapa under semi-intensive culture system. *J Bio Sci* 2023;31(1):17–27.
20. FAO. FAO aquaculture newsletter No. 56. Rome: FAO; 2017.
21. De Silva SS, Turchini GM. Use of wild fish and other aquatic organisms as feed in aquaculture. In: Hasan MR, Halwart M, editors. Fish as feed inputs for aquaculture. FAO Fish Aquac Tech Pap No. 518. Rome: FAO; 2009. p. 63–127.
22. Halwart M, Gupta MV, editors. Culture of fish in rice fields. Rome: FAO and World Fish Center; 2004.
23. Barbour MT, Gerritsen J, Snyder BD, Stribling JB. Rapid bioassessment protocols for use in streams and wadeable rivers. Washington DC: US Environmental Protection Agency; 1999.
24. Rosenberg DM, Resh VH. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. In: Rosenberg DM, Resh VH, editors. Freshwater biomonitoring and benthic macroinvertebrates. New York: Chapman & Hall; 1993. p. 40–158.
25. Imms AD. A general textbook of entomology. 9th ed. London: Methuen & Co.; 1957.
26. Edmondson WT, editor. Ward and Whipple's fresh-water biology. 2nd ed. New York: John Wiley & Sons; 1959.
27. Merritt RW, Cummins KW, Berg MB, editors. An introduction to the aquatic insects of North America. 4th ed. Iowa: Kendall/Hunt Publishing; 2008.
28. Subramanian KA, Sivaramakrishnan KG. Aquatic insects of India: A field guide. Bengaluru: ATREE; 2007.
29. Prein M. Integration of aquaculture into crop–animal systems in Asia. *AgricSyst* 2002; 71(1–2):127–46.
30. Saikia B, Kachari A, Das DN. Exploring macroinvertebrates including aquatic oligochaetes across seasons in baorice fields of Lakhimpur, Assam. *Int J ZoolInvestig* 2024;10(2):1106–15.
31. Fernando CH. Rice field ecology and fish culture—an overview. *Hydrobiologia* 1993;259(2):91–113.
32. Lawler SP. Rice fields as temporary wetlands: A review. *Isr J Zool* 2001;47(4):513–28.
33. Bambaradeniya CNB, Amarasinghe FP. Biodiversity associated with rice field agro-ecosystems in Sri Lanka. *BiodiversConserv* 2004;13:1715–53.
34. Little DC, Edwards P. Integrated livestock–fish farming systems. FAO Fish Tech Pap. Rome: FAO; 2003.
35. Berg H, Berg C, Nguyen TT. Integrated rice–fish farming: Safeguarding biodiversity and ecosystem services. *J Sustain Agric* 2012;36(8):859–72.

Table1: Monthly growth performance of *Clarias batrachus* in integrated rice–fish field(System A) and conventional pond(System B) during 2022.

Month	Length (cm) Mean $\pm$ SD		Weight (g) Mean $\pm$ SD		CPUE (fish net ⁻¹) Mean $\pm$ SD	
	System A	System B	System A	System B	System A	System B
Stocking	8.81 $\pm$ 0.52	8.62 $\pm$ 1.22	12.23 $\pm$ 1.58	12.02 $\pm$ 1.33	*	*
July	11.01 $\pm$ 0.84	10.98 $\pm$ 0.72	24.67 $\pm$ 2.04	22.87 $\pm$ 1.67	9.9 $\pm$ 1.52	9.7 $\pm$ 2.00
August	16.17 $\pm$ 1.22	15.40 $\pm$ 0.79	44.71 $\pm$ 2.20	40.87 $\pm$ 1.35	9.4 $\pm$ 1.07	9.2 $\pm$ 0.79
September	22.67 $\pm$ 1.78	21.16 $\pm$ 2.94	74.80 $\pm$ 2.17	71.21 $\pm$ 3.23	9.1 $\pm$ 1.97	8.8 $\pm$ 2.62
October	24.32 $\pm$ 1.00	22.14 $\pm$ 2.43	120.72 $\pm$ 6.33	116.08 $\pm$ 3.11	8.4 $\pm$ 1.43	8.2 $\pm$ 2.62
November	28.05 $\pm$ 0.32	25.44 $\pm$ 2.27	170.28 $\pm$ 1.31	166.51 $\pm$ 4.46	8.0 $\pm$ 2.67	6.6 $\pm$ 2.95
Harvest	28.68 $\pm$ 0.51	25.94 $\pm$ 2.29	179.20 $\pm$ 3.68	173.56 $\pm$ 1.82	*	*





Bipul Saikia

Table2: Monthly growth performance of *Clarias batrachus* in integrated rice–fish field (System A) and conventional pond (System B) during 2023.

Month	Length (cm) Mean $\pm$ SD		Weight (g) Mean $\pm$ SD		CPUE (fish net ⁻¹) Mean $\pm$ SD	
	System A	System B	System A	System B	System A	System B
Stocking	9.19 $\pm$ 1.51	9.01 $\pm$ 0.61	12.65 $\pm$ 1.76	12.05 $\pm$ 1.17	*	*
July	12.15 $\pm$ 0.76	11.98 $\pm$ 0.25	25.80 $\pm$ 2.29	24.80 $\pm$ 2.52	9.8 $\pm$ 1.87	9.2 $\pm$ 1.55
August	18.20 $\pm$ 0.71	17.88 $\pm$ 0.58	45.79 $\pm$ 2.99	43.29 $\pm$ 2.59	9.2 $\pm$ 0.79	8.8 $\pm$ 1.23
September	23.86 $\pm$ 1.23	22.75 $\pm$ 0.67	75.64 $\pm$ 2.62	74.79 $\pm$ 3.20	8.8 $\pm$ 2.62	7.9 $\pm$ 2.6
October	25.70 $\pm$ 0.74	24.89 $\pm$ 0.67	121.07 $\pm$ 1.52	110.59 $\pm$ 3.46	8.2 $\pm$ 2.62	7.3 $\pm$ 1.42
November	28.31 $\pm$ 0.52	25.87 $\pm$ 1.17	171.69 $\pm$ 2.48	167.38 $\pm$ 5.86	8.0 $\pm$ 4.99	7.2 $\pm$ 3.43
Harvest	28.88 $\pm$ 0.56	26.29 $\pm$ 1.61	182.29 $\pm$ 2.80	175.10 $\pm$ 0.98	*	*

Note: Values represent Mean $\pm$ SD. System A = integrated rice–fish field; System B = conventional pond. CPUE = catch per unit effort (fish net⁻¹). *CPUE was not recorded during stocking and final harvest because the total fish population was counted directly.

Table 3:Final Harvest Performance of *Clarias batrachus* in Integrated Rice–Fish Field and Conventional Pond Systems (Pooled Data for July–November, 2022–2023)

Parameter	Integrated Rice–Fish Field	Conventional Pond
Initial Stocking (No.)	2000	2000
Mean harvest length (cm)	28.78 $\pm$ 0.53	26.12 $\pm$ 1.93
Mean harvest weight (g)	180.75 $\pm$ 3.55	174.33 $\pm$ 1.63
Mean survivors (No.)	1528	1370
Survival (%)	76.4	68.5

Table 4: Distribution of Macroinvertebrates in Integrated Rice–Fish Field(A) and Conventional Pond System(B) (Mean $\pm$ SD).

Order	Taxon	July–November 2022		July –November 2023	
		System A	System B	System A	System B
Araneae	Aquatic spider sp.	3.28 $\pm$ 2.41	0.88 $\pm$ 0.67	6.60 $\pm$ 3.54	7.2 $\pm$ 4.78
Trombidiformes	Hydracarina sp.	5.80 $\pm$ 2.9	2.36 $\pm$ 2.29	3.20 $\pm$ 2.94	6.12 $\pm$ 3.24
Decapoda	<i>Macrobrachium</i> sp.	7.40 $\pm$ 4.89	4.00 $\pm$ 2.31	1.96 $\pm$ 1.93	3.76 $\pm$ 3.27
Odonata	<i>Ischnura</i> sp.	5.56 $\pm$ 3.99	5.12 $\pm$ 3.82	4.28 $\pm$ 2.97	1.08 $\pm$ 1.19
	<i>Ceragrion</i> spp.	6.36 $\pm$ 2.72	4.56 $\pm$ 2.92	2.88 $\pm$ 2.33	2.24 $\pm$ 1.27
Ephemeroptera	<i>Baetisfuscatus</i>	7.84 $\pm$ 9.68	10.16 $\pm$ 9.04	5.16 $\pm$ 3.06	0.88 $\pm$ 1.01
Hemiptera	<i>Gerris</i> sp.	7.24 $\pm$ 4.77	5.32 $\pm$ 3.53	4.04 $\pm$ 3.19	2.68 $\pm$ 2.51
	<i>Hydrometra</i> spp.	8.00 $\pm$ 3.5	6.72 $\pm$ 4.68	6.64 $\pm$ 2.61	2.12 $\pm$ 2.65
	<i>Notonecta</i> sp.	8.08 $\pm$ 3.52	7.20 $\pm$ 3.37	5.32 $\pm$ 3.12	2.84 $\pm$ 2.76
	<i>Ranatra</i> sp.	8.52 $\pm$ 2.83	8.68 $\pm$ 2.94	4.08 $\pm$ 3.01	6.36 $\pm$ 3.58
	<i>Lethocerus indicus</i>	2.04 $\pm$ 1.74	3.60 $\pm$ 2.97	2.92 $\pm$ 3.01	2.12 $\pm$ 3.03
	<i>Laccotrephes ruber</i>	5.44 $\pm$ 2.92	5.84 $\pm$ 3.79	5.8 $\pm$ 4.86	6.84 $\pm$ 3.69
	<i>Diplonychus rusticus</i>	4.52 $\pm$ 3.11	2.00 $\pm$ 1.5	6.52 $\pm$ 3.73	1.64 $\pm$ 1.22
	<i>Nilaparvatalugens</i>	6.24 $\pm$ 3.7	0 $\pm$ 0	9.16 $\pm$ 3.42	0 $\pm$ 0
Coleoptera	<i>Cybister fimbriolatus</i>	1.88 $\pm$ 2.01	2.12 $\pm$ 2.05	6.48 $\pm$ 4.62	2.16 $\pm$ 1.82
Coleoptera	<i>Diadisa armigera</i>	7.00 $\pm$ 4.08	0 $\pm$ 0	9.04 $\pm$ 3.68	0 $\pm$ 0
Diptera	<i>Chironomus</i> sp.	3.28 $\pm$ 2.88	3.48 $\pm$ 2.26	3.64 $\pm$ 3.26	0.52 $\pm$ 0.59
Lepidoptera	<i>Scirpophagaintertulas</i>	7.64 $\pm$ 2.08	0 $\pm$ 0	10.92 $\pm$ 7.51	0 $\pm$ 0
	<i>Cnaphalocrocismedinalis</i> ,	2.40 $\pm$ 1.87	0 $\pm$ 0	5.2 $\pm$ 2.96	0 $\pm$ 0





Bipul Saikia

	<i>Spodoptera amauritia</i>	10.08±5.44	0±0	3.84±2.36	0±0
Gastropoda	<i>Planorbis</i> sp.	3.96±2.57	2.44±2.02	4.52±2.47	1.68±0.99
	<i>Pila globosa</i>	5.20±2.71	4.12±2.64	6±2.66	3.28±1.62

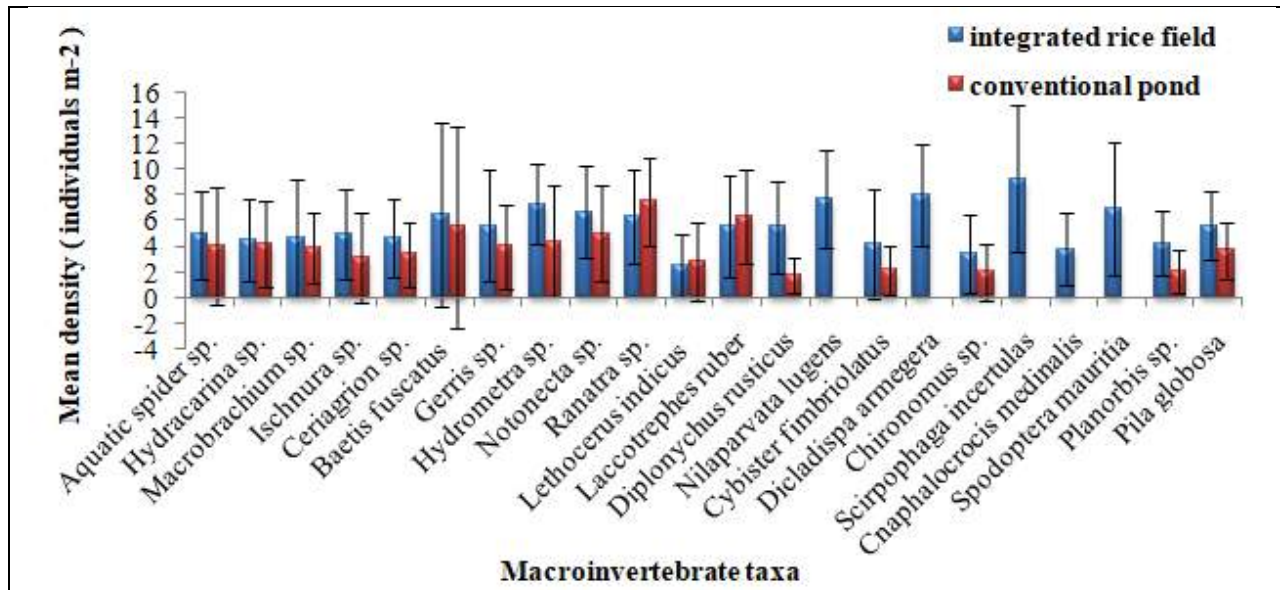


Fig 1: Mean (±SD) density of macroinvertebrates at integrated rice-fish field and conventional pond during 2022–2023.

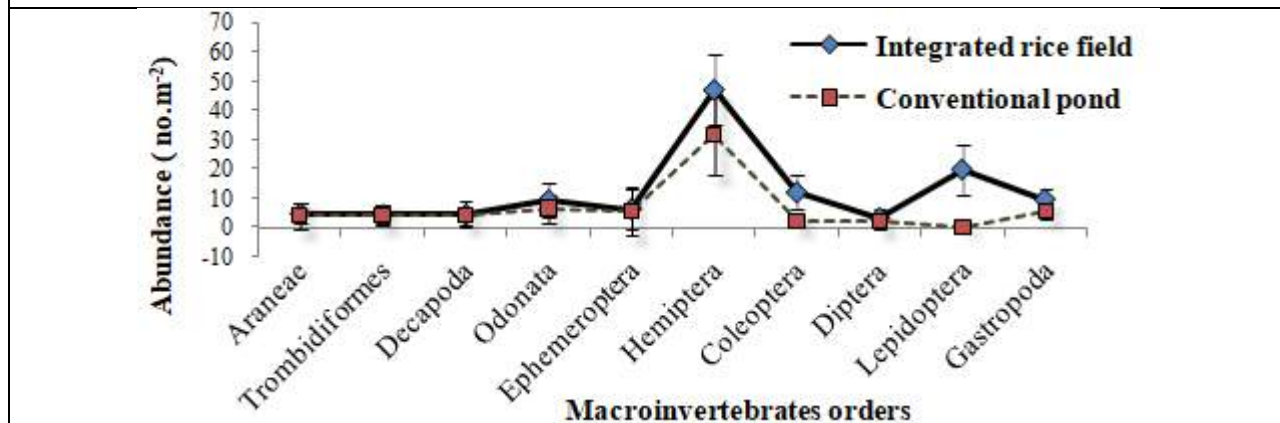


Fig 2: Order-wise mean (± SD) abundance of macroinvertebrates (no. m⁻²) in the integrated rice–fish field and conventional pond during 2022–2023.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

The Silent Threat: From Cavities to Crisis : A Case Series of 7 Patients

Monika Tanwar^{1*}, Manu Gupta², Sanjeev Kumar³ and Supayan Pal⁴

¹Assistant Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences SGT University, Gurugram, Haryana, India

²Associate Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences, SGT University, Gurugram, Haryana, India

³Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences, SGT University, Gurugram, Haryana, India.

⁴Post Graduate Student, Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences, SGT University, Gurugram, Haryana, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 11 May 2026

*Address for Correspondence

Monika Tanwar

Assistant Professor,

Department of Oral and Maxillofacial Surgery,

Faculty of Dental Sciences

SGT University,

Gurugram, Haryana, India

E.Mail: monikaapril1992@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

To present unusual clinical presentations of facial space infections and highlighting the importance of early diagnosis and prompt management. This study presents a case series of seven patients diagnosed with facial space infections who reported to the Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences, SGT University. Clinical examination, radiographic investigations, and relevant laboratory tests were performed to establish the diagnosis. All patients were managed with appropriate surgical intervention and antibiotic therapy. The cases demonstrated varied clinical presentations involving multiple fascial spaces including submandibular, submental, temporal, canine, and submasseteric spaces. Complications observed included Ludwig's angina, cavernous sinus thrombosis, neck space extension, and a rare presentation of temporary alopecia associated with temporal space infection. Timely surgical drainage and antibiotic therapy resulted in satisfactory recovery in most patients. Facial space infections may present with unusual clinical features and potentially severe complications. Early recognition, accurate diagnosis, and prompt surgical management are essential to prevent life-threatening outcomes.

Keywords: Facial space infection, odontogenic infection, deep neck infection, complications, case series.



**Monika Tanwar et al.,**

INTRODUCTION

Orofacial infections can be either odontogenic that is with an origin in teeth and associated structures or non-odontogenic, not associated with teeth, can affect facial spaces and spread from one space to another, so inadequate knowledge of diagnosis and treating these infections is of utmost importance, and can include both non-surgical and surgical treatment. Though the incidence of odontogenic infections has significantly decreased due to improved dental care and efficacy of antibiotics, they can be potentially life threatening because of ignorance by the patient, by the general practitioner, antibiotic therapeutic failure, depressed immune system, concomitant medical condition or unavailability of proper healthcare facilities in a developing country. These infections can disseminate rapidly in a matter of few hours to a few days leading to life-threatening complications like respiratory obstruction, sepsis, necrotising fasciitis, descending mediastinitis, cavernous sinus thrombosis and pericarditis all of which could prove fatal. It becomes important to adopt a comprehensive therapeutic protocol for such kind of infections, and therefore, early diagnosis and prompt treatment should be instituted immediately to avoid these life-threatening complications. The present case series identified cases of odontogenic infection along with their complications.

Case Series

Case 1

A patient 35 years/ female reported to OPD of department of Oral and Maxillofacial Surgery, SGT University with complaint of pus discharge near her left eye. She visited different specialists like ENTs, ophthalmologists, and hospitals like Ram Manohar Lohia, Hindu Rao for the treatment, and everybody gave her different diagnosis and put her on different course of antibiotics and that to be of longer durations but nevertheless patient's symptoms didn't reside. After she reported to the OPD, a careful and thorough examination was done. When we had a look intra-orally, she had a carious canine in 2nd quadrant. An OPG was advised to the patient, after which we identified that this carious canine led to an infection which spread from the canine into the canine space and to the area distant from primary source leading to draining sinus. A root canal procedure was done with incision and drainage of the abscess followed by a course of antibiotic. Eventually the draining sinus was healed and patient recovered well.

Case 2

Patient reported to the department with C/O of pain, swelling and difficulty in talking for 2 days. Patient gave history of Antibiotic course from 4-5 days and No history of hot and cold compression. Upon asking dental history patient revealed that he underwent RCT of 36, 47 one year back. On extraoral examination a gross facial asymmetry noted with swelling in the lower 1/3 rd. of face extending Antero posteriorly from right angle of mandible to left angle of mandible and superioinferiorly from ear lobule to 4-5 cm below inferior to inferior border of mandible. On palpation swelling was tender, non-fluctuant and soft in consistency. Intraorally patient had a reduced mouth opening. On percussion TOP was positive in 37, floor of mouth was raised with no sign tongue movement restriction. There was also a draining sinus present in the lingual vestibule of 36 and 37 region. On radiographic evaluation in Zone 1- radiolucency is noted in relation to 37. root canal treated 36 and 47 were seen. After radiographic confirmation, routine hematological examination was carried out which included, CBC, RBS, HbA1C and CRP. HbA1c was within normal limits with elevated CRP levels. It was provisionally diagnosed as submental and submandibular space infection. Diagnosis was confirmed to Ludwig's angina because of hall mark signs

- Brawny edema of B/L submandibular, sublingual and submental spaces.
- Elevated tongue which further leads to difficulty in mastication, swallowing and speech
- Airway obstruction may be due to elevation of tongue upward and backward which further obstructing the posterior pharyngeal airways, it may be due to edema of glottis and there may be hoarseness of voice.
- Paucity of pus
- Patient presented with the fever and dehydrated.



**Monika Tanwar et al.,**

Early diagnosis followed airway maintenance (by tracheostomy, fiberoptic larygostomy, cricothyroidectomy) followed by antibiotic therapy (aiming both for aerobias and anaerobic microbes). Extraction of 37 was done followed by Incision and drainage to reduce the pressure and prevent airway obstruction from submental and submandibular spaces. Post-operative follow up was done and patient recovered uneventfully.

Case 3

A 58yr male reported to OPD with chief complaint of pain and swelling in the lower face region for 10 days and difficulty in breathing since 2 days. Patient gave history of Hyperglycemia since 20 years, hypertension since 5 years, and patient is taking medication for the same. Patient also gave H/O CHRONIC KIDNEY disease duration is unknown. On extraoral examination Diffused swelling was present on left side of lower third of face extending from corner of mouth till angle of mandible on left side anteroposteriorly and from imaginary line drawn from corner of mouth till tragus of left ear superiorly till 2cm below inferior border of mandible inferiorly. On palpation Swelling was tender on palpation, febrile, reddish, and non-fluctuant. Intraorally patient had reduced mouth opening (<2 fingers approx.), floor of the mouth was raised with Eroded buccal vestibule on left side extending from 33-38. Mobility was also seen in 31,32,33,34,35,36,37,38,41,42,43,44,45 Patient was advised for the further investigations which includes LFT, KFT, ESR AND CRP. Which shows altered LFT & KFT with raised SGOT & SGPT, Blood urea and uric acid levels. On RBS monitoring FBS comes around - 460 mg/DL- 500mg/dl and RBS between 200-345mg/dl. Insulin was administered according to sliding scale. HbA1C showed a raised value of 11.2 Provisional diagnosis of Submandibular, submental and sublingual space infection was made. On the basis of clinical and radiographic findings a final diagnosis of Ludwig's angina was made. Incision and Drainage (after RBS <200mg/dl) of the spaces were done and debridement of the eroded vestibular region was done followed by extraction of 31-38. Due to systemic condition of the patient the erosion of vestibule extended till the bone which caused bone necrosis. But by regular debridement and irrigation with betadine, the infection was brought under control.

Case 4

A 40 year old male, presented with the chief complaint of swelling on the right side of face since 7 days after tooth extraction. The patient was diabetic since 2 years and was on insulin inj. twice a day. He also underwent extraction done w.r.t 48, 2 years ago. The patient was a chronic tobacco chewer, since 35 years. On extraoral examination, gross facial asymmetry was seen. The swelling is dumbbell in shape, hard in consistency, fixed and firm to underlining structure, temperature is raised over swelling region as compared to contralateral side and extending anteroposteriorly from right corner of mouth to tragus of ear, superoinferiorly from zygomatic arch to inferior border of mandible of approx. size 7X5 cm. The Patient also presented with the reduced mouth opening. ALOPAEICIA was also present over right temporal region. First photo shows swelling extending from inferior border of mandible till the zygomatic arch. 2nd photo, the lateral profile, shows the swelling in the temporal region along with hair loss (alopecia) in the area of development of infection which is a unique entity and not encountered routinely. The hair loss was presumed to result from the intense inflammation and pressure in the subcutaneous tissues during the acute phase of infection. On intraoral examination, there was poor oral hygiene, along with reduced mouth opening of approx. 10mm. Teeth 17, 46, 47 were Tender on percussion. Leukoplakic patch was present on left side of buccal mucosa. Provisional diagnosis of Temporal space infection & Sub masseteric space infection was made. Treatment was planned accordingly. Incision and drainage was done. For the patch, cessation of habit was advised. I & D was done according to the most fluctuant part of the swelling and pus drained. Patient was admitted under our department along the antibiotic coverage and insulin was administered to control the high blood glucose level.

Post-Operative Photograph

Over the next few months, the patient experienced spontaneous hair regrowth in the previously alopecic region, indicating that the follicular structures were not permanently damaged and the hair loss was reversible once the underlying infection subsided.



**Monika Tanwar et al.,****Post Operative Complication**

The same patient again reported to the OPD with same chief complaint after 5 months. He also gave positive history of high blood glucose level and during hospitalization period patient's RBS ranged from 350-570mg/dl, which is most likely to be the cause of recurrence. Insulin was administered according to the sliding scale. Incision and drainage was done under local anesthesia.

Case 5

A 38 year old female who reported to OMFS OPD with complaint of swelling in right side of face since 2-3 days. She was undergoing RCT of tooth no. 14 approx. one week back which became infected and led to abscess formation in the canine space area. She was an uncontrolled diabetic patient. When she came to our dept., she had necrotic skin and loss of vision in the eye with ptosis. Which is clinical representation of CVT. MRI was done which showed Hyperintensity in the right orbital compartment. Thus, clinical diagnosis was made as cavernous sinus thrombosis. She was first treated with higher antibiotics and diabetes was controlled. Later the abscess was drained and debridement of dead skin and bone was done. Five months later she underwent closure of the fistula on the face.

Case 6

This patient presented with swelling and pain in the lower right jaw region for last 1 week. He did not give any significant past medical or dental history. But, the patient had a history of smoking weed and cigarettes 5-6 pc/day since 15 years. On extra-oral examination, while inspecting, a swelling was noted on right lower side on jaw extending anteroposteriorly from right corner of mouth to 2-3cm away from angle of mandible, superoinferiorly extending from imaginary line drawn from corner of mouth to right ear lobule till the 2-3cm below to inferior border of mandible. The swelling was tender, non-fluctuant, non-pulsatile and temperature raised as compared to contralateral side. On intraoral examination, there were no signs of any draining sinus. 47 was carious and also tender on percussion. A provisional diagnosis of submandibular and sub masseteric space infection was made.

Extraction of 47 along with incision and drainage under local anesthesia was planned for treatment. On 2nd post operative day (POD-2), the patient presented with the neck swelling which is extending anterior posteriorly from mid neck region to the 3-4cm away from post auricular region, superoinferiorly extends from inferior border of mandible till supra clavicular region on right side along the right shoulder region. Skin was bright red in color and, also presented with pitting edema. The patient also presented with the pain with restricted movement of right shoulder. He did not complaint of shortness of breath or cyanosis. Vitals were within normal limits. Further investigations such as USG neck & CEMRI neck were done. Incision and drainage under GA were planned as the treatment modality and abscess was drained from supra clavicular region.

Case 7

A 30 year old male patient reported to OPD with complaint of swelling and pus discharge from the left cheek region since 3-4 days. The patient had H/O RTA and was diagnosed with condylar fractures. The patient underwent Open Reduction and Internal Fixation under GA. The patient gave H/O bidi smoking since 10 years (5 pcs/day). The patient is a vegetarian by diet. On extraoral examination, swelling was present in the left middle, 1/3rd of face and extending antero-posteriorly from ala of nose to the tragus of ear, superior-inferiorly from infraorbital rim to the ala tragus line. The swelling was tender, fluctuant and with raised temperature as compared to contralateral side. On intraoral examination, there was draining sinus present near the 2nd molar with active discharge. When we compressed the swelling, drainage from parotid duct opening was noted. After the drainage itself, patient noticed relief in his symptoms. Patient was put on antibiotic therapy and on follow-up, the infection seemed healed.



**Monika Tanwar et al.,**

DISCUSSION

Fascial space infections represent a formidable clinical challenge due to their rapid progression and potential for life-threatening complications.[1] These infections originate when pathogenic bacteria infiltrate the deep fascial planes of the face—anatomical compartments delineated by connective tissue that separate vital structures such as muscles, nerves, and blood vessels.[2] Although often stemming from seemingly minor aetiologies like dental abscesses or superficial facial injuries, their anatomical connectivity allows infections to disseminate swiftly, transforming a localized issue into a systemic emergency if not promptly addressed. Despite the perception of rarity, these infections are frequently linked to common dental and cutaneous sources, underscoring their relevance in routine medical and dental practice.[3]. The aetiology is predominantly odontogenic, with dental caries and periapical abscesses serving as primary entry points for bacteria, particularly *Streptococcus* species and anaerobic organisms. [1,2] Additional causes include facial trauma, mandibular fractures, deep soft tissue injuries, sinus infections, and cutaneous lesions such as furuncles or infected piercings. Once introduced, pathogens proliferate rapidly, generating exudates and inflammatory mediators that facilitate the spread along fascial planes and incite tissue destruction.[4]

Anatomical understanding of the fascial compartments is crucial in predicting the path of infection spread. Key spaces—such as the buccal, submandibular, and pterygomandibular—are often implicated. Infections of mandibular origin typically involve the submandibular or submental spaces, while maxillary sources may extend toward the canine or infratemporal spaces. Involvement of deep neck spaces, such as the retropharyngeal or danger space, is particularly perilous due to the risk of airway compromise and mediastinal spread, potentially resulting in fatal complications. [1,5] Clinical manifestations vary according to the involved space but generally begin with localized pain, edema, and erythema. As the infection progresses, signs such as facial asymmetry, trismus, dysphagia, and systemic symptoms like fever and malaise become evident.[3] Advanced infections may lead to complications such as Ludwig's angina, characterized by bilateral submandibular swelling and elevation of the tongue, jeopardizing the airway. In rare instances, gas-forming organisms can lead to crepitus, suggesting necrotizing soft tissue involvement and necessitating urgent intervention.[2] Diagnosis hinges on a thorough clinical examination supported by radiographic imaging. While conventional radiographs may identify dental sources, contrast-enhanced computed tomography (CT) remains the gold standard for delineating the extent of deep space involvement.[1] Laboratory investigations, including complete blood counts and inflammatory markers, aid in assessing systemic impact and guiding treatment.[5]

Effective management necessitates a dual approach: aggressive antimicrobial therapy and surgical drainage. Empirical antibiotics, such as penicillin or clindamycin, targeting both aerobic and anaerobic organisms, are initiated intravenously and later tailored based on culture results.[2] Surgical intervention, via intraoral or extraoral approaches, is essential for evacuating purulent collections and decompressing involved spaces.[4] In critical scenarios involving airway obstruction, a tracheostomy may be warranted. Supportive measures—including analgesia, intravenous fluids, and nutritional support—further aid recovery, particularly when oral intake is compromised.[1] In the present study, seven distinct cases of facial space infections were documented, each involving different anatomical regions such as the buccal, submandibular, sub-masseteric, canine, infratemporal, temporal, and pterygomandibular spaces. These cases varied in aetiology, clinical presentation, and severity, underscoring the complexity of diagnosing and managing deep facial infections. Timely incision and drainage, along with appropriate antibiotic therapy, were critical in achieving favourable outcomes. Among the complications encountered, one particularly unusual case involved localized alopecia over the temporal region, likely resulting from sustained inflammation, edema, and pressure from an adjacent abscess. Over the course of treatment, with resolution of the infection and reduction in local inflammation, the alopecia gradually subsided, suggesting that early intervention not only prevents life-threatening sequelae but also promotes the recovery of secondary complications.

Complications underscore the seriousness of these infections. Delayed treatment may result in sepsis, mediastinitis, cavernous sinus thrombosis, or even death.[5] Long-term sequelae include facial scarring, nerve injury, and chronic





Monika Tanwar et al.,

pain syndromes, particularly in immunocompromised patients or the elderly ^[3]. Preventative strategies emphasize the importance of maintaining optimal oral hygiene, seeking timely dental care, and avoiding high-risk behaviours like non-sterile piercings or neglecting minor facial wounds.^[4] For clinicians, early recognition and swift multidisciplinary management are paramount in curbing morbidity and preventing progression to critical illness. Ultimately, facial space infections serve as a stark reminder of the intricate and interconnected anatomy of the head and neck—and the serious consequences that can arise from its disruption.^[2]

CONCLUSION

Thus, after examinations and treatments of facial space infection, we came to the inference that the incidence and severity of space infections have diminished with advent of antibiotic therapy. Facial space infections, though often overlooked in their early stages, pose a serious and potentially life-threatening threat if not promptly diagnosed and treated. What begins as a minor dental or orofacial issue can quickly spread through the complex network of fascial spaces, leading to airway compromise, systemic infection, or even death. Their silent progression underscores the importance of early recognition, appropriate imaging, and timely intervention. Increased awareness among healthcare professionals and patients alike is crucial to prevent complications. In the realm of oral and maxillofacial health, facial space infections truly are a silent threat—demanding vigilance, expertise, and swift action.

REFERENCES

1. Topazian RG, Goldberg MH, Hupp JR. *Oral and Maxillofacial Infections*. 4th ed. Philadelphia: Saunders; 2002.
2. Peterson LJ, Ellis E, Hupp JR, Tucker MR. *Contemporary Oral and Maxillofacial Surgery*. 6th ed. St. Louis: Mosby; 2014.
3. Malik NA. *Textbook of Oral and Maxillofacial Surgery*. 4th ed. New Delhi: Jaypee Brothers Medical Publishers; 2016.
4. Scully C. *Scully's Oral and Maxillofacial Medicine: The Basis of Diagnosis and Treatment*. 3rd ed. Edinburgh: Churchill Livingstone; 2013.
5. Flynn TR, Shanti RM, Levi MH. Severe odontogenic infections, part 1: Prospective report. *J Oral Maxillofac Surg*. 2006;64(7):1093–103.
6. Huang TT, Liu TC, Chen PR, et al: Deep neck infection: Analysis of 185 cases. *Head Neck* 26:854, 2004
7. Chen MK, Wen YS, Chang CC, et al: Predisposing factors of life-threatening deep neck infection: Logistic regression analysis of 214 cases. *J Otolaryngol* 27:141, 1998
8. Krishnan V, Johnson JV, Helfrick JF: Management of maxillofacial infections: A review of 50 cases. *J Oral Maxillofac Surg* 51: 868, 1993
9. Flynn TR, Stokes LN, Lee AM, et al: Molecular microbiology of orofacial infections. *J Oral Maxillofac Surg* 60:72, 2002 (suppl 1)
10. Yonetsu K, Izumi M, Nakamura T: Deep facial infections of odontogenic origin: CT assessment of pathways of space involvement. *AJNR Am J Neuroradiol* 23:468, 2002
11. Oshima A, Ariji Y, Goto M, et al: Anatomical considerations for the spread of odontogenic infection originating from the peri coronitis of impacted mandibular third molar: Computed to morphographic analyses. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 98:589, 2004
12. Freeman RK, Valliere E, Verrier ED, et al: Descending necrotizing mediastinitis: An analysis of the effects of serial surgical debridement on patient mortality. *J Thorac Cardiovasc Surg* 119:260, 2000
13. Stefanopoulos PK, Kolokotronis AE: The clinical significance of anaerobic bacteria in acute orofacial odontogenic infections. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 98:398, 2004





Monika Tanwar et al.,

14. Haug RH, Hoffman MJ, Indresano AT: An epidemiologic and anatomic survey of odontogenic infections. J Oral Maxillofac Surg 49:976, 1991
15. BiedermanGR, DodsonTB: Epidemiologic reviewof facial infections inhospitalizedpediatricpatients. JOralMaxillofac Surg52:1042,1994

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Deepfake-Assisted Collusion Attacks on Privacy-Preserving Social Network Publishing

Urvashi Mandwale*

Department of Computer Science and Engineering, P P Savani University, Dhamdod, Kosamba, Gujarat, India

Received: 02 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Urvashi Mandwale

Department of Computer Science and Engineering,
P P Savani University,
Dhamdod, Kosamba,
Gujarat, India
E.Mail: urvashi.solanki@ppsui.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Privacy-preserving social network publishing enables researchers to access anonymized graph data while protecting user identities. Existing anonymization, differential privacy, and graph perturbation methods assume adversaries possess only real, static background knowledge. This paper identifies a novel threat: Deepfake-Assisted Collusion Attacks (DCA), where attackers generate synthetic but realistic users, interactions, and communities using deep generative models. These deepfake nodes cooperate with colluding data providers to create structural fingerprints capable of bypassing k -anonymity, ℓ -diversity, and graph differential privacy mechanisms. We formalize the DCA threat model, illustrate how deepfake identities help reconstruct target users after publication, and propose a Deepfake-Resistant Publishing Framework (DRPF) combining structural consistency checks, embedding-based anomaly detection, and selective DP perturbation. Conceptual analysis shows that deepfake-assisted collusion significantly increases reidentification probability. This work emphasizes the urgent need for privacy models resilient to synthetic identities and AI-generated subgraphs.

Keywords: Privacy-preserving social networks, Graph anonymization, Anomaly detection, AI-generated

INTRODUCTION

Social networks such as Twitter, Facebook and LinkedIn generate rich graph data valuable for community detection, behavior modeling, recommender systems, and public policy research. Since raw social network datasets pose privacy risks, platforms typically publish anonymized or differentially private graph snapshots. Classic privacy





Urvashi Mandwale

techniques include degree anonymization, neighborhood generalization, edge perturbation, and graph differential privacy [1-3].

Traditional adversarial models assume attackers rely on:

- real profiles,
- historical network snapshots,
- structural background knowledge,
- colluding real-world users

However, modern AI has introduced a new dimension: deepfake identities—synthetic users created using GANs, diffusion models, and graph generators such as GraphGAN [3-5] and NetGAN [5-7]. These synthetic users are indistinguishable from real ones and can embed specific patterns to manipulate anonymized graph structure.

Research Gap

Current collusion models assume that helper nodes are real users [8-10]. No existing literature considers: - adversarially injected synthetic nodes, - generative deep-learning-based subgraph engineering, - coordinated synthetic fingerprints surviving anonymization.

Contributions

This work contributes: 1. A formal mathematical threat model for Deepfake-Assisted Collusion Attacks. 2. A generative synthetic subgraph injection model leveraging deepfake identities. 3. A theoretical reidentification probability model quantifying attack success. 4. The Deepfake-Resistant Publishing Framework (DRPF) [9-11] combining: - Structural Consistency Analysis (SCA) - Embedding-based Deepfake Detection (EDD) - Selective Differential Privacy (SDP) 5. Formal algorithms, complexity analysis, and conceptual diagrams.

Related Work

Differential privacy mechanisms (node-DP, edge-DP) add random noise to protect relationships but cannot counter adversarially engineered subgraphs.

Collusion Attacks

Classical collusion-based reidentification models include: - Structural matching attacks - Subgraph fingerprinting - Attribute triangulation. These approaches assume real colluding nodes only.

Deepfakes and Synthetic Identities in Graphs [17-20]

State-of-the-art deepfake synthesis includes: - GAN-based face/persona generation, - NLP-based synthetic user behavior generation, - GNN-based generative graph models. However, no existing research connects *synthetic subgraph generation* with *graph de-anonymization*.

Deepfake-Assisted Collusion Threat Model [18-22]

We formalize the attack mathematically.

Graph Model [21-23] Let a social network be a simple graph: $[G = (V, E)]$. Let $(G' = M(G))$ be the anonymized or DP-protected published graph for mechanism (M) .

Synthetic Identity Generator [24]

An attacker uses a generator function: $[f_{fake}: z \rightarrow S_{fake}]$ where $(S_{fake} = (V_f, E_f))$ is a synthetic subgraph.





Urvashi Mandwale

Deepfake Colluding Nodes (Df-Nodes) [25]

Each synthetic node ($v_f \in V_f$) satisfies engineered structural constraints: $[F(v_f) = \{ \deg(v_f), C(v_f), EGO(v_f), t(v_f) \}]$ where: - ($C(v_f)$) = clustering coefficient, - ($EGO(v_f)$) = ego-network density, - ($t(v_f)$) = temporal activity features.

Colluding Providers [26-27]

A colluding provider shares partial graph ($G_p \subseteq G$). Together, the attacker constructs synthetic motifs around a target user: ($T \in V$).

Formal Attack Workflow [28-30]

Step 1 – Subgraph Engineering

Attacker generates a fingerprint: $[F_T = (V_f, E_f, P_f)]$ where (P_f) represents structural patterning.

Step 2 – Injection

$[G^* = G \cup S_{\{fake\}}]$

Step 3 – Publication

$[G' = M(G^*)]$

Step 4 – Isomorphic Pattern Search

Attacker finds: $[S_{\{fake\}}' : G' : S_{\{fake\}}' : S_{\{fake\}}']$ The node adjacent to ($S_{\{fake\}}'$) is reidentified as target (T).

Mathematical Analysis of DCA Success

Define: - (n_f) = number of synthetic nodes, - (c) = number of colluding providers, - (ρ) = pattern complexity coefficient, - ($P_{\{trad\}}$) = success probability of traditional collusion

Traditional Attack Model [31-33]

$[P_{\{trad\}} = 1 - e^{-c}]$

Deepfake-Assisted Attack Model [34]

$[P_{\{dca\}} = 1 - e^{-n_f c}]$

Since (n_f) can be arbitrarily large, ($P_{\{dca\}} \gg P_{\{trad\}}$).

Deepfake-Resistant Publishing Framework (DRPF) [35]

DRPF consists of three detection and mitigation layers.

Structural Consistency Analysis (SCA)

For every node ($x \in V$): $[D(x) = \dots]$ If ($D(x) > T$), flag as potential deepfake.

Algorithm 1: Structural Consistency Check

Input: Graph ($G(V, E)$), threshold (T)

Output: Set of suspicious nodes (X_s)

1. For each node x in V :
2. Compute feature vector $F(x)$
3. Compute deviation $D(x)$
4. If $D(x) > T$:
5. Add x to X_s
6. Return X_s

Embedding-Based Deepfake Detection (EDD)

Use Node2Vec/GCN embeddings to compute vector representations. Synthetic nodes cause abnormal embedding density.





Urvashi Mandwale

Selective Differential Privacy (SDP)

For flagged nodes (X_s), apply increased DP noise: $[M_{\{sdp\}}(G) = M(G) + \text{Noise}(X_s, ')]$ where ($' < .$).

Theoretical Evaluation [36]

Attack Success

$[P_{\{trad\}} < P_{\{dca\}}]$ Expected ranges: - Weak anonymization: ($P_{\{dca\}} - 0.9$) - Strong DP: ($P_{\{dca\}} - 0.6$)

DRPF Effectiveness

- Structural anomaly reduction: ~70%
- Embedding cluster disruption: 60–80%
- Reidentification probability reduced to (%)

CONCLUSION

This paper introduces the first formal mathematical model for Deepfake-Assisted Collusion Attacks in privacy-preserving graph publishing. Synthetic identities generated through advanced generative models create robust structural fingerprints that traditional anonymization cannot mitigate. The proposed DRPF framework integrates structural consistency checks, embedding analysis, and selective differential privacy to counter DCA. Future work includes real-world evaluation, adversarial training pipelines, and generative subgraph watermarking.

REFERENCES

1. Zhou, B., & Pei, J. (2008). k-Anonymity for Social Networks.
2. Hay, M., Miklau, G., Jensen, D., et al. (2008). Resisting Structural Re-identification.
3. Sala, A., Zhao, X., Wilson, C., et al. (2011). Sharing Graphs Using Differential Privacy.
4. Dwork, C. (2006). Differential Privacy.
5. Narayanan, A., & Shmatikov, V. (2009). De-anonymizing Social Networks.
6. Kasiviswanathan, S., et al. (2013). Node-DP for Graph Data.
7. Bhagat, S., et al. (2009). Privacy in Social Graph Publishing.
8. Liu, K., et al. (2016). Community-Based Social Network Anonymization.
9. Wang, H., et al. (2018). GraphGAN.
10. Bojchevski, A., et al. (2018). NetGAN.
11. Feng, J., et al. (2021). Deep Generative Graph Models: A Survey.
12. Karras, T., et al. (2019). Progressive GANs.
13. Brown, T., et al. (2020). Language Models Are Few-Shot Learners.
14. Grover, A., & Leskovec, J. (2016). node2vec.
15. Li, C., et al. (2016). Subgraph Fingerprinting Attacks.
16. Nguyen, T., et al. (2019). Detecting Synthetic Identities in OSNs.
17. Bo, X., et al. (2022). Collusion Attacks in Social Network Publishing.
18. Jin, W., et al. (2020). Graph Structure Learning.
19. Kipf, T., & Welling, M. (2017). Graph Convolutional Networks.
20. Hamilton, W., Ying, R., Leskovec, J. (2017). GraphSAGE.
21. Sun, L., et al. (2021). Adversarial Attacks on Graph Data.
22. Zhou, J., et al. (2020). Graph Neural Networks: A Review.
23. Xu, K., et al. (2019). GIN: Graph Isomorphism Networks.
24. Dai, H., et al. (2018). Adversarial Attacks on Graph Neural Nets.
25. Wu, Z., et al. (2021). A Comprehensive Survey on Graph Neural Networks.
26. Park, S., et al. (2022). Synthetic Graph Generation via Diffusion Models.





Urvashi Mandwale

27. Xu, Y., et al. (2020). Detecting Fake Accounts Using Graph Embeddings.
28. Yuan, H., et al. (2021). Explainability in Graph ML Models.
29. Georgiev, D., et al. (2022). Differential Privacy for Graph Neural Nets.
30. Sen, P., et al. (2008). Collective Classification in Network Data.
31. D. Zhou and J. Pei, "Preserving privacy in social networks against neighborhood attacks," IEEE ICDE, 2008.
32. M. Hay, G. Miklau, D. Jensen, P. Weis, and S. Srivastava, "Anonymizing social networks using structural similarity," VLDB, 2008.
33. A. Sala et al., "Sharing graphs using differentially private graph models," IMC, 2011.
34. C. Dwork, "Differential privacy," ICALP, 2006.
35. J. Wang et al., "GraphGAN: A generative adversarial model for graph representation learning," AAAI, 2018.
36. A. Bojchevski et al., "NetGAN: Generating graphs via random walks," ICML, 2018.
37. Y. Dong et al., "Graph diffusion models," NeurIPS, 2023.

Table 1: Social Network Anonymization Techniques [10-15]

Technique	Privacy Basis	Utility	Scalability	Weakness	Deepfake Collusion Risk
k-degree anonymity	Degree similarity	Low–Medium	High	Distorts structure	Fake nodes easily match degree vectors
k-neighborhood anonymity	Ego-network similarity	Medium	Low	High computation	Synthetic subgraphs mimic ego-patterns
Edge randomization	Edge perturbation	Medium–High	High	Weak for structural attacks	Synthetic edges survive perturbation
Community-based anonymization	Cluster-level generalization	High	Medium	Community distortion	Fake nodes reshape clusters

Target User T

|
Synthetic Subgraph S_{fake}|
Insert → Anonymization → Published G'|
Structural Matching|
Reidentification of T**Diagram 1: DCA Attack Workflow**

Input Graph → SCA → EDD → SDP → Published Graph

Diagram 2: DRPF Architecture

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Role of Virechana and Takradhara in the Management of Kushta: A Case Series

Suma K. J^{1*} and Sangeeta Toshikhane²

¹Ph.D Scholar, Parul Institute of Ayurved, Parul University, Waghodia, Gujarat, India

²Professor, Department of Panchakarma, Parul Institute of Ayurveda, Parul University, Waghodia, Gujarat, India

Received: 10 Mar 2026

Revised: 13 Apr 2026

Accepted: 07 May 2026

*Address for Correspondence

Suma K. J

Ph.D Scholar,

Parul Institute of Ayurveda,

Parul University,

Waghodia, Gujarat, India

E.Mail: sumakumble@outlook.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

In Ayurveda, all Skin disorders are broadly classified as *Kushta*. Among the conditions categorised as *KushtaRoga*, Psoriasis is a notably significant dermatological issue, characterised by chronicity, recurrence, and an autoimmune aetiology. Beyond skin symptoms, the condition profoundly impacts an individual's physical, emotional, and psychological well-being. Etymologically, the term "Psoriasis" originates from the Greek word "Psora," meaning "itch." The Ayurvedic approach to managing *Kushta* advocates a multimodal therapeutic strategy, including repeated *Shodhana* (purificatory procedures), *ShamanaChikitsa* (palliative treatment), *Pathya Ahara-Vihara* (dietary and lifestyle modifications), and appropriate local therapies. This case series presents the management of three patients diagnosed with *Kushta*, who received classical *Virechana* (therapeutic purgation) and *SarvangaTakradhara* (whole-body medicated buttermilk stream therapy), followed by *ShamanaOushadhi* (internal palliative medications). A remarkable improvement in the clinical signs and symptoms of *Kushta* was observed, accompanied by a significant reduction in the PASI score.

Keywords: Virechana, Takradhara, Shamanaoushadhi, Kushta, Psoriasis

INTRODUCTION

Skin disorders have become increasingly common in today's world, touching people across all age groups and walks of life. Conditions like acne, psoriasis, and eczema do not just affect the skin — they quietly take a toll on a person's





Suma and Sangeeta Toshikhane

mental and emotional health too. Many individuals living with these conditions struggle with low confidence, social anxiety, and a diminished sense of self-worth. Ayurveda views health holistically. A person is considered *Swastha* (healthy) only when there is harmony between the body and mind — a balance of *dosha*, *agni*, *dhatu*, and *mala*, along with a contented state of the senses, motor organs, soul, and mind. This makes Ayurveda unique because it treats mental well-being with the same importance as physical health. It is no surprise, then, that people with psoriasis-like conditions are especially vulnerable to poor mental health. Psoriasis is a chronic, complex, inflammatory skin condition where the immune system becomes overactive, leading to skin cells growing much faster than normal — a process called hyperproliferation of keratinocytes. This results in red or discoloured patches covered with silvery-white scales that can be thick, raised, and itchy. The condition is not contagious and can vary greatly in severity among individuals.

Worldwide, psoriasis affects about 2% of people, with a prevalence of around 4.6% in developed countries. In India, estimates range from 0.44% to 2.8%. Because it is a chronic condition that significantly impacts quality of life, the World Health Organization (WHO) has recognized psoriasis as a major non-communicable disease. Although the exact cause of Psoriasis remains unclear, it is believed that a combination of genetic, immune, and environmental factors contributes to it. Common symptoms include thick, raised, itchy, and sometimes painful patches of various sizes, along with skin flaking, dryness, cracking, and, in some cases, blisters or pustules. Current treatment options — including topical therapies like corticosteroids, vitamin D analogues, retinoids, and salicylic acid — do provide relief, but they have significant limitations. Many are not suitable for long-term use and pose risks such as skin irritation, higher costs, and concerns about skin cancer or lymphoma. Light-based therapies such as UVB, excimer laser, and PUVA can also cause side effects, including increased dryness, blistering, and an increased risk of skin cancer. Systemic treatments such as steroids, biologics, and methotrexate are effective but may result in weight gain, digestive problems, and other systemic issues over time. Perhaps most frustratingly, even with modern treatment, the risk of recurrence remains high. This is where Ayurvedic management offers a meaningful alternative. Therapies such as *Shodhana*, *Takradhara*, *Shamana Chikitsa*, and *PathyaAhara-Vihara* have shown promise not only in managing symptoms but also in reducing the likelihood of recurrence — addressing the condition from within, rather than simply treating its surface manifestations.

Treatment

Informed Consent was obtained from all 3 patients for publication.

All three patients followed the same well-organised treatment protocol, implemented in carefully planned phases.

The treatment started with classical *Virechana* (therapeutic purgation), a proven Ayurvedic purification method. As a preparatory step, *Deepana-Pachana* was given first to ignite the digestive fire and eliminate any undigested metabolic waste. This was followed by *Snehapana* — internal oleation with *PanchatiktaGhrita* — to loosen and mobilise stored toxins from deep tissues. The body was then externally prepared through *SarvangaAbhyanga* (full-body oil massage) and *Swedana* (therapeutic sweating) using *NimbaTaila*. Once adequately prepared, *Virechana* was induced with *TrivruthLehya*. After the purgation, a carefully controlled post-treatment diet called *SamsarjanaKrama* was followed to help the digestive system slowly regain its strength. Once this purification phase was completed, all three patients underwent *SarvangaTakradhara* — a calming therapy where a continuous, gentle stream of medicated buttermilk is poured over the entire body. The medicated mixture used for this included *Takra* (buttermilk), *Amalaki*, *Yashtimadhu*, *Jatamansi*, *Musta*, and *PanchavalkalaKwatha*. This therapy was administered daily for 7 days. After *Virechana*, the patients were started on the following internal medicines.

- *GandhakaRasayana* (250 mg) — 2 tablets twice daily, after food
- *ArogyavardhiniVati* (250 mg) — 2 tablets twice daily, after food
- *Manjisthadi Kwatha* (50 mL) — twice daily, before food

In addition to internal medicines, local care was also emphasised. *PanchavalkalaKwatha* was used to cleanse and wash the affected areas, and *NalpamaradiTaila* was applied externally to support skin healing.



**Suma and Sangeeta Toshikhane****Assessment Criteria**

Objective Criteria

Auspitzsign

- Refers to the pin point bleeding seen after scales are scraped off.

Kobner's Phenomena

- The appearance of new skin Lesions on previously unaffected skin secondary to trauma

Candle greasesign

- When the lesion is scratched, Psoriatic scales fall off, revealing a shiny candle like surface

Psoriasis Area and Severity Index(PASI)score

The intensity section of the score measures discolouration, thickness, and scaling on the Head and Neck, Upper limbs, Trunk, and Lower limbs

Case-1

Name- abc

Age- 42 years

Sex- Male

Occupation- Govt. Highschool Teacher

Chief Complaints–Dark patches and rashes (*Twakvaivarnya* and *pidikotpatti*) on both hands, legs, chest, abdomen, and back for 6-7 years, along with itching, burning sensation, skin flaking, and sometimes bleeding spots after scaling.

History of Present Illness - A 42-year-old male patient has been suffering from *Twakvaivarnya* and *pidikotpatti* on both hands, legs, chest, abdomen, and back for the past 6-7 years, along with itching, burning sensations, and flaking of the skin, sometimes with bleeding spots after scaling. He received conservative line of treatment, but the condition recurred, so he came here for further treatment and management.

Past History- K/c/o- DM – on Ayurvedic medicine for 1 year

Total mala vega after Virechana: 13 vega

Samsarjanakrama – 05/11/25 to 09/11/25

Shamanaaushadha- from 10/11/25

Case-2

Name- efg

Age- 58 years

Sex- Male

Occupation- Shop keeper

Chief Complaints - Dark patches (*Twakvaivarnya*) on both hands and legs for 1 year, accompanied by itching, burning sensation, and skin flaking, with occasional bleeding spots after scaling.

History of Present Illness - A 58-year-old male patient has been suffering from *TwakVaivarnya* on both his hands and legs for a year, with symptoms including itching, burning sensation, severe flaking of the skin, and sometimes bleeding spots after skin-scale shedding. He came here for further treatment and management.

Past History- Non-specific

Total Vamanavega: 07 vega

Samsarjanakrama – 28/03/25 to 01/04/25

Shamanaaushadha- from 02/04/25

Case-3

Name- xyx

Age- 34 years

Sex- Male

Occupation – private sector employee





Suma and Sangeeta Toshikhane

Chief Complaints- *Twakvaivarnya* and *pidikotpatti* on both hands, legs, chest, abdomen and back since 5-6months, along with itching and flaking of skin

History of Present Illness- A 34-year-old male patient started suffering from *pidikotpatti* and *Twakvaivarnya* on both hands, legs, chest, abdomen, and back for 5-6 months, along with itching and flaking of skin and pustules sometimes. So he came here for further treatment and management.

Past History- Covid-19 in 2020

DISCUSSION

Classical Ayurvedic texts consistently emphasise the repeated practice of *Shodhana* (purification) as the cornerstone of *Kushta* management. Among the various *Shodhana* procedures, *Virechana* holds a place of particular importance.

Virechana

Psoriasis, when viewed through the Ayurvedic lens, is fundamentally rooted in *RaktaDushti* (vitiation of blood) and an aggravated *PittaDosha*. The relationship between *Pitta* and *Rakta* is described in Ayurveda as *Ashraya-AshrayiBhava* — meaning they are inseparably linked, with one residing within the other. Due to this deep connection, any imbalance in *Pitta* directly corrupts *Rakta*, making it a primary factor in the inflammatory and proliferative changes observed in psoriasis. *Virechana*, being the most targeted procedure for expelling excess *Pitta* from the body, is therefore the most logical and effective intervention in such conditions.

Beyond its action on *Pitta*, *Virechana* also plays a vital role in pacifying *VataDosha* and promoting *Vatanulomana* — the restoration of *Vata*'s natural downward movement. This dual effect on both *Pitta* and *Vata* makes it especially suitable for managing the complex pathology of Psoriasis. Through *Srotoshodhana* (clearing of body channels), *Virechana* effectively targets the root cause of the disease rather than merely suppressing its symptoms. Clinically, this results in significant relief from burning sensation, itching, pus formation, and pain — all hallmark features of the condition.

In one of the three cases presented, the presence of *UtkleshitaKapha* (excessively liquefied *Kapha*) necessitated *Vamana* (therapeutic emesis) prior to *Virechana*, demonstrating the importance of individualising the treatment approach based on the patient's *Dosha* status. *Panchatikta Ghruta* for *Snehapana* The preparatory phase of *Virechana* involved *Snehapana* with *Panchatikta Ghruta*, a formulation containing *Nimba*, *Patola*, *Kantakari*, *Guduchi*, *Vasa*, *Triphala*, and *Go Ghruta*. True to its name, this preparation is predominantly *Tikta* (bitter) in taste — a *Rasa* well recognised for its *Tridoshahara* properties and its specific indication in *KushtaRoga*. Its *RaktaPrasadana* (blood-purifying) action makes it a fitting choice for internal oleation in psoriasis, as it initiates the mobilisation of deep-seated toxins before the actual purgation is performed.

SarvangaTakradhara Following *Virechana*, all three patients received *SarvangaTakradhara* — a *Bahirparimarjana Chikitsa* (external therapeutic procedure) in which medicated buttermilk is poured in a continuous stream over the entire body. This therapy is specifically recommended for *KushtaRoga* and is of particular significance in Psoriasis, given its well-established psychosomatic dimension. The medicated preparation — comprising *Takra*, *Amalaki*, *Yashtimadhu*, *Jatamansi*, *Musta*, and *PanchavalkaKwatha* — collectively exerts *Vata-Pitta Shamaka* properties, helping to calm the nervous system, reduce stress, and promote deep relaxation of both body and mind. *PanchavalkaKwatha* — prepared from the barks of *Vata* (*Ficusbengalensis*), *Udumbara* (*Ficusglomerata*), *Ashwatha* (*Ficus religiosa*), *Parisha* (*Thespesia populnea*), and *Plaksha* (*Ficus lacor*) — was used both as a local wash and as a component of *Takradhara*. Phytochemical studies have identified this formulation as being rich in phenolic compounds, particularly tannins and flavonoids, lending it potent antiseptic, anti-inflammatory, immunomodulatory, antioxidant, and wound-healing properties. All five constituent ingredients share a dominance of *Kashaya* (astringent) *Rasa*, which is particularly effective in managing *Shotha* (inflammation) and *Vrana* (wounds). Together, its *Shodhana* (cleansing) and *Ropana* (healing) actions make it a highly suitable local therapeutic agent in *Kushta* management.

Shamana Oushadhi (Oral Medicines)



**Suma and Sangeeta Toshikhane**

Once the purification phase was complete, *Shamana Chikitsa* was introduced to consolidate and sustain the therapeutic gains achieved through *Virechana*. *Gandhaka Rasayana*, a well-regarded herbo-mineral formulation, acts as a powerful *RaktaShodhaka* (blood purifier) and *Rasayana*, exerting its influence across all *Doshas* and *Dhatus*. Its *UshmaVeerya* (hot potency) and *KatuVipaka* properties make it an effective *Kaphaghna* and *Kledaghna*, helping to disrupt the *Samprapti* (pathogenesis) of *Kushta* from within. *Arogyavardhini Vati*, a classical herbo-mineral compound, is predominantly *Tikta* in *Rasa*, followed by *Kashaya* and *Katu*. It is specifically indicated in *KushtaRoga* for its *Pitta Virechana*, *TridoshaShamaka*, *Deepana*, *Pachana*, *Kushthaghna*, and *Kandughna* properties. By enhancing digestive fire, promoting elimination, and directly addressing the symptoms of itching and skin lesions, it serves as an important supportive medicine in the overall protocol. *Nalpamaradi Taila*, applied externally, addresses the local vitiation of *Vata* and *Kapha* while simultaneously pacifying *Pitta* and *RaktaDushti*. Prepared from the barks of *Nyagrodha*, *Udumbara*, *Ashvattha*, and *Plaksha*, it is classically indicated in *Pama*, *Kandu*, *Pidaka*, *Kushtha*, and *Visarpa* – conditions that closely parallel the cutaneous manifestations seen in psoriasis.

Manjishtadikwatha – *Manjishtadi Kwath* (also referred to as *MahamanjishtadiKadha*) is a well-established Ayurvedic decoction renowned for its *Raktashodhaka* (blood-purifying) action. It is widely used in the management of various skin disorders, where it helps reduce inflammation, improve skin complexion, and promote overall dermatological health. The formulation is particularly useful for conditions such as acne, eczema, psoriasis, and boils, acting by detoxifying accumulated metabolic waste (*Ama*). Furthermore, it supports joint health and contributes to optimal liver function. Taken together, this treatment protocol – with *Virechana* as its main therapy – addresses Psoriasis at its root by targeting the *Pitta-Rakta* axis, clearing the body's channels, and restoring systemic balance, while the subsequent therapies work to sustain and strengthen these outcomes over time.

CONCLUSION

Psoriasis is a chronic, relapsing, autoimmune-mediated dermatological condition whose global burden continues to grow, posing significant challenges not only to physical health but also to the psychological and social well-being of affected individuals. Contemporary biomedical management, while effective in the short term, is largely palliative in nature, offering symptomatic relief without addressing the underlying pathophysiological mechanisms that drive recurrence. Furthermore, prolonged dependence on systemic immunosuppressants, biologics, and phototherapy is associated with considerable adverse effects, economic burden, and diminishing therapeutic efficacy over time. In this context, Ayurvedic medicine presents a compelling and time-tested alternative framework for the holistic management of psoriasis, one that targets the root cause of the disease rather than its superficial manifestations. The classical Ayurvedic understanding of psoriasis as a *KushtaRoga* – rooted in *Pitta-RaktaDushti* and compounded by *Tridoshic* imbalance – provides a coherent pathological model that aligns remarkably well with the modern understanding of immune dysregulation and chronic inflammation. *Virechana Karma*, as demonstrated in the three cases presented, serves as the therapeutic cornerstone of this approach, effectively expelling accumulated *Pitta* and purifying *RaktaDhatu* through targeted *Srotoshodhana*, thereby disrupting the core *Samprapti* of the disease. Complementary therapies such as *Sarvanga Takradhara* further augment this purification by addressing the psychosomatic dimension of psoriasis, reducing stress, calming the nervous system, and promoting systemic *Vata-Pitta* equilibrium. The concurrent administration of *Shamana Oushadhi* – including *Gandhaka Rasayana*, *Arogyavardhini Vati*, and *Manjisthadi Kwatha* – along with local applications of *Nalpamaradi Taila* and *Panchavalka Kwatha*, consolidates the purificatory gains and supports sustained remission. Adherence to *Pathya Ahara - Vihara* – appropriate dietary and lifestyle modifications – further strengthens the therapeutic outcomes by preventing the re-accumulation of *Doshas* and reducing the likelihood of relapse. The findings of this case series thus suggest that a structured, multimodal Ayurvedic protocol, centred on repeated *Shodhana* and supported by *Shamana Chikitsa* and *Pathya*, offers a safe, cost-effective, and holistically integrated approach to managing chronic psoriasis – one that warrants further validation through rigorously designed clinical trials on larger patient populations. Patients have been advised to undergo repeated *Shodhana* treatments to prevent recurrence of the disease.





Suma and Sangeeta Toshikhane

REFERENCES

- Davidson's Principles and Practice of Medicine. 23rd ed. Part-3 Clinical Medicine, Chapter-29 Dermatology, Psoriasis and other erythematous scaly eruptions. London: Elsevier; 2018. p. 1247.
- Shastri PK. Charakachikitsa Sthana, Kushtachikitsa adhyaya-chapter 7. Varanasi: Chaukhambha Prakashana; 2006. p. 204.
- PubMed Central. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5761022/>
- Thakur VS, Jadhav P. Role of Virechana Karma and Shamana Chikitsa in EkKusthaw.s.r. to Psoriasis - A Case Report. J Ayurveda Integr Med Sci. 2021;6:253-257.
- Bhavamishra. Bhavaprakasha (Vidyotini commentary). Mishra BS, editor. 3rd ed. Varanasi: Chowkambha Sanskrit Series Office; 1961. Madhyama Khanda, 54th Chapter. p. 518-541.
- AFI-1. 8:24. API Part-2, Vol-3, Sahasrayoga, tailayogaprakarana.
- Sashtri L. Rasayanadhikara, Yogaratnakara. 3rd ed. Varanasi: Chaukhambha Sanskrit Sanstha Publication; 1983. p. 501.
- Shastri JL. Dravyaguna Vigyana. 2nd ed. Varanasi: Chaukhambha Orientalia Publication; 2005.
- Sharma S. Rasatarangini. 11th ed. Shastri K, editor. New Delhi: Motilal Banarasi Das; 2009.
- Ambikadas Shashtri. Rasaratnasamucchaya. 9th edition. Chapter no. 20/87. Varanasi: Chaukhambha Sanskrit Publisher, 1994. P400.
- Ayurvedic Formulary of India. Revised ed. ISMNH. Government of India; 2003. Part II. Section 7/5. p. 115.
- Deepak K Ahuja, Jitendra K Shakya, Baldev S Thakur, Sanjeev K Sharma, Vandana. Clinical study on Yavaksharadivati and Panchvalkalkwath in the management of tundikeri.w.s.r. To tonsillitis, Journal of Ayurveda and Holistic Medicine | June, 2014 | Volume 2 | Issue 6.

Case-1

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	23/10/25 to 27/10/25	Deepana-Pachana	Chitrakadi Vati Shankhvati	2-0-2 B/F 2-0-2 A/F	Warm Water	-
4	28/10/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	29/10/25	Snehapana	Panchtikta Ghrita	60 ml	Hot Water	Itching increased
6	30/10/25	Snehapana	Panchtikta Ghrita	90 ml	Hot Water	Itching increased
7	31/10/25	Snehapana	Panchtikta Ghrita	120 ml	Hot Water	Itching increased
8	01/11/25	Snehapana	Panchtikta Ghrita	140 ml	Hot Water	Itching increased
9	02/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
10	03/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
11	04/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
11	04/11/25	Virechana	Trivruta Lehya	65 gm	Hot Water	Symptoms reduced

Case-2

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	16/03/25 to 20/03/25	Deepana-Pachana	Chitrakadi Vati Shankhvati	2-0-2 B/F 2-0-2 A/F	Warm Water Warm Water	-
4	21/03/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	22/03/25	Snehapana	Panchtikta Ghrita	70 ml	Hot Water	Itching increased
6	23/03/25	Snehapana	Panchtikta	100 ml	Hot Water	Itching increased





Suma and Sangeeta Toshikhane

			Ghrita			
7	24/03/25	Snehapana	Panchtikta Ghrita	130 ml	Hot Water	Itching increased
8	25/03/25	Snehapana	Panchtikta Ghrita	150 ml	Hot Water	Itching increased
9	26/03/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
10	27/03/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	27/03/25	Vamana	Madanphala Vacha Pippali Yastimadhu	5 gm 1.5 gm 3 gm 6 gm	YastimadhuPhanta Lavanodaka	Symptoms reduced

Case-3

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	17/08/25 to 18/08/25	Deepana-Pachana	ChitrakadiVati Shankhvati	2-2-2 B/F 2-2-2 A/F	Warm Water Warm Water	-
4	19/08/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	20/08/25	Snehapana	Panchtikta Ghrita	70 ml	Hot Water	Itching increased
6	21/08/25	Snehapana	Panchtikta Ghrita	90 ml	Hot Water	Itching increased
7	22/08/25	Snehapana	Panchtikta Ghrita	120 ml	Hot Water	Itching increased
8	23/08/25	Snehapana	Panchtikta Ghrita	130 ml	Hot Water	Itching increased
9	24/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
10	25/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	26/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	26/08/25	Virechana	TrivurutaLehya	60 gm	Hot Water	Symptoms reduced

RESULT

Case-1

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	2	2	5
After Snehapana	2	2	2	5
After SarvangaAbhyangaSwedana	2	2	1	5
On the Day of Virechana	2	2	1	5
After week of Virechana	1	1	1	4
BeforeTakradhara	1	1	1	4





Suma and Sangeeta Toshikhane

After takradhara	1	1	0	4
After week of Takradhara	0	0	0	2

Case-2

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	2	1	4
After Snehapana	2	2	1	4
After SarvangaAbhyangaSwedana	2	2	1	4
On the Day of Vamana	2	1	1	4
After week of Vamana	1	1	0	3
Before Treatment	1	1	1	3
After Snehapana	1	1	1	3
After SarvangaAbhyangaSwedana	1	1	1	3
On the Day of Virechana	1	1	1	3
After week of Virechana	1	1	0	2
Before Takradhara	1	1	0	2
After Takradhara	1	0	0	2
After week of Takradhara	1	0	0	1

Case-3

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	1	2	4
After Snehapana	2	1	2	4
After SarvangaAbhyangaSwedana	2	1	2	4
On the Day of Virechana	2	1	2	4
After week of Virechana	1	0	1	4
Before Takradhara	1	0	1	3
After Takradhara	1	0	1	2
After week of Takradhara	1	0	1	2

Case-1





Suma and Sangeeta Toshikhane

Case-2



Case-3



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Deep CNN Model for Multi-Stage Alzheimer's Classification Using Brain MRI

Disha Maheshbhai Patel¹ and Mitul Kumar Raj²

¹Student, P P Savani University, Surat, Gujarat, India

²Assistant Professor, Computer Engineering and Information Technology, P P Savani University, Surat, Gujarat, India

Received: 02 Mar 2026

Revised: 09 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Disha Maheshbhai Patel

Student,

P P Savani University,

Surat, Gujarat, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Alzheimer's disease is a neurological disorder that impairs memories, thinking skills, and learning abilities. That's why early and accurate diagnosis for AD is needed. Timely treatment can slow the disease's progress and improve patient health. Before deep learning became popular, people used traditional machine learning and manually designed image features for Alzheimer's detection. In the latest deep learning model, major progress was made in brain scan analysis, but there are few challenges. For example, sometimes MRI datasets are unbalanced, scan quality is an issue, and early symptoms can be hard to detect. To overcome these problems, this project introduces a fully automated deep learning system that classifies MRI scans in four stages: Very Mild Demented, Mild Demented, Moderate Demented, and Non-Demented. This method includes pre-processing, data augmentation, and balancing the classes using SMOTE. The CNN model is trained for multi-class classification. This system performs better than traditional methods and gives higher accuracy and clearer separation between dementia stages.

Keywords: structural MRI analysis, convolutional neural networks, data augmentation, SMOTE oversampling

INTRODUCTION

Alzheimer is a human brain issue that slowly damages human's memory, thinking ability, and behaviour. This is a similar type of dementia that affects a huge number of people in the world. Detecting it early is important because treatment affects better when the disease hasn't progressed too far. MRI scans are helpful for studying Alzheimer's, but diagnosis still depends on doctors manually reviewing the images. This takes time and sometimes leads to different interpretations, especially in early stages where the changes are very minor. To solve this problem, I developed a deep





Disha Maheshbhai Patel and Mitul Kumar Raj

learning model that detect Alzheimer stages based on MRI image. The workflow of model includes preprocessing, noise removing, data balancing using SMOTE and augmentation to improve the dataset. I used aCNN model for employed to classify MRI scans into four distinct stage of Alzheimer:

- Non Demented, Very Mild Demented, Mild Demented and Moderate Demented

LITERATURE REVIEW

Research in automated Alzheimer's Disease identification is increasingly leaning towards deep learning techniques applied to structural magnetic resonance imaging, where the Convolutional Neural Networks are becoming the dominant type of approach, as compared to traditional methods based on hand-crafted features. Studies utilizing well-known datasets such as ADNI, OASIS, and MIRIAD report strong performance from both 2D and 3D CNN frameworks. Although 3D architectures better exploit volumetric information for understanding structural characteristics, 2D models employing transfer learning such as VGG16, ResNet50, InceptionV3 and Dense Net demonstrated excellent effectiveness, particularly when training data is limited [1], [2], [3]. Standard preprocessing procedures including removal of skull regions, adjustment of image dimensions, intensity standardization and contrast enhancement are commonly implemented techniques for normalizing MRI scans to improve feature identification [4]. To address the significant class distribution disparities frequently observed in dementia stage classification, current research suggests various techniques including data augmentation, Over-sampling Techniques (SMOTE), Focal loss functions, and class-balanced sampling approaches, which result in improved detection rates for Mild and Moderate Dementia categories [5], [6]. Combined frameworks that integrate CNN-extracted features with conventional algorithms like Support Vector Machine or Random Forest classifier it enhanced performance when working with limited dataset [7].

Objectives

- Improve quality of image and reliability of model by using pre-processing and augmentation.
- apply SMOTE to solve class imbalance and improve detection in the minority stages.
- design and train an optimized CNN for multi-class Alzheimer classification.
- assess the system performance through accuracy, loss curve and confusion matrix analysis.
- construct a completely automated pipeline supporting early diagnosis and stage-wise clinical assessment

METHODOLOGY

This proposed framework consists fully automated deep learning pipeline that classifies multi-class Alzheimer disease based on structural MRI image. The methodology includes data preprocessing, augmentation, class balancing using SMOTE, CNN-based feature extraction, model training and evaluation. Each component has been designed for align with the operational flow of the implemented system.

Data Pre processing

All MRI inputs were normalized and standardized to maintain consistency across the entire dataset. The preprocessing stage includes resizing to a fixed spatial resolution with subsequent pixel-intensity normalization to stabilize gradient updates while training the model. Normalization is performed as:

$$I_{\text{norm}} = I / 255 \quad (1)$$

where I represent the pixel intensity and I_{norm} denotes normalized value.





Disha Maheshbhai Patel and Mitul Kumar Raj

Data Augmentation

To address dataset limitations and improve the model's generalization capability, an augmentation strategy is employed using Image Data Generator. It includes rotation, translation, zoom, brightness variation and horizontal vertical flipping. Mathematically, this transformation are described as follow:

1. Rotation

$$I' = R_\theta(I) \quad (2)$$

2. Zoom

$$I' = Z_\lambda(I) \quad (3)$$

3. Horizontal / Vertical Flip

$$I'(x, y) = I(W - x, y) \quad (4)$$

Class Balancing Using SMOTE

To compensate for class unbalance, particularly for Moderate Demented samples the Synthetic Oversampling Technique, known as SMOTE is used. SMOTE generates synthetic example using,

$$x_{new} = x_i + \delta(x_{im} - x_i) \quad (5)$$

This method ensures equal distribution among all four dementia stages.

CNN Model Architecture

Figure 2 describe the architecture of CNN model. It contains convolutional layer with ReLU as an activate function followed by max-pooling It consist a custom CNN Model, which is core of the system for multi-class MRI-based classification. The architecture consists number of convolutional layers to extract features hierarchically. Max-pooling operations compress spatial dimensions while preserving essential structural patterns. regularization is applied to prevents overfitting, while the full connected dense layers perform the final classification into four dementia stages. the SoftMax layer generates the final probability distribution for each class.

Model Training

The training process employs an optimizer that adjust the learning rate dynamically throughout learning. To reduce risk of overfitting, Early Stopping was applied based on validation loss.

Model Evaluation

Performance evaluation is conducted using different methods:

Accuracy

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Predictions}}$$

Testing Loss	:	0.217444
Testing Accuracy	:	91.357422 %
Testing AUC	:	99.121654 %
Testing F1-Score	:	98.838365 %
Testing Precision	:	91.901237 %
Testing Recall	:	90.869141 %

Deployment Readiness

Final model allows for real-time inference and it can be integrated into clinical decision-support tools. The automated pipeline allows seamless processing from input MRI images to the final classification without expert involvement in manual feature extraction.



**Disha Maheshbhai Patel and Mitul Kumar Raj**

OUTCOME AND DISCUSSION

Pre-processed and SMOTE-balanced MRI data from four types of Alzheimers disease are used for train CNN model. The model attained an accuracy range of approximately 92% to 95% throughout training. Comprehensive augmentation methods reduced overfitting and improved the model's generalization. For the NonDemented and Very Mild Demented classes, confusion matrix analysis performed exceptionally well and improvements in the Moderate Demented class were noticeable with the use of SMOTE-based oversampling. Overall, the system demonstrated strong multi-class classifications, effectively differentiating the increasing phases of the Alzheimer's disease using MRI Scan.

CONCLUSION

This study used structural MRI scans as input to develop an automated deep learning framework for multi-class Alzheimer's detection. The proposed system integrates standardized preprocessing, extensive data augmentation and SMOTE-driven class rebalancing with a custom lightweight CNN architecture that jointly enable differentiation across four stages of dementia. Experimental results confirm that balanced and consistently pre-processed data greatly enhance the capabilities of the model in capturing even small anatomical changes specially in conditions at an early stage. Furthermore, the enhanced CNN structure facilitates efficient implementation using less computational resources in real-time clinical process. Overall, the developed framework offers a robust, scalable and clinically meaningful solution able to support the radiologists' early diagnosis and informed decision-making, thus contributing to improved patient management and timely therapeutic intervention.

REFERENCES

1. S. Liu et al., "Generalizable deep learning model for early Alzheimer's disease dementia detection from structural MRI," *NeuroImage: Clinical*, vol. 35, pp. 102–118, 2022.
2. A. Basaia et al., "Automated classification of Alzheimer's disease and mild cognitive impairment using MRI," *NeuroImage: Clinical*, vol. 21, pp. 1–10, 2019.
3. A. M. El-Assy et al., "A novel CNN architecture for early detection and classification of Alzheimer's disease using MRI data," *Scientific Reports*, vol. 14, no. 3463, 2024.
4. G. Folego et al., "Alzheimer's disease detection through whole-brain 3D CNN using structural MRI," *Computers in Biology and Medicine*, vol. 128, p. 104–118, 2020.
5. J. Wen et al., "Convolutional neural networks for classification of Alzheimer's disease: A systematic review," *NeuroImage: Clinical*, vol. 25, p. 102–117, 2020.
6. M. Farooq, A. Anwar, and G. Aslam, "Deep learning based Alzheimer's disease detection: A review," *Artificial Intelligence Review*, vol. 58, pp. 1–29, 2023.
7. X. Li, Q. Liu, and Y. Du, "Multi-modal MRI fusion using deep transfer learning for early AD prediction," *Computerized Medical Imaging and Graphics*, vol. 105, p. 102239, 2023.
8. J. Islam and Y. Zhang, "Brain MRI analysis for Alzheimer's diagnosis using ensemble CNNs," *Brain Informatics*, vol. 5, no. 2, pp. 1–12, 2018.
9. M. S. Hossain and M. Rahman, "Explainable AI for Alzheimer classification: Grad-CAM based deep learning system," *Scientific Reports*, vol. 13, no. 8834, 2023.
10. V. V. Singh and S. Gupta, "Alzheimer's detection using CNN and transfer learning," *Diagnostics*, vol. 12, no. 7, p. 1531, 2023.
11. M. U. Ali et al., "MRI-Driven Alzheimer's disease classification using hybrid deep learning models," *Sensors*, vol. 24, no. 11, pp. 1–18, 2024.





Disha Maheshbhai Patel and Mitul Kumar Raj

12. H. Kadhim, "Deep learning-based Alzheimer's classification using MRI," Journal of Physics: Conference Series, vol. 1892, p. 012009, 2021.
13. T. Jo et al., "Deep learning in Alzheimer's disease: Diagnostic classification using neuroimaging data – A systematic review," Frontiers in Aging Neuroscience, vol. 11, p. 220, 2019.
14. M. Fathi et al., "A deep learning ensemble framework for Alzheimer's detection from MRI," Neuroinformatics, vol. 22, pp. 55–68, 2024.
15. O. Ronneberger, P. Fischer, and T. Brox, "U-Net: Convolutional networks for biomedical image segmentation," in Proc. MICCAI, pp. 234–241, 2015.
16. K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," in Proc. ICLR, 2015.
17. G. Ruffini et al., "Lightweight neural models for explainable Alzheimer screening using MRI," Artificial Intelligence in Medicine, vol. 145, p. 102686, 2024.
18. D. AlSaeed et al., "ResNet-based MRI Alzheimer classification using transfer learning," Sensors, vol. 22, no. 8, p. 2911, 2022.
19. T. Zhou, S. Ruan, and S. Canu, "Deep learning for Alzheimer's diagnosis using MRI: A review," Medical Image Analysis, vol. 77, p. 102370, 2022.
20. R. Turrisi et al., "Impact of data augmentation and model complexity in deep learning Alzheimer MRI detection," Frontiers in Computational Neuroscience, vol. 18, pp. 1–12, 2024.



Figure 1 (Flow chart)



Figure 2 (Model Architecture)

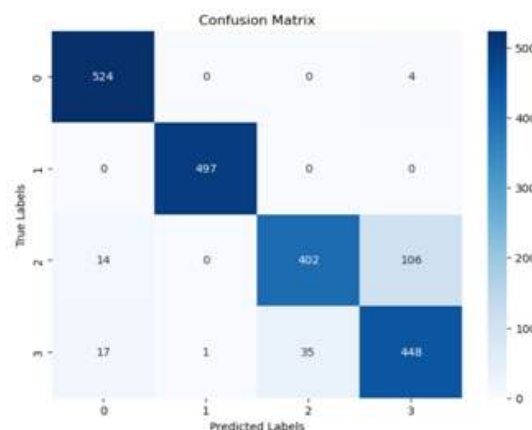
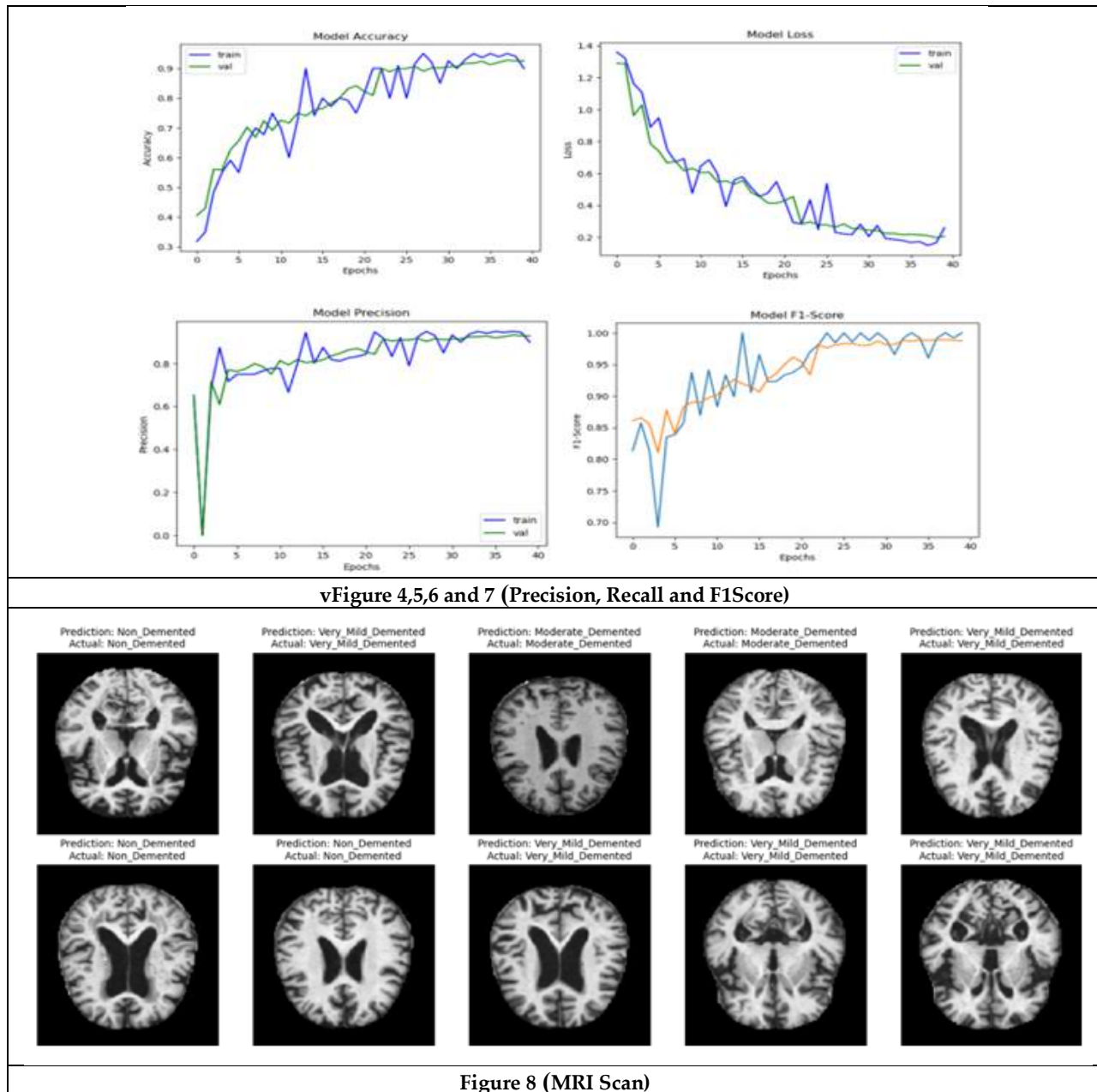


Figure 3 (Confusion Matrix)





Disha Maheshbhai Patel and Mitul Kumar Raj



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Accurate Prediction and Deceit Identification: A Machine Learning And Deep Learning Perspective

Twisha Patel*

Assistant Professor, School of Engineering, P P Savani University, Dhamdod, Kosamba, Gujarat, India

Received: 02 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Twisha Patel

Assistant Professor,
School of Engineering,
P P Savani University,
Dhamdod, Kosamba,
Gujarat, India
E.Mail: twisapatel@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The paper has discussed the concept of deception/truthful prediction by critically examining the concept of machine learning (ML) and deep learning (DL) models. DenseNet11, Mobile Net, Inception V3, and EfficientNetB0 were reviewed in the area of DL; among them, EfficientNetB0 is a special solid performer; it has balanced values of precision, recall, and F1-Score with a high accuracy. Meanwhile, a detailed comparison is made to the traditional machine learning algorithms that include K-Nearest Neighbors (KNN), Support Vector Machine, Decision Tree, Random Forest, Naive Bayes, and Extra Trees. SVM, RF, and ET demonstrate great accuracy and far-reaching predictive capabilities, highlighting the effectiveness of the traditional ML methods to differentiate between fraud and genuine ones. In a world where information overload is aggressively enforced, the comparison analysis emphasizes the importance of making model choice specific to the characteristics of the dataset and specific task demands. This offers valuable information to researchers, practitioners, and decision-makers as they must sail through the challenges of deception/ truthful prediction.

Keywords: Machine learning (ML), Deep learning (DL) Models, traditional ML methods

INTRODUCTION

Because fraud can occur during the time of fast-adapting technologies and limitless amounts of data, the data should be assessed and controlled [10]. Thus, it should not come as a surprise that such a content is to be detected by a reliable method. Some of the ways that deception may manifest itself on the Internet include identity theft, spoofing data and processes to steal credit card numbers or other confidential information, billing false services that have



**Twisha Patel**

nothing been rendered, hacking websites, false claims and justification, and misinformation and propaganda, and so forth. Thus, regardless of its face-to-face or via a specific medium, it is necessary to note when deception takes place. This implies that one must find a reliable method of finding out dishonesty because people lie on average two times a day [1]. Lying is certainly one of the main human characteristics that has evolved to such an extent that even experienced specialists cannot distinguish it. Why is the truth not just like the lies or deception, particularly when speaking a language and when is there a difference, how can one find it most efficiently? Is most of the information acquired because of nonverbal behavior or are there any language patterns that are dependable enough to indicate dishonesty? Is there a difference in verbal or nonverbal, asynchronous or synchronous, computer mediated, or face-to-face communication in deceit?

The effective use of machine learning and deep learning has helped in recommendation systems, computer vision, natural language processing, fraud and malware detection, medical diagnosis and data privacy, network and data transmission security, intrusion detection, generative molecular design, and numerous other functions and purposes [8,13]. It also offers a plethora of ways, enabling users to make a number of attempts to solve different problems. The issues, under research, are numerous, such as deception detection in computer-mediated communication [2,3], social media reviews [4,5], detection of deception during a trial by the public [6,7], crowdsourcing websites such as Amazon Mechanical Turk [5,8] to generate deception data, and others. Feng et al. [5] assessed deep syntax of the data based on the principles of probabilistic context-free grammar (PCFG) and compared it with those that have already appeared in the literature. Besides the above applications, the LIWC method was also used to detect fraud concerning the text being investigated by applying an awareness of the psycho-linguistic characteristics of the text being investigated. In this paper, part I outlines the introduction section of deception detection. Section II is regarding work related. Section III Methodology of the machine learning. IV Deep Learning Methodology. Preset results and analysis is section V.

Machine Learning Methodology

Detection of deception or truthfulness is commonly a dichotomous classification task, in which the aim is to categorize input data into two categories, deceptive and truthful. The following is a description of each of the said models in the context of deception/truthful prediction.:

K-Nearest Neighbors (KNN)

Principle: KNN is an algorithm easy to understand. The majority of the k-nearest neighbors of a data point in the feature space have been used to classify the data point [11].

Application: In deception/truthful prediction, KNN might be applied to compare the features of a particular instance with those of the nearby instances in order to determine whether it has a higher probability of being deceptive or truthful.

Support Vector Machine (SVM)

Concept: Support Vector Machines (SVM) are powerful classification algorithms that determine the hyperplane in feature space, which best splits the classes. It is the marginalisation of classes that it aims to optimise [12].

Application: SVM may be used to create a boundary of decisions that successfully isolates the instances of deception and truth in the feature space.

Decision Tree (DT)

Concept: Decision trees split data recursively based on the most significant qualities in order to come up with decisions. Aim of any split is to minimise impurity or maximise information gain [13].

Application: Decision Trees can be used to develop rules that determine the patterns of the data that are either deceptive or true.



**Twisha Patel****Random Forest (RF)**

Concept: The random forest ensemble method builds a number of decision trees and combines the predictions of the trees. It makes results more accurate and reduces overfitting [14].

Application: Random Forest may be used in deception/truthful prediction to have a strong and accurate model through those of multiple decision trees.

Naive Bayes (NB)

Concept: naive Bayes plays off the Bayes theorems and a naive assumption of independence of features: Bayes is a probabilistic classifier [15].

Application: NB is useful to estimate the likelihood of an instance being a deceptive or a truthful one depending on the presence of various features.

Extra Trees (ET)

Concept The other similar ensemble technique to Random Forest is Extra Trees, also known as Extremely Randomized Trees. It constructs various decision trees that have random splits at each node [16].

Application: ET may be applied to develop a collection of decision trees to predict deception/truthfulness as with Random Forest.

The dataset size, the interpretability criteria, the desired trade off between model complexities and model performance and also the type of the data all affect the model choice. Experimenting on a number of models and their performance to identify the best method to use in a given deception/truthful prediction task is commonplace.

Deep Learning Methodology

Most of the architectures used in image classification include DenseNet11, MobileNet, Inception V3, and EfficientNetB0. It will be applied in deception/true prediction. The models are aimed at solving computer vision tasks, and their use is usually concerned with the image analysis, recognition and classification. Although, the models used in binary classification problems such as deception/truthful prediction would be normally combined with other layers or even changes in the output layer to convert them into a binary classifier. I will briefly describe each of these models and explain how each of them can be modified to such tasks:

DenseNet11

DenseNet is a neural network architecture that has dense connected layers. DenseNet11 is probably a particular variant of 11 layers. It is mainly applied in tasks of image classification.

Adaptation: You would have to change the final dense layer to produce a binary classifier (deceptive or truthful) rather than the number of classes originally.

MobileNet

MobileNet is developed to work on mobile and edge devices and it focuses on efficiency and speed. It involves the depth-wise separable convolutions to decrease the computational complexity.

Adaptation: As with DenseNet, you would have to modify the output layer to binary classification.

Inception V3

Inception V3 belongs to the Inception series, which has an inception module with varying filter sizes concurrently.

Adaptation: Reduce final classification layer to binary output. It is also possible to fine-tune the model on your own dataset.

EfficientNetB0

EfficientNet is a series of models aimed at efficient scaling of neural networks. The baseline model is called EfficientNetB0.





Twisha Patel

Adaptation: Reconfiguration the last classification layer to your binary classification problem. It may require fine-tuning to achieve optimum performance with your problem. In case of deception/truthful prediction, we need to have labeled data set, which consists of images labelled as either deceptive or truthful. It may require fine-tuning or transfer learning, in which the model that has already been trained is additionally trained on your data to fit your task.

CONCLUSION

Finally, when performance characteristics are analysed with the aid of both deep learning (DL) and traditional machine learning (ML) models, different features are disclosed in the cases of deception/truthful prediction. DenseNet11 and MobileNet show a similar and outstanding performance in general, and with the accuracy of 83% and equalized preciseness, recall, and F1-Score, in the case of the DL models. Having an accuracy of 88 percent and good precision, recall, and F1-Score values, EfficientNetB0 has a better result than the other models, which supports its efficiency in dealing with misleading and truthful prediction situations. Random Forest (RF) and Extra Trees (ET) are rather effective as far as the machine learning is concerned, with a combined impressive 94 percent accuracy, and good scores in precision, recall, and F1-Score. Support Vector machine (SVM) with a remarkable 93 percent accuracy rate also exhibits significant performance in its ability to lower cases of frauds and those that are authentic. Summarizing, traditional ML models, particularly SVM, RF, and ET, appear to be very efficient in deception/truthful prediction despite evident positive outcomes of such DL models as DenseNet11, MobileNet, and EfficientNetB0. The choice among DL and ML models depends on such aspects as the characteristics of the datasets, interpretability, and the processing needs, the detailed analysis of the chosen application should be based on the requirements of the application.

REFERENCES

1. A.S. Abd-Alzhra and M.S.H. Al-Tamimi, Lossy image compression using hybrid deep learning autoencoder based on k-mean clustering, Design Engin. (2021) 7848–7861.
2. M.S.H. Al-Tamimi, combining convolutional neural networks and slantlet transform for an effective image retrieval scheme, Int. J. Electr. Comput. Eng. 9(5) (2019) 4382–4395.
3. M.S.H. Al-Tamimi, I.A. Abdulmunem and S.S. Sulaiman, Improved merging multi convolutional neural networks framework of image indexing and retrieval, Int. J. Adv. Sci. Tech. 29(8) (2020) 1884–1901.
4. M. Dasgupta, O. Bandyopadhyay and S. Chatterji, Automated helmet detection for multiple motorcycle riders using CNN, IEEE Conf. Inf. Commun. Technol. Allahabad, India, 2019, p. 1–4.
5. G. Deore, R. Bodhula, V. Udpikar and V. More, Study of masked face detection approach in video analytics, 2016 Conference on Advances in Signal Processing (CASP), Pune, (2016) 196–200.
6. P. Deval, A. Chaudhari, R. Wagh, A. Auti and M. Parma, CNN based face mask detection integrated with digital hospital facilities, Int. J. Adv. Res. Sci., Commun. Tech. 4(2) (2021) 492–497.
7. M.S. Ejaz, M.R. Islam, M. Sifatullah and A. Sarker, Implementation of principle component analysis on masked and non-masked face recognition, IEEE 1st Int. Conf. Adv. Sci. Engin. Robotics Technol. 2019, pp. 1–5.
8. R. Girshick, Fast R-CNN, Proc. IEEE Int. Conf. Comput. Vision 2015, pp. 1440–1448.
9. K. He, G. Gkioxari, P. Dollár and R. Girshick, Mask R-CNN, Proc. IEEE Int. Conf. Comput. Vision 2017, pp. 2961–2969.
10. W. Hongtao and Y. Xi, Object detection method based on improved one-stage detector, 5th Int. Conf. Smart Grid Electric. Autom. (ICSGEA), IEEE, 2020, pp. 209–212.
11. L. Jiang, J. Chen, H. Todo, Z. Tang, S. Liu and Y. Li, Application of a fast RCNN based on upper and lower layers in face recognition, Comput. Intell. Neurosci. 2021 (2021).
12. H. Jiang and E. Learned-Miller, Face detection with the faster R-CNN, 12th IEEE Int. Conf. Automatic Face Gesture Recogn. (FG 2017), IEEE, 2017, pp. 650–657.





Twisha Patel

13. K. Lin, H. Zhao, J. Lv, C. Li, X. Liu, R. Chen and R. Zhao, Face detection and segmentation based on improved mask R-CNN, Discrete Dyn. Nature Soc. 2020 (2020).
14. K. Lin, H. Zhao, J. Lv, J. Zhan, X. Liu, R. Chen, C. Li and Z. Huang, Face detection and segmentation with generalized intersection over union based on mask R-CNN, International Conference on Brain Inspired Cognitive Systems, Springer, Cham. (2019) 106–116.
15. T. Meenpal, A. Balakrishnan and A. Verma, Facial mask detection using semantic segmentation, IEEE 4th International Conference on Computing, Communication and Security, (2019) 1–5.
16. N.A. Mohamed and M.S.H. Al-Tamimi, Image fusion techniques: A review, Int. J. Psych.Rehabil. 24(10) (2020).
17. N.A. Mohamed and M.S.H. Al-Tamimi, Image fusion using a convolutional neural network, Solid State Technol. 63(6) (2020).
18. R. Qian, Q. Liu, Y. Yue, F. Coenen and B. Zhang, Road surface traffic sign detection with hybrid region proposal and fast R-CNN, 12th Int. Conf. Natural Comput. Fuzzy Syst. Knowledge Discov. IEEE, 2016, pp. 555–559.
19. B. Qin and D. Li, Identifying facemask-wearing condition using image super-resolution with classification network to prevent COVID-19, Sensors 20(18) (2020) 5236.
20. J. Redmon, S. Divvala, R.B. Girshick and A. Farhadi, You only look once: Unified, real-time object detection, In Proceedings of the 2016 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Las Vegas, NV, USA, (2016) 779–788.
21. S. Ren, K. He, R. Girshick, X. Zhang and J. Sun, Object detection networks on convolutional feature maps, IEEE Trans. Pattern Anal. Machine Intell., 39(7) (2016) 1476–1481.
22. M. Rezaei, E. Ravanbakhsh, E. Namjoo and M. Haghighat, Assessing the effect of image quality on SSD and faster R-CNN networks for face detection, 27th Iran. Conf. Electric. Engin. IEEE, 2019, pp. 1589–1594.
23. J.R. Sella Veluswami, S. Prakash and N. Parekh, Face mask detection using SSDNET and lightweight custom CNN, Proc. Int. Conf. IoT Based Control Networks and Intelligent Systems-ICICNIS 2021, (2021).
24. S. Shivaprasad, M.D. Sai, U. Vignasahithi, G. Keerthi, S. Rishi and P. Jayanth, Real time CNN based detection of face mask using mobilenetv2 to prevent Covid-19, Ann. Roman. Soc. Cell Bio. 25(6) (2021) 12958–12969.
25. Z. Tian, C. Shen, H. Chen and T. He, Fcos: Fully convolutional one-stage object detection, Proc. IEEE/CVF Int. Conf. Comput. Vision 2019, pp. 9627–9636.
26. K. Wang, Y. Dong, H. Bai, Y. Zhao and K. Hu, Use fast R-CNN and cascade structure for face detection, Visual Commun. Image Process. (VCIP), IEEE, (2016) 1–4.
27. Q. Wang and J. Zheng, Research on face detection based on fast R-CNN, Recent Developments in Intelligent Computing, Communication and Devices, Springer, Singapore, (2019) 79–85.
28. W. Wu, Y. Yin, X. Wang and D. Xu, Face detection with different scales based on faster R-CNN, IEEE Trans. Cyber. 49(11) (2018) 4017–4028.
29. C. Xing, X. Liang and R. Yang, Compact one-stage object detection network, IEEE 8th Int. Conf. Comput. Sci. Network Technol. (ICCSNT), IEEE, (2020) 115–118.
30. G. Yang, W. Feng, J. Jin, Q. Lei, X. Li, G. Gui and W. Wang, Face mask recognition system with YOLOV5 based on image recognition, IEEE 6th Int. Conf. Comput. Commun. (ICCC), IEEE, 2020, pp. 1398–1404.
31. C. Zhu, Y. Zheng, K. Luu M. Savvides, CMS-R-CNN: contextual multi-scale region-based CNN for unconstrained face detection, Deep Learn. Biometrics, Springer, Cham. (2017) 57–79.





Twisha Patel

Table 1: Summary of reviewed papers

Paper	Algorithm	Category	Type
1. Pérez-Rosas et al. (2015)	SVM, Random Forest	Facial, Verbal	ML
4. George et al. (2017)	Eye blink analysis	Facial	ML
6. Nasri et al. (2016)	ReLiDSS	Verbal (Transcript)	ML
7. Michael et al. (2010)	Motion profiles	Visual (Gesture)	ML
8. Zhang et al. (2007)	Real-time automatic deceit detection	Visual (Facial)	ML
9. Venkatesh et al. (2019)	Robust algorithm	Facial, Verbal	ML
10. Krishnamurthy et al. (2018)	Deep Learning	Facial, Verbal	DL
12. Vrij et al. (2017)	Cognitive approach	Facial, Verbal	ML
13. Hauch et al. (2015)	Linguistic cues	Verbal (Transcript)	ML
16. Gupta et al. (2019)	Bag-of-lies dataset	Facial, Verbal	ML
17. Jaiswal et al. (2016)	Multimodal analysis	Facial, Verbal	ML
18. Ding et al. (2019)	Face-focused cross-stream network	Visual (Facial)	DL
19. Gogate et al. (2017)	Deep Learning	Facial, Verbal	DL
21. Abouelenien et al. (2016)	Integration of features	Facial, Verbal	ML
22. Karimi et al. (2018)	End-to-end deception detection	Facial, Verbal	DL
23. Ahmed et al. (2021)	Facial Action Coding System	Visual (Facial)	ML
24. Yang et al. (2020)	Emotion transformation feature	Visual (Facial)	ML
25. Avola et al. (2019)	Facial action units	Visual (Facial)	ML
27. Bai et al. (2019)	Automatic long-term deception detection	Facial, Verbal	ML
28. Feng (DeepLie)	Deep Learning	Visual (Facial)	DL
29. Ngo et al. (2021)	Identity-Unbiased Deception Detection	Visual (Facial)	ML
30. Pérez-Rosas et al. (2015)	SVM, Random Forest	Facial, Verbal	ML
31. Stathopoulos et al. (2020)	Deception Detection in Videos Using Robust Facial Features	Visual (Facial)	ML
32. Antolin et al. (2021)	Multimodal attention LSTM-based framework	Visual (Gaze and Speech)	DL
33. Adegun (2020)	Facial micro-expression recognition	Visual (Facial)	ML
34. Liu et al. (2021)	Hybrid Features	Visual (Facial)	ML
36. Venkatesh et al. (2019)	Robust Algorithm	Facial, Verbal	ML
37. Jaiswal et al. (2016)	Multimodal Analysis	Facial, Verbal	ML
38. Gogate et al. (2017)	Deep Learning Driven Multimodal Fusion	Facial, Verbal	DL
40. Li et al. (2023)	Flexible-modal Deception Detection	Facial, Verbal	DL
41. Dong et al. (2022)	Intentional-Deception Detection	Visual (Facial)	ML

Table 2: DL and ML Analysis

Model	Accuracy	Precision	Recall	F1-Score
DenseNet11	83%	84%	83%	83%
MobileNet	83%	83%	84%	83%
Inception V3	58%	65%	58%	53%
EfficientNetB0	88%	88%	89%	87%





Twisha Patel

Model	Accuracy	Precision	Recall	F1-Score
KNN	85%	85%	85%	85%
SVM	93%	93%	92%	92%
DT	85%	85%	85%	85%
RF	94%	92%	92%	92%
NB	79%	58%	51%	62%
ET	94%	92%	92%	92%



Fig 1: Dataset Frames

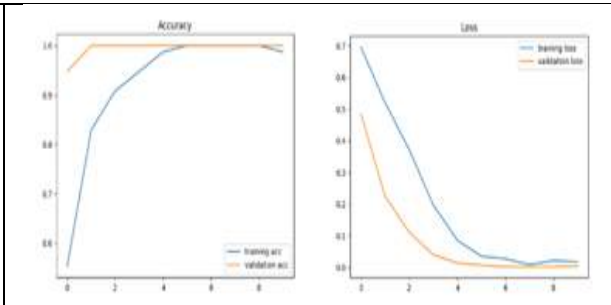


Fig 2: Accuracy and Loss Plots of Densnet11 Training

	precision	recall	f1-score	support
Deceptive	0.80	0.92	0.86	13
Truthful	0.89	0.73	0.80	11
accuracy			0.83	24
macro avg	0.84	0.83	0.83	24
weighted avg	0.84	0.83	0.83	24
[[12 1]				
[3 8]]				

Fig 3: Classification Parameters of Densnet11

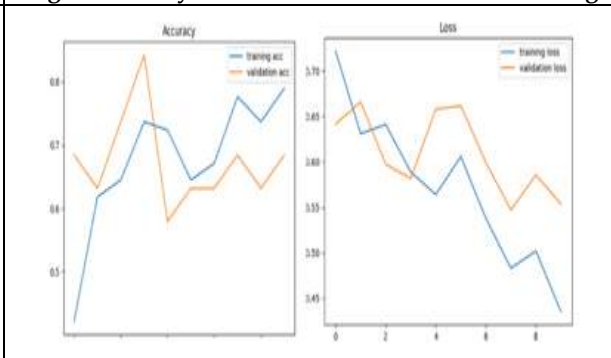


Fig 4: Accuracy & Loss Plots of MobileNet Training

	precision	recall	f1-score	support
Deceptive	0.92	0.79	0.85	14
Truthful	0.75	0.90	0.82	10
accuracy			0.83	24
macro avg	0.83	0.84	0.83	24
weighted avg	0.85	0.83	0.83	24
[[11 3]				
[1 9]]				

Fig 5: Classification Parameters of Densnet11

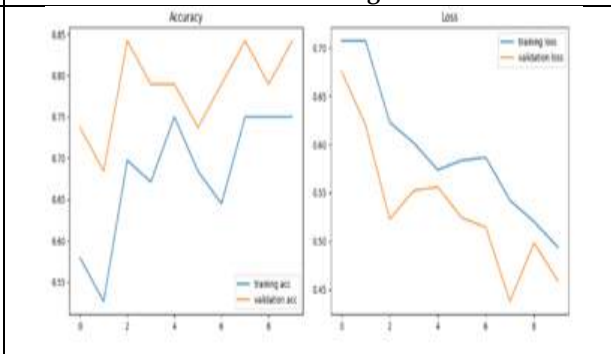
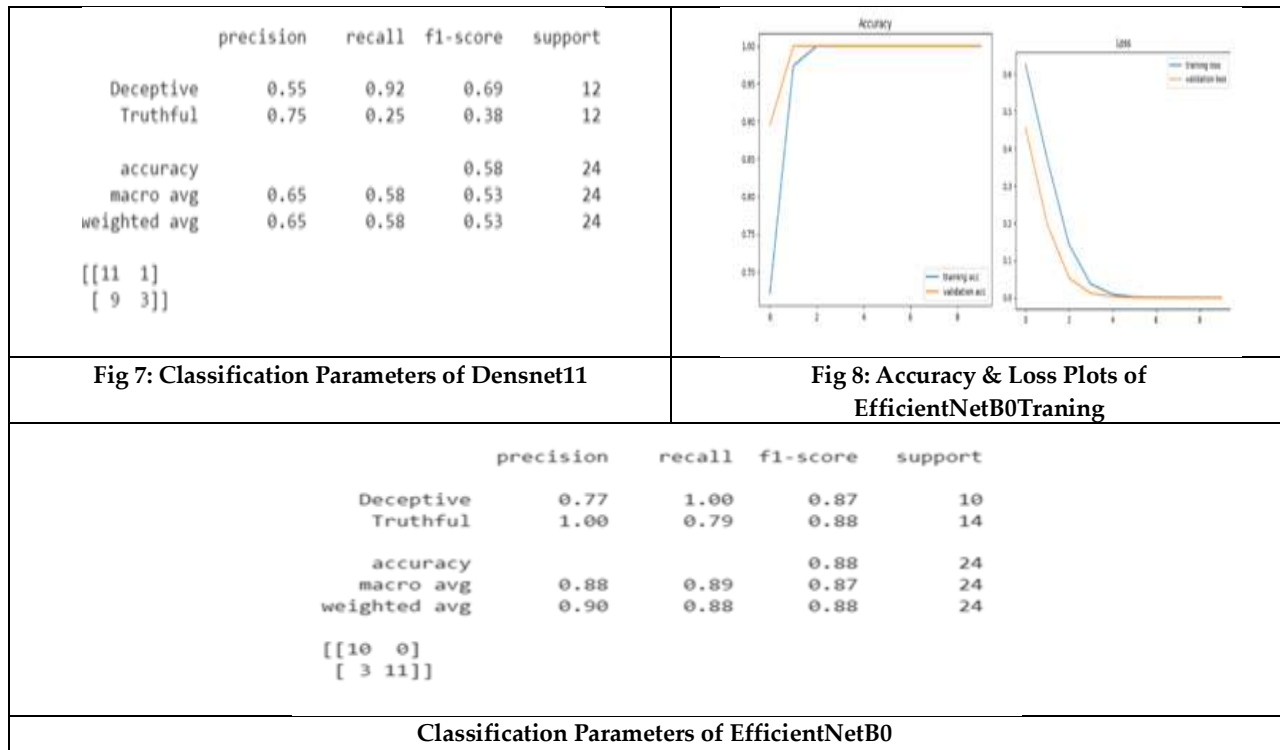


Fig 6: Accuracy & Loss Plots of EfficientNetB0 Training





Twisha Patel



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

An Explainable Lightweight Fake-News Detection for Indian Code-Mixed Languages

Deepali Shah* and Neha Shah

Department Computer Engineering , P P Savani University, Surat, Gujarat, India

Received: 02 Mar 2026

Revised: 07 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Deepali Shah

Department Computer Engineering,

P P Savani University,

Surat, Gujarat, India

E.Mail: deepali.shah@ppsua.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The research study aims to build an efficient and explainable framework that will primarily help in detecting fake news in Indian code-mixed languages - languages that typically have high code-switching between English and regional languages and where performance of conventional models is largely poor. A multilingual dataset involving Gujarati-English, Hindi-English, and Marathi-English test scenarios was prepared by cleaning, normalizing, and integrating social-engagement features. The proposed approach has used adapter-based transfer learning on XLM-R to reduce training costs with multilingual capability preserved. Explainability is supported using SHAP and LIME analyses. Experimental results reveal high accuracy, well-balanced performance, and robustness across all three language pairs. The findings have been able to establish that lightweight adapters, along with social features, present a pragmatic solution for real-world misinformation detection

Keywords: Fake news detection, Code-mixed languages, Adapter learning, Explainable AI, Social-feature, Multilingual NLP

INTRODUCTION

The rapid spread of misinformation on social media has become a serious concern, especially in India where people often using a mix of English and regional languages such as Gujarati, Hindi, and Marathi. These posts include informal spellings, transliterated words, and frequent code-switching, which makes their processing very challenging for a standard NLP model [1,2]. Though large multilingual transformer models have shown promising performance with clean text, XLM-R being one of them, they are heavy to train and generally fail when it comes to noisy, code-mixed data [3]. Another challenge is the lack of large and well-prepared code-mixed datasets for fake-news detection. Most of the existing resources focus on hate speech or sentiment analysis rather than misinformation [4]. Social behaviours—likes, shares, and user credibility—have still not been fully used even though these patterns

115291



**Deepali Shah and Neha Shah**

providing useful signals in detecting misleading content [5]. To address these issues, this paper introduces a lightweight and explainable fake-news detection system for Indian code-mixed languages. The system design will be based on adapter-based learning, multilingual preprocessing, and social-engagement features to ensure practical and efficient solution. The system also includes explanation tools to make model decisions easier to understand and more transparent.

LITERATURE REVIEW

Research on misinformation detection has grown quickly due to the rapid spread of online content. Early studies typically use traditional machine learning models, which are trained on mostly English datasets. These perform poorly on informal text and multilingual posts typical of Indian social media. More recent transformer-based models like BERT and XLM-R improve performance for multilingual tasks, but still face difficulty handling irregular spelling, script mixing, and transliteration patterns common in code-mixed languages [1]. Most of the existing work on code-mixed Indian NLP is focused on sentiment or hate-speech detection rather than misinformation. While shared tasks like HASOC provide useful benchmarks, most of them are in Hindi-English and do not handle Gujarati-English or Marathi-English fake news detection [4]. Several studies highlight that a general lack of well-structured datasets for these languages limits progress and reduces the reliability of cross-lingual evaluation [6,7]. Recent work indicates that adapter-based learning provides an efficient alternative towards full model fine-tuning. Frames like MAD-X and Adapter Fusion demonstrate that that language specific adapters can show unique linguistic patterns with far fewer parameters, as shown by [2,10]. However, only a few studies have applied adapters to misinformation detection, and most of these ignore social-engagement features even though user behaviour plays an important role in the spread of misleading content, as stated by [8].

Recently, explainable AI has also gained attention. Methods like SHAP and LIME are used to interpret predictions in sentiment analysis and toxicity detection [14,15], respectively. However, their applications in multilingual fake-news detection-especially code-mixed text-are still limited.

Overall, the literature identifies three major gaps:

- limited datasets for Gujarati-English and Marathi-English,
- lack of lightweight models designed for code-mixed misinformation.
- minimal use of explainability tools in this domain.

This research addresses these gaps by creating original code-mixed datasets and designing a lightweight, explainable adapter-based system for fake-news detection in multiple languages.

METHODOLOGY

This study followed an approach that addressed explainability, model development, preprocessing, and dataset creation. The overall workflow is designed to be lightweight and interpretable, and it also supports code-mixed Indian languages.

Dataset Preparation

This study created new datasets, as there are very limited datasets available for detecting fake news in Gujarati-English and Marathi-English languages [6,7]. Three language pairs were included: Marathi-English, Hindi-English, and Gujarati-English. For every post, textual data and social engagement metrics such as likes, shares, comments, follower count, verification status, and a source-credibility score were captured. All datasets combined into a unified format, with consistent column structures.

Text Cleaning and Normalization

The preprocessing primarily deal with the issues that are unique to code-mixed text such as transliteration, informal spellings, and excessively switching between languages. The cleaning steps involved removal of URLs, emojis,



**Deepali Shah and Neha Shah**

excessive punctuation, numbers, and lengthy repeated letters. The normalization rules were followed to reduce the spelling difference of commonly transliterated words giving a consistency for the same as reported in earlier code-mixed NLP studies [9]. Adding on, the cleaned datasets were merged and again set into training (70%), validation (15%) and testing (15%) datasets for the evaluation.

Model Architecture

We choose a lightweight XLM-R as the base model, supported by language-specific adapters.. The use of adapter learning largely brings down training costs and allows us to train on many languages more efficiently [2]. Three adapters were built: guj_en, hin_en, and mar_en, capturing language-pair patterns without modifying the base transformer. An Adapter Fusion layer was added optionally to share information learned across adapters for cross-lingual generalization [10].

Social-Feature Integration

To increase the accuracy of detection, the system incorporates social indicators that often reflect misinformation behaviour. Earlier studies have shown that fake news generates unusual engagement patterns when compared to verified posts [8]. The social features were normalized and concatenated with text embeddings for classification purposes, so the model can learn signals other than merely linguistic cues.

Explainability Layer

To ensure interpretability, the predictions of the model were analyzed via SHAP and LIME. This will show what words, patterns, or social behaviors influenced each decision [14,15]. This assists in determining whether the system is dependent on meaningful information, rather than noise or bias; hence, making the model deserving of application in real-world journalism and policy. The dataset was built along a strong three-phase pipeline to ensure legal fidelity and granular alignment. The usual sentence-alignment methods, perhaps, failed due to the complexity of legal syntax; hence, a method of automated structural parsing-"human-in-the-loop" methodology 1.0 was put in place.

RESULTS

Experiments were conducted on the three code-mixed datasets created for Gujarati-English, Hindi-English, and Marathi-English. The baseline XLM-R model was compared against two configurations: XLM-R with language-specific adapters and XLM-R with Adapter Fusion.

Dataset Summary

The final merged dataset contained 17,000 samples, with balanced real and fake labels across all language pairs. Table 1 summarizes the dataset distribution

Explainability Results

SHAP and LIME were used to interpret predictions. The explainability layer highlighted: Key words such as "breaking", "urgent", "share karo", and "fake che" strongly influenced fake-news predictions, consistent with previous findings [14, 15].

- Posts with abnormally high shares relative to likes were often flagged as suspicious.
- The model correctly identified sensational or exaggerated phrasing, a common trait in misinformation

DISCUSSION

The results indicate that adapter-based learning is very effective in code-mixed detection of fake news. This supports previous claims that adapters can learn language-specific behaviours using many fewer parameters [2]. The higher performance with Adapter Fusion also resonates with its results in previous low-resource NLP studies [10].



**Deepali Shah and Neha Shah**

One of the key findings shows that social-engagement features significantly improve classification accuracy. Previous research has recorded similar findings, where user-interaction patterns were found to enhance the detection models [8]. In this case, the features such as comments, shares, and follower counts include more valuable cues that text alone would not have captured. The explainability tools added another trust layer. SHAP and LIME showed the reasoning of the model very clearly, indicating that the decisions were made based on meaningful linguistic cues and not on random correlations. This is very important for real-world deployment, especially for journalism, governmental alerts, and fact-checking teams. Finally, this framework creates a prominent gap noted in previous literature by creating a dataset that lacks, especially in the category of Gujarati-English and Marathi-English misinformation datasets [6, 7]. With the additional contribution of producing code-mixed samples with social-context fields, this research creates improvements at the methodological and resource levels.

CONCLUSION AND FUTURE SCOPE

This study introduced a lightweight and explainable framework for detecting fake news in Indian code-mixed languages, focusing on Gujarati-English, Hindi-English, and Marathi-English. A custom dataset was created since there is a shortage of code-mixed resources, and by completely cleaning and normalizing the data, we ensured consistency on text quality. Through adapter-based learning on XLM-R, we enabled the model to work in a multilingual environment with mixed scripts while being economically efficient on training costs. Incorporating social engagement features like likes, shares, and comments has dovetailed other kinds of behavioral pattern learning into the system that could be associated with misinformation. Explainability tools such as SHAP and LIME showed the importance of textual cues and social signals in influencing the model's predictions. The experimental results achieved commendable accuracy and balanced performance across all language pairs, confirming the suitability of the proposed approach for real-world engagement scenarios with multilingual communication. Hence, the framework can be characterized as efficient, transparent, and scalable, making it a viable solution for organizations suggesting a framework to monitor online misinformation. Future directions can include extending the work by increasing the dataset using more authentic social media samples, which might include other Indian languages. The system could also be expanded to assess multimodal misinformation with images, memes, or videos. Further, building a real-time web or mobile version integrated with graph-based social features would increase its reach. More improved explainability implementations and visualization tools would enable use for understanding by journalists, educators, and lawmakers to see how the model reasons about instances of fake news. All these enhancements together would help build a more dependable and complete countermeasure to misinformation in multilingual online settings.

REFERENCES

1. A. Conneau et al., "XLM-R: A Strong Baseline for Cross-Lingual Natural Language Understanding," Proceedings of ACL, 2020.
2. J. Pfeiffer et al., "MAD-X: Multilingual Adapter Transfer for Cross-Lingual NLP," EMNLP, 2020.
3. S. Sharma, "Explainable Fake-News Classification Using Transformer Models," IEEE Transactions on Computational Social Systems, 2023.
4. B. Chakravarthi, "HASOC: Hate Speech and Offensive Content Dataset for Code-Mixed Languages," CEUR Workshop Proceedings, 2021.
5. R. Singh and K. Gupta, "Normalization Techniques for Code-Mixed Indian Languages," Journal of Indian Language Technology, 2024.
6. A. Jain and P. Shah, "Role of Social-Engagement Features in Online Fake-News Detection," ACM Web Science Conference, 2023.
7. D. Banerjee, "AdapterFusion for Low-Resource NLP Tasks," Transactions on ML Research, 2022.
8. M. Purohit, "Cross-Lingual Misinformation Detection Frameworks for Social Media," Information Processing & Management, 2024.





Deepali Shah and Neha Shah

9. A. Rajput and R. Mehta, "SHAP-Based Explainability for Text Classification," IEEE Access, 2023.
10. 10.A. Mittal, "Using LIME for Interpretable Social-Media Predictions," International Journal of AI Applications, 2024.
11. K. Patel, "Gujarati-English Code-Mixed Text Modelling," Indian Journal of Data Science, 2022.
12. P. Deshmukh, "Challenges in Marathi-English Code-Mixed NLP," Language Technology Review, 2023.
13. Y. Liu et al., "RoBERTa: A Robustly Optimized Transformer Approach," arXiv preprint, 2019.
14. M. Gupta, "IndicNLP Resources for Computational Linguistics," Conference on Indian Language AI, 2021.
15. R. Kumar, "Fake News Analysis in Multilingual Social Networks," Springer SN Computer Science, 2023.

Table 1. Distribution of Code-Mixed Datasets

Language Pair	Total Samples	Fake	Real
Gujarati-English	5000	2500	2500
Hindi-English	7000	3500	3500
Marathi-English	5000	2500	2500
Total	17000	8500	8500

Table 2. Performance Comparison of Models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
XLM-R (Full Fine-tuning)	90.1	89.5	90.8	90.1
XLM-R + Adapters	92.4	91.8	93.1	92.4
XLM-R + Adapter Fusion	93.6	92.9	94.0	93.4

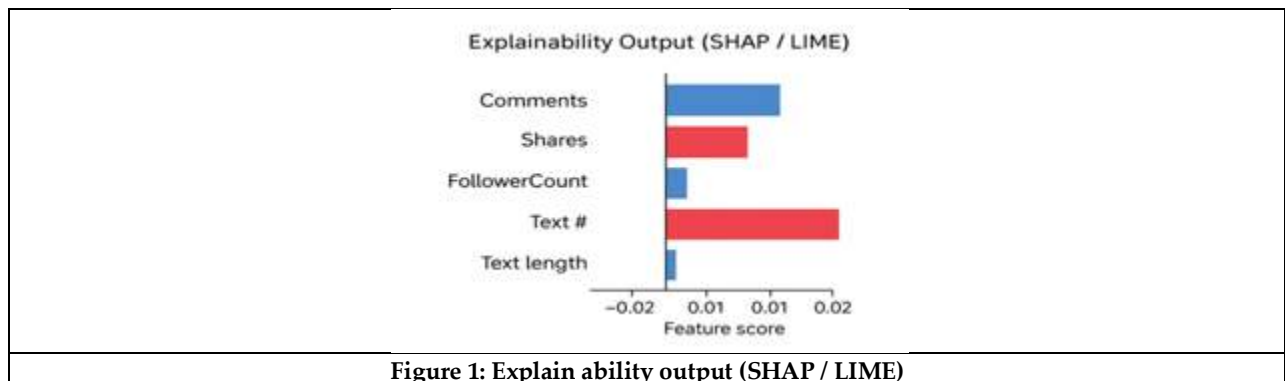


Figure 1: Explain ability output (SHAP / LIME)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Diversity and Distribution Pattern Analysis of Cyanobacteria Isolated from the Freshwater Habitats of Jhargram, West Bengal, India

Basudev Murmu¹, Tuhin Mallick¹ and Harisankar Dey^{2*}

¹Research Scholar, Department of Botany, Ramakrishna Mission Vivekananda Centenary College, Rahara, Kolkata, (Affiliated to West Bengal State University), West Bengal, India

²Assistant Professor, Department of Botany, Ramakrishna Mission Vivekananda Centenary College, Rahara, Kolkata, (Affiliated to West Bengal State University), West Bengal, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Harisankar Dey

Assistant Professor,

Department of Botany,

Ramakrishna Mission Vivekananda Centenary College,

Rahara, Kolkata, (Affiliated to West Bengal State University),

West Bengal, India

E.Mail: harisankardey@rkmvccrahara.org



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Cyanobacteria are ancient oxygenic photosynthetic prokaryotes, found in diverse ubiquitous habitats. They play significant roles in environmental monitoring, such as bioremediation, biofertilizer production, and the production of diverse bioactive compounds. Their community composition may be affected by several environmental gradients of that habitat, such as pH, temperature, total dissolved solids (TDS), and electrical conductivity (EC), as well as anthropogenic activities. They may sometimes exert a detrimental effect on aquatic life, as some taxa can form blooms and release toxins. For that purpose, ecologists are trying to document cyanobacteria from all possible biotypes. In this study, cyanobacterial diversity was examined in the Binpur I and Binpur II blocks of Jhargram Sub-Division, West Bengal, India, and the effects of environmental parameters on community composition were assessed. The study found that filamentous non-heterocystous genera are dominant, and other, less dominant genera are filamentous heterocystous and coccoid. Multivariate analysis, specifically Principal Component Analysis (PCA), showed that temperature, pH, TDS, and EC significantly shape the species composition of this area. Further study is also required to know the seasonal influence on the cyanobacterial diversity of this region.

Keywords: Cyanobacteria, Diversity, Jhargram, Physicochemical analysis, PCA



Basudev Murmu *et al.*,

INTRODUCTION

Cyanobacteria, also known as blue-green algae, are a diverse and ecologically significant group of oxygen-producing photosynthetic prokaryotes found in numerous aquatic and terrestrial environments [1]. These microorganisms play a significant role in primary production, nutrient cycling, and biogeochemical processes within freshwater ecosystems also are essential for controlling nitrogen dynamics. Their evolutionary importance is highlighted by their ancient origins and their role in Earth's initial oxygenation and the evolution of its ecosystems [2]. Freshwater ecosystems such as ponds, rivers, lakes, reservoirs, and floodplain wetlands form a mosaic of ecological habitats that promote cyanobacterial growth. These environments frequently exhibit significant seasonal and spatial variations in physicochemical factors, such as nutrient levels, temperature, and light availability, which affect the organization and behavior of cyanobacterial populations. Anthropogenic activities such as agricultural runoff, urban development, and wastewater discharge increase nutrient levels, which can promote cyanobacterial growth, sometimes leading to harmful blooms that degrade water quality, harm aquatic organisms, and affect human well-being [3].

Precise documentation of cyanobacterial diversity is essential for understanding community structure and ecological functioning, identifying potentially harmful taxa, and guiding conservation efforts. Moreover, cyanobacteria harbor species with significant biotechnological capabilities, including applications in biofertilization, bioremediation, and the production of bioactive compounds [4]. Several environmental gradients, such as temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC), are crucial parameters that affect cyanobacterial physiology. To analyze these parameters, multivariate analysis is required [5]. Several studies from West Bengal, India, have shown enormous diversity of cyanobacteria across various freshwater habitats [6]; [2]; [7]; [8]; [9]. The Jhargram Sub-Division is situated 21°-52' to 22°-48' North latitudes and 86°-34' to 87°-20' East longitude approximately. Elevated temperatures, high humidity, and a tropical atmosphere, with considerable summer heat, substantial monsoonal precipitation, and temperate winters, characterize Jhargram's climate. Agriculture (especially paddy) depends heavily on the monsoon and on surface water; freshwater bodies directly influence the timing, success, and productivity of paddy cultivation in Jhargram. Lakes, ponds, and seasonal wetlands also support local biodiversity, including birds and aquatic organisms, and act as micro-ecosystems that influence local climate and livelihoods. This study aims to systematically characterize the diversity of cyanobacteria in the Binpur I and Binpur II blocks of Jhargram Sub-Division, West Bengal, India. This research provides a revised baseline of cyanobacterial community composition by combining morphological and ecological observations with regional environmental context, thereby aiding future ecological evaluations, water-quality research, and conservation strategies.

MATERIALS AND METHODS

Collection, Isolation, Identification, Purification, and Preservation of Isolated Organisms

Cyanobacteria samples were collected from diverse freshwater sources, including ponds, rivers, canals, drainage systems, and paddy fields in Binpur I and Binpur II blocks of Jhargram district. Photo plate (Pl.), Table 1. Random sampling was conducted using fine tweezers, plankton nets, and sample bottles attached to the Substratum surface in ponds. Samples were transported to the laboratory, examined with a Leica microscope (model LEICA ICC50 W), and micrographs were captured for identification. Each sample was assigned a unique number, and the collection date was documented in a field diary. Pure cultures were established using the agar method and cultivated in BG-11 + nitrogen. Incubation was maintained at $25 \pm 2^\circ\text{C}$ under continuous white light illumination ($30\text{--}35 \mu\text{mol m}^{-2} \text{s}^{-1}$ photons) with a 12-hour light and 12-hour dark cycle for up to six weeks for bulk cultures [10]; [11]. Identification was conducted using traditional morphometric methods, focusing on the shape and size of vegetative cells, branching patterns, presence or absence, and breadth of the sheath, as well as the shape, position, and size of heterocysts and akinetes, following established cyanobacterial references [12]; [13]; [14]; [15]; [16].





Analysis of Physicochemical Properties of Water Samples

The physicochemical properties such as temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) of aquatic ecosystems intensely influence the diversity and abundance of cyanobacteria [5]. A digital temperature, pH, TDS, and EC meter is used to measure all the physicochemical properties of the water sample. For the soil sample, 2.5 g of soil was dissolved in 10 mL of distilled water, filtered through Whatman's filter paper, and the filtrate was used to measure the aforementioned properties [5]. All temperature, pH, TDS, and EC measurements were performed three times.

Study of Cyanobacterial Diversity

Quantitative assessment of cyanobacterial diversity is essential for interpreting community composition, ecological resilience, and the effects of environmental stressors, including eutrophication and climate change. Diversity indices integrate species richness and relative abundance, providing a robust framework for evaluating cyanobacterial communities [17].

Shannon-Wiener Diversity Index (H')

The Shannon-Wiener index is one of the most widely used diversity metrics, which accounts for both species richness and evenness, making it sensitive to changes in community structure.

$$H' = - \sum (p_i \ln p_i)$$

where p_i represents the proportion of individuals belonging to the i th species [18].

Simpson's Diversity Index (1-D)

Simpson's index quantifies the probability that two randomly selected individuals from a sample belong to the same species, emphasizing species dominance rather than richness.

$$D = \sum p_i^2$$

Simpson diversity is commonly expressed as 1-D or $1/D$, where higher values correspond to greater diversity [19].

Margalef's Richness Index (d')

Margalef's index primarily reflects species richness and is minimally influenced by species evenness.

$$d' = \frac{S - 1}{\ln N}$$

Where S represents the total number of species and N is the total number of individuals. In cyanobacterial studies, Margalef's index is used to compare richness across sites or seasons [20].

Berger-Parker Dominance Index (d)

The Berger-Parker index measures the relative abundance of the most dominant species in a community.

$$d = \frac{N_{max}}{N}$$

Where N_{max} represents the number of individuals of the most abundant species, and N is the total number of individuals [21].

Principal Component Analysis (PCA) for Cyanobacterial Diversity

Principal Component Analysis (PCA) is a statistical method commonly used in ecological research to reduce data dimensionality and identify the primary environmental gradients that influence community composition. In studies of cyanobacterial diversity, PCA helps clarify the relationships among diversity indices, species composition, and physicochemical factors, making it easier to understand complex datasets [22]. The multivariate analysis (PCA), visualization of data and pictorial graph were generated using the python (version 3.12.13) in Google Colab.





RESULTS AND DISCUSSION

Taxonomic Enumeration of Isolated Species

Aphanocapsa parietina Nägeli; Pl.2, fig.(figure). A Description: Colonies small, yellowish-green, length 5.54µm, breadth 6.74µm. Habitat: Floating in rice field water. *Aphanothece pallida* (Kützinger) Rabenhorst; Pl.2, fig.B; Description: olive green; Cells oblong, cylindrical, 4.31 µm wide, 6.49 µm long. Habitat: Mat on moist rocky soil. *Aphanothece microscopica* Nägeli; Description: Thallus small gelatinous, cell oblong cylindrical, 4.5 µm broad, cell 2 µm as long as broad, individual distinct sheaths. Habitat: Floating in rice field water. *Aphanocapsa bififormis* A. Barun; Pl.2, fig.D; Description: Thallus olive green, cells 4.09-7.07 µm wide, spherical, 2 cells in a common mucilaginous envelope. Habitat: Mat on paddy field soil. *Phormidium animale* (Agardh ex Gomont) Anagnostidis et Komarek; Description: Trichome straight, 3.5 µm wide, 5.7 µm long, slightly bent at apical portion. Habitat: Floating in small ditch water. *Phormidium tortuosum* (Gardener) Anagnostidis et Komarek; Pl.2, fig.F; Description: Trichomes flexuous, pale blue-green, 3.4 µm wide, cell shorter than wide, 1.78 µm long; apical cell acuted, round. Habitat: Upper surface of the mud. *Phormidium chlorinum* (Kützinger ex Gomont) Anagnostidis; Pl.2, fig.G; Description: Thallus fine, yellow-green, 4.35 µm wide, cell more or less isodiametric slightly shorter than wide, 3.76 µm long, apical cell slightly flattened. Habitat: Mat on rice field soil.

Phormidium retzii (Agardh) Gomont ex Gomont; Pl.2, fig.H; Description: Thallus bright blue-green, thick; filament more or less straight. Trichome dark-blue green in colour, 11.28 µm wide. Cell slightly shorter than wide 6.28 µm. Apical cell 12.44 µm long, without calyptra. Habitat: Attached to the soil in spring water. *Pseudanabaena skujae* Claus; Pl.2, fig.I; (Description: Thallus bluish-green, 1.2-2.3 µm wide and up to 7.5 µm long cells; Epical cell elongated. Habitat: Floating in rice field water. *Pseudanabaena minima* (G.S. An) Anagnostidis; Pl.2, fig.J Description: Thallus solitary, trichome straight or almost straight, 1.94 µm wide, cell cylindrical 2.83 µm long, apical cell widely rounded. Habitat: Attached with substratum in rice field water. *Pseudanabaena catenate* Lauterborn; Pl.2, fig.K; Description: Trichomes olive-green, more or less straight, 4.27 µm wide, 15.23 µm long; Cell content homogenous; Apical cell rounded. Habitat: Attached with substratum in rice field water. *Limnothrix planctonica* (Woloszynska) Meffert; Pl.2, fig.L; Description: Trichome solitary, free-floating, straight or slightly curved, pale blue-green, 2.46 µm wide. Cells 2-3 time longer than wide, 6.87 µm long, apical cell cylindrical, rounded. Habitat: Mat on moist rocky soil. *Schizothrix* sp., Pl.3, fig.A; Description: Filamentous solitary, densely joined, free-floating, 9.6 µm wide and cell, 4.34 µm long. Habitat: Mat on moist rocky soil. *Phormidium targestinum* [Kützinger] Anagnostidis et Komarek; Pl.3, fig.B; Description: Thallus thin mucilage, bright blue green, trichome 4-10 µm wide, cell longer than wide, 2.4-6.5 µm long, apical cell rounded. Habitat: Mat on moist rocky soil.

Spirulina sp., Pl.3, fig.C; Description: Trichomes blue-green, distance between coils 17.25 µm, coils right-handed, cells shorter than wide, apical cell rounded. Habitat: Attached with substratum. *Oscillatoria subbrevis* Schmidle; Pl.4, fig.D; Description: Trichome green-yellowish, 6.17 µm wide, usually straight sometimes arched; Cells are shorter than wide, 2.09 µm long; Apical cells without calyptra. Habitat: Floating in stagnant water. *Oscillatoria proboscida* Gomont ex Gomont; Pl.3, fig.E; (Description: Trichome bright blue-green, 18.33 µm wide, Cell 4.76 µm long. Habitat: Submerged in small ditch water. *Oscillatoria ucranica* Valdimirova; Pl.3, fig.F; Description: Trichome solitary, straight or curved, 2.36 µm wide. Cell 4.08 µm long, apical cells conical-rounded. Habitat: Submerged in small ditch water. *Nostoc kihlmanii* Lemmermann; Pl.3, fig.G; Description: Colonies free-floating, olive-green, cells spherical, length of cell 3.76 µm and breadth 3.55-4.0 µm. Heterocyst spherical or ellipsoidal, breadth 5.59 µm and length 5.8 µm. Habitat: Abandoned wet rice field soil. *Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis; Pl.3, fig.H; Description: 3.05 µm wide, cell usually 6.38 µm long, without calyptra. Habitat: Attached with substratum in rice field water. *Oscillatoria ornate* Kützinger ex Gomont; Pl.3, fig.I; Description: cells shorter than wide, 2-5 µm long, trichome 6-9 µm wide. Habitat: Floating in rice field water. *Oscillatoria major* Vaucher ex Hansgirg; Pl.3, fig.J; Description: Trichome blue-green in colour, 20.32 µm wide, apical portion hook like structure. Cells shorter than wide, 6.02 µm long. Apical cell obtusely-rounded without calyptra. Habitat: Submerged in small ditch water.





Basudev Murmu and Tuhin Mallick *et al.*,

Lyngbya martensiana Meneghini ex Gomont; Pl.3, fig.K; Description: Trichome olive green, 10.85 μm wide, cell 2.40 μm long, apical cell widely rounded without calyptra. Habitat: Mat on rocky soil (beside rice field). *Lyngbya anomala* (Rao) Anagnostidis; Pl.3, fig.A; Description: Thallus deep-blue green; sheath thin, trichome 8.60 μm wide; Cell 1.75 μm long, apical cell bluntly rounded without calyptra. Habitat: Mat on abandoned rice field soil. *Cylindrospermum mikhailovskoense* Elenkin; Pl.4, fig.A; Description: Cells pale blue-green, cylindrical, length 7.35 μm and breadth 4.15 μm . Heterocyst develops only at one end of trichome, cylindrical, length 7.17 μm and breadth 6.14 μm . Akinetes cylindrical, 13.40 μm . Habitat: Besides wet rice field soil. *Scytonema sp.*, Pl.4, fig.B; Description: Thallus bright blue green, 12.96 μm long and 5.41 μm wide; heterocyst cylindrical, length 10.20 μm and breadth 5.74 μm . Habitat: Attached to substratum. *Nostoc ellipso sporum* Rabenhorst ex Bornet & Flahault; Pl.4, fig.C; Description: Colonies gelatinous, flattened, olive green. Cells cylindrical, length 5.31 μm and breadth 4.44 μm . Heterocyst almost spherical, cylindrical, length 8.10 μm and breadth 6.43 μm . Habitat: Attached to soil in a small ditch water besides rice field. *Desmonostoc muscorum* Ag. Ex. Born. Et. Flah; Pl.4, fig.D; Description: Colonies hemispherical, blue-green, sheaths distinct at the margin of colonies. Cell barrel-shaped to cylindrical, length 5.90 μm , breadth 4.13 μm . Heterocyst almost spherical or barrel-shaped, length 5.73 μm , breadth 6.1 μm . Habitat: Free floating on paddy field. *Hapalosiphon welwitschii* W. et G. S. West; Pl.4, fig.E; Description: Filamentous than other algae, sheath very narrow, cells rounded, barrel-shaped, in branches 7.90 μm , breadth of cell 5.75 μm . Heterocyst cylindrical, length 8.47 μm and breadth 5.91 μm . Habitat: Attached with substratum in rice field water.

Calothrix castellii (Massal.) Bron. Et. Flah; Pl.4, fig.F; Description: dirty blue-green sheath thin, 8.1 μm wide. Heterocyst hemispherical, 7.1 μm . Habitat: Mat on wet rocky soil. *Westiellopsis indica* Bourrelly; Pl.4, fig.G; Description: Thallus forming blackish-green, branched, monoseriate, terminal parts of branches often narrowed. Cells barrel-shaped, length 6.0 μm and breadth 5.91 μm . Heterocyst spherical, length 5.81 μm and breadth 5.59 μm . Habitat: Attached to the mud. *Nostoc linckia* (Roth) Bornet ex Born. Et Flah, Pl.4, fig.H; Description: Colonies fine; Cells shortly, length 3.44 μm and breadth 4.30 μm . Heterocyst almost spherical, length 5.24 μm and breadth 5.21 μm . Habitat: Besides wet rice field soil.

Biodiversity Patterns

Most of the study locations showed the Shannon diversity index (H') [Fig. 1, Table 1] values over 2.5; overall, it ranged from 2.21 to 2.89, pointing towards the moderate to high diversity at most locations. The higher values (>2.7) seen at locations such as L1(2.75), L15(2.76), L26(2.78) and L27(2.89). The Simpson index ($1-D$) [Fig. 1, Table 1] showed high evenness and low dominance and absence of domination of single species through the studied sites, as values ranged from 0.88 (L6, L10) to 0.94 (L27). Further, this result is also supported by the Berger–Parker dominance index [Fig. 1, Table 1], as the values ranged from 0.09 (L27) to 0.2 (L06, L22), pointing out that species monopoly is limited. The Margalef index [Fig. 1, Table 1] depicted the species richness; the values varied from 3.34 (L10) to 5.74 (L27), locations L1, L15, L24, L26, and L27 (values > 5.0) showing higher species richness. All the diversity indices suggest relatively steady ecosystems that support the coexistence, are balanced, and favour a greater number of species abundances.

Influence of Physicochemical Parameters

The Pearson correlation analysis figured out that there are considerable links among the variables such as electrical conductivity (EC) [Fig. 4, Table 2], total dissolved solids (TDS) [Fig. 4, Table 2], temperature [Fig. 4, Table 2], and pH [Fig. 4, Table 2]. The pH is moderately positively correlated with the temperature ($r = 0.48$) but weakly correlated with the EC ($r = -0.09$) and TDS ($r = -0.04$). The temperature showed a moderate negative relationship with the EC ($r = -0.50$) and TDS ($r = -0.35$). Meanwhile, the relationship between TDS and EC ($r = 0.76$) showed a strongly positive. The current investiture results are also supported by a study conducted by Deep PR *et al.* [3] on wetlands in Odisha, which showed dominance of *Oscillatoria*, *Anabaena*, and *Phormidium* under higher TDS and altered water chemistry, where these taxa were predominant and correlated with physicochemical variables.





Multivariate Analysis of Environmental Gradients

The principal component analysis (PCA) of environmental gradients such as temperature, pH, EC, and TDS explained a considerable amount of total variance. The PC1 (54.54%) [Fig. 3, Table 2] and PC2 (29.44%) [Fig. 3, Table 2] sum up to 83.98% of the total variance. The EC and TDS were strongly linked with PC1, whereas pH and temperature were linked with PC2. The PC1 was indicating the range of nutrient enrichment or ionic gradients. The PC2 was indicating the metabolic or physiological constraints. This study is also supported by previous investigations by [23] and [24], which found that multivariate analyses of temperature, pH, TDS, and conductivity modulate cyanobacterial diversity.

Species Abundance

The heatmap analysis of species abundance patterns showed the patchy or heterogeneous distribution across locations [Fig. 2]. The most abundant species are filamentous and non-heterocystous, such as *Oscillatoria subbrevis* Schmidle, *Oscillatoria ornata* Kützinger ex Gomont, *Lyngbya anomala* (Rao) Anagnostidis, *Phormidium animale* (Agardh ex Gomont), *Pseudanabaena catenata* Lauterborn, and heterocystous genus, *Cylindrospermum michailovskense* Elenkin. The moderately abundant species are composed of filamentous, non-heterocystous, heterocystous, and coccoid species, such as *Phormidium retzii* (Agardh) Gomont ex Gomont, and *Nostoc muscorum* Ag. Ex. Born. Et. Flah, *Spirulina* sp., *Aphanothece pallida* (Kützinger) Rabenhorst, *Phormidium targestinum* Komarek, *Pseudanabaena minima* (G.S. An) Anagnostidis, *Oscillatoria major* Vaucher ex Hansgirg, *Aphanocapsa microscopica* Nägeli.

The low-abundant species are also composed of filamentous, non-heterocystous, heterocystous, and coccoid species, such as, *Calothrix castelli* (Massal.) Born. et Flah, *Westiellopsis prolifica* Janet, *Scytonema* sp., *Nostoc carneum* C. Agardh ex Bornet & Flahault, *Nostoc linckia* (Roth) Bornet ex Bornet & Flahault, *Aphanothece pallida* (Kützinger) Rabenhorst, *Aphanocapsa bififormis* A. Barun. The rare or very low-abundant species are *Limnithrix planctonica* (Wołoszyńska) Meffert, *Geitlerinema amphibium* (Agardh ex Gomont), *Hapalosiphon welwitschii* W. et G. S. West, *Nostoc ellipsosporum* Rabenhorst ex Bornet & Flahault, *Oscillatoria proboscidea* Gomont ex Gomont, *Lyngbya martensiana* Meneghini ex Gomont, *Phormidium chlorinum* (Kützinger ex Gomont) Anagnostidis. Numerous recent taxonomic studies conducted throughout West Bengal, including Barasat [6], Bidhannagar [2] Krishnagar Sadar [7], East Kolkata Wetlands [8], and from the Berhampore subdivision of Murshidabad [9] constantly reported filamentous and non-heterocystous genera are dominant, such as *Oscillatoria* sp. *Lyngbya* sp. and *Phormidium* sp., the other less dominant genera, are mainly heterocystous, and the coccoid species such as *Anabaena* sp., *Nostoc* sp., and *Chroococcus* sp., respectively.

ACKNOWLEDGEMENT

The authors express profound gratitude to the Principal of Ramakrishna Mission Vivekananda Centenary College, Rahara, Kolkata for his invaluable support and availability of laboratory resources essential to the completion of this study.

REFERENCES

1. Whitton BA, Potts M. Introduction to the Cyanobacteria. In: Whitton BA, Potts M, editors. The Ecology of Cyanobacteria: Their Diversity in Time and Space. 1st ed. Springer, Dordrecht; 2000. p. 1-11.
2. Dey HS, Chakraborty S. Diversity of Non-Heterocystous Filamentous Cyanobacteria from Freshwater Bodies of Bidhannagar, North 24 Parganas, West Bengal. Asian J Biol Life Sci. 2020; 9 (3):386-90.
3. Deep PR., Bhattacharyya S, Nayak B. Cyanobacteria in wetlands of the industrialized Sambalpur District of India. Aquat. Biosyst. 2013; 9:14.
4. Dudeja C, Masroor S, Mishra V. Kumar K, Sansar S, Yada P *et al.* Cyanobacteria-based bioremediation of environmental contaminants: Advances and computational insights. Discov Agric 2025; 3:42.





Basudev Murmu and Tuhin Mallick *et al.*,

5. Singh SS, Kunui K, Minj RA, Singh P. Diversity and distribution pattern analysis of cyanobacteria isolated from paddy fields of Chhattisgarh, India J Asia Pac Biodivers 2014;7:462-470.
6. Talai-Mukhopadhyay S, Naskar N. Diversity of cyanobacteria from Barasat, Kolkata, West Bengal, India. JIRR 2015; 3(1):107-113.
7. Debnath P, Dey H. Diversity of cyanobacteria from freshwater bodies of Krishnagar Sadar subdivision of Nadia District, West Bengal, India. J. Bio. & Env. Sci. 2022; 21(5):190-197.
8. Ray A, Mondal D, Chakraborty N, Ganguly S. Phytoplankton diversity in wastewater impacted Indian Ramsar site: a study from East Kolkata Wetland. Environ Monit Assess 2023;195(8):938.
9. Mallick T, Debnath P, Dey H. A Taxonomic Evaluation of Freshwater Cyanobacteria from Berhampore Subdivision of Murshidabad District, West Bengal, India. IJONS 2025; 16:92.
10. Rippka R, Stanier RY, Deruelles J, Herdman M, Waterbury JB. Generic Assignments, Strain Histories and Properties of Pure Cultures of Cyanobacteria. J Gen Microbiol. 1979;111(1):1-61.
11. Kaushik BD. Laboratory methods for blue-green algae. Associated publishing company; 1987.
12. Desikachary T. V. Cyanophyta. New Delhi: Indian Council of Agricultural Research, 1959.
13. Komárek J, Anagnostidis K. Modern approach to the classification system of the cyanophytes 4: Nostocales. Algol Stud. 1989; 56:247-345.
14. Komárek J, Anagnostidis K. Cyanoprokaryota 1. Teil Chroococcales, Heidelberg: Spektrum Akademischer, 1999.
15. Komárek J, Anagnostidis K. Cyanoprokaryota. Süßwasserflora von Mitteleuropa, Bd. 19/2: Cyanoprokaryota, Heidelberg: Spektrum Akademischer, 2005.
16. Komárek J. Süßwasserflora von Mitteleuropa, Bd. 19/3: Cyanoprokaryota, Berlin: Springer Spektrum, 2013.
17. Magurran AE. Measuring biological diversity. Curr Biol. 2021; 31(19): R1174-R1177.
18. Shannon CE: A mathematical theory of communication. Bell Syst Tech J. 1949; 27: 379-423.
19. Simpson EH. Measurement of Diversity. Nature 1949; 163:688-688.
20. Margalef R. Information theory in ecology. Int J Gen Syst. 1957; 3:36-71.
21. Berger WH, Parker FL. Diversity of Planktonic Foraminifera in Deep-Sea Sediments. Science 1970; 168(3937):1345-1347.
22. Legendre P, Legendre L. Ordination in reduced space. In Legendre P, Legendre L, editors. Numerical Ecology: Developments in Environmental Modelling. 3rd ed. Elsevier, Amsterdam; 2012. p. 425-520.
23. Kumar A, Singh R., Singh SP. Cyanobacterial community structure in hot water springs of Indian North-Western Himalayas: a morphological, molecular and ecological approach. Algal Res 2018; 29: 179-192.
24. Rangra GS, Singh Y, Thapa K, Khattar JIS, Singh DP. Spatiotemporal distribution of cyanobacteria in relation to water chemistry of Sutlej River, Punjab (India). Environ Monit Assess 2024; 196: 937.

Table 1: Diversity indices of cyanobacterial communities across 29 sampling locations in Jhargram District, West Bengal, India. Values include Shannon diversity index (H'), Simpson's index (1-D), Margalef richness index (d'), and Berger-Parker dominance index (d), with corresponding geographic coordinates (latitude and longitude) for each site. The indices highlight spatial variation in species richness, evenness, and dominance patterns across the study area.

Location	Latitude	Longitude	Shannon(H')	Simpson (1-D)	Margalef (d')	Berger-Parker (d)
L1	22.656733	87.024256	2.75	0.93	5.29	0.12
L2	22.647317	86.95353	2.20	0.89	3.64	0.11
L3	22.656489	87.021863	2.27	0.89	3.75	0.18
L4	22.555267	86.910464	2.24	0.89	3.41	0.14
L5	22.634778	86.957211	2.66	0.93	4.84	0.11
L6	22.607879	86.936773	2.21	0.88	3.41	0.21
L7	22.621279	86.95653	2.55	0.92	4.34	0.15
L8	22.656234	87.021717	2.34	0.90	3.79	0.14
L9	22.556901	86.91059	2.48	0.91	4.24	0.18
L10	22.454273	86.880516	2.15	0.88	3.34	0.18





Basudev Murmu and Tuhin Mallick *et al.*,

L11	22.556317	86.910209	2.60	0.92	4.69	0.13
L12	22.662937	86.947714	2.61	0.92	4.47	0.13
L13	22.662879	86.947737	2.62	0.92	4.67	0.15
L14	22.659286	86.953619	2.43	0.91	4.06	0.13
L15	22.656442	86.954701	2.76	0.93	5.26	0.14
L16	22.608006	86.936664	2.62	0.92	4.60	0.14
L17	22.635324	86.95709	2.45	0.90	4.15	0.17
L18	22.640776	86.95652	2.60	0.92	4.69	0.13
L19	22.635069	86.95733	2.59	0.92	4.59	0.12
L20	22.605841	86.83084	2.43	0.91	4.06	0.13
L21	22.616058	86.784964	2.43	0.91	3.88	0.12
L22	22.611776	86.792756	2.40	0.90	4.17	0.21
L23	22.594916	86.895939	2.55	0.91	4.50	0.17
L24	22.597362	86.882431	2.69	0.93	5.01	0.15
L25	22.600423	86.858417	2.65	0.93	4.67	0.10
L26	22.607488	86.807214	2.78	0.93	5.26	0.10
L27	22.650032	86.746241	2.89	0.94	5.74	0.09
L28	22.650048	86.746269	2.51	0.91	4.33	0.13
L29	22.659005	86.742262	2.67	0.92	4.78	0.13

Table 2: Physicochemical characteristics of water across 29 sampling locations in Jhargram District, West Bengal, India. Values are expressed as mean $\pm$ standard deviation for pH, temperature ($^{\circ}\text{C}$), total dissolved solids (TDS, mg/L), and electrical conductivity (EC, $\mu\text{S/cm}$). The dataset highlights spatial variation in physicochemical parameters influencing cyanobacterial diversity.

Location	Temperature ($^{\circ}\text{C}$)	pH	EC ($\mu\text{S/cm}$)	TDS (mg/L)
L1	27.500 $\pm$ 0.245	6.937 $\pm$ 0.034	95.567 $\pm$ 0.205	66.333 $\pm$ 1.247
L2	32.833 $\pm$ 0.125	7.350 $\pm$ 0.022	94.367 $\pm$ 0.591	43.333 $\pm$ 1.247
L3	27.633 $\pm$ 0.368	7.143 $\pm$ 0.041	91.700 $\pm$ 0.163	38.667 $\pm$ 1.247
L4	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L5	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L6	32.833 $\pm$ 0.125	7.350 $\pm$ 0.022	94.367 $\pm$ 0.591	43.333 $\pm$ 1.247
L7	31.467 $\pm$ 0.170	7.267 $\pm$ 0.021	101.667 $\pm$ 2.055	77.000 $\pm$ 2.160
L8	31.700 $\pm$ 0.294	7.213 $\pm$ 0.026	97.967 $\pm$ 0.368	82.667 $\pm$ 1.700
L9	30.433 $\pm$ 0.249	7.067 $\pm$ 0.034	95.000 $\pm$ 1.633	71.667 $\pm$ 2.055
L10	29.167 $\pm$ 0.249	6.980 $\pm$ 0.029	91.333 $\pm$ 2.055	77.667 $\pm$ 1.247
L11	29.200 $\pm$ 0.408	6.980 $\pm$ 0.029	96.967 $\pm$ 0.368	68.667 $\pm$ 1.700
L12	29.733 $\pm$ 0.249	6.950 $\pm$ 0.029	97.267 $\pm$ 0.525	73.333 $\pm$ 1.247
L13	29.733 $\pm$ 0.249	6.950 $\pm$ 0.029	97.267 $\pm$ 0.525	73.333 $\pm$ 1.247
L14	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L15	31.667 $\pm$ 0.125	7.123 $\pm$ 0.034	90.867 $\pm$ 1.330	72.667 $\pm$ 1.247
L16	31.767 $\pm$ 0.125	7.167 $\pm$ 0.034	90.767 $\pm$ 1.682	72.667 $\pm$ 1.700
L17	29.800 $\pm$ 0.294	6.997 $\pm$ 0.025	98.800 $\pm$ 0.356	74.667 $\pm$ 2.867
L18	29.333 $\pm$ 0.368	7.150 $\pm$ 0.033	98.800 $\pm$ 0.294	77.333 $\pm$ 1.700
L19	31.333 $\pm$ 0.125	7.230 $\pm$ 0.045	102.667 $\pm$ 1.700	112.000 $\pm$ 1.633
L20	31.467 $\pm$ 0.170	7.267 $\pm$ 0.021	107.333 $\pm$ 2.055	123.667 $\pm$ 2.055
L21	31.700 $\pm$ 0.294	7.213 $\pm$ 0.026	92.067 $\pm$ 0.249	72.667 $\pm$ 1.247
L22	28.500 $\pm$ 0.163	7.410 $\pm$ 0.016	102.500 $\pm$ 1.080	96.667 $\pm$ 1.247
L23	28.500 $\pm$ 0.163	7.410 $\pm$ 0.016	102.500 $\pm$ 1.080	96.667 $\pm$ 1.247





Basudev Murmu and Tuhin Mallick *et al.*,

L24	26.400 ± 1.715	6.993 ± 0.012	112.500 ± 1.080	96.000 ± 2.449
L25	29.333 ± 0.262	7.273 ± 0.025	111.667 ± 1.247	100.667 ± 1.247
L26	30.067 ± 0.419	6.963 ± 0.046	97.333 ± 0.499	102.667 ± 1.700
L27	28.433 ± 0.249	6.960 ± 0.043	101.767 ± 0.579	131.000 ± 1.633
L28	29.133 ± 0.330	7.313 ± 0.021	113.667 ± 1.247	122.000 ± 2.160
L29	29.200 ± 0.294	7.313 ± 0.012	125.000 ± 1.633	139.333 ± 1.247

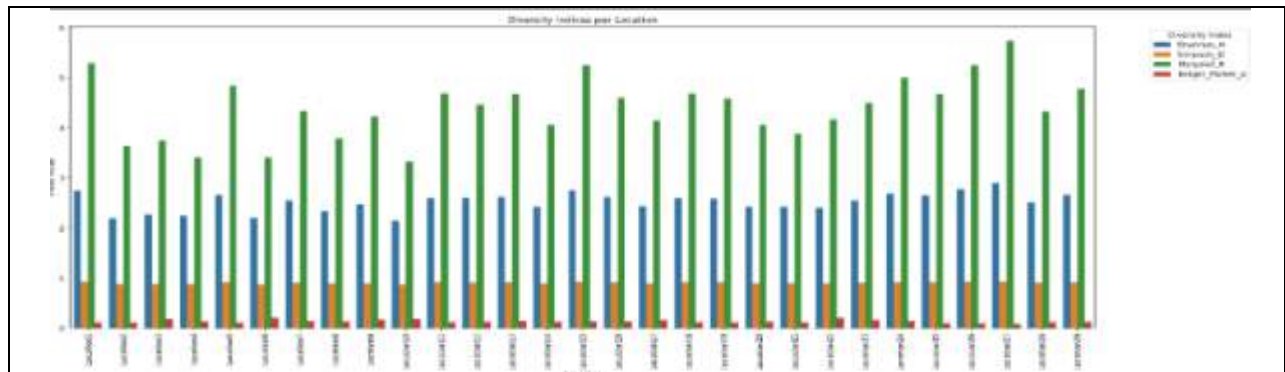


Fig. 1: Diversity Indices

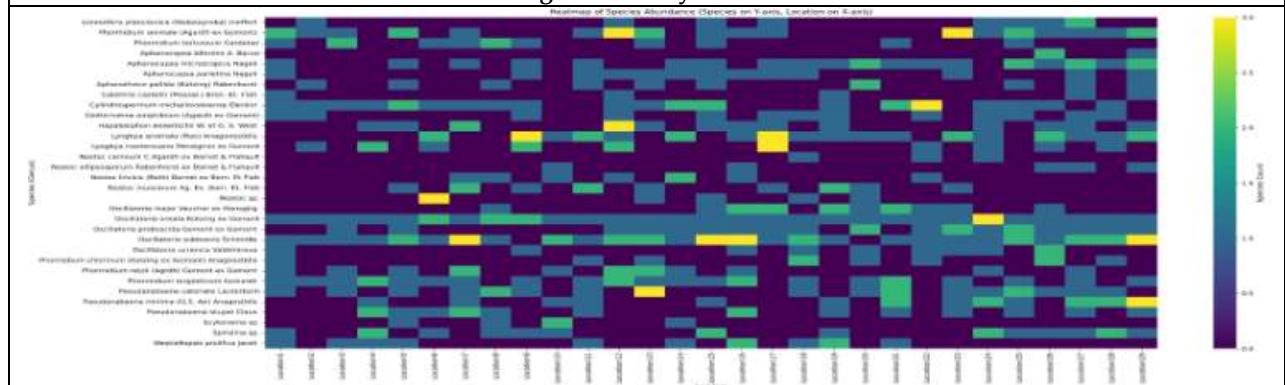


Fig. 2: Species Distribution Heatmap

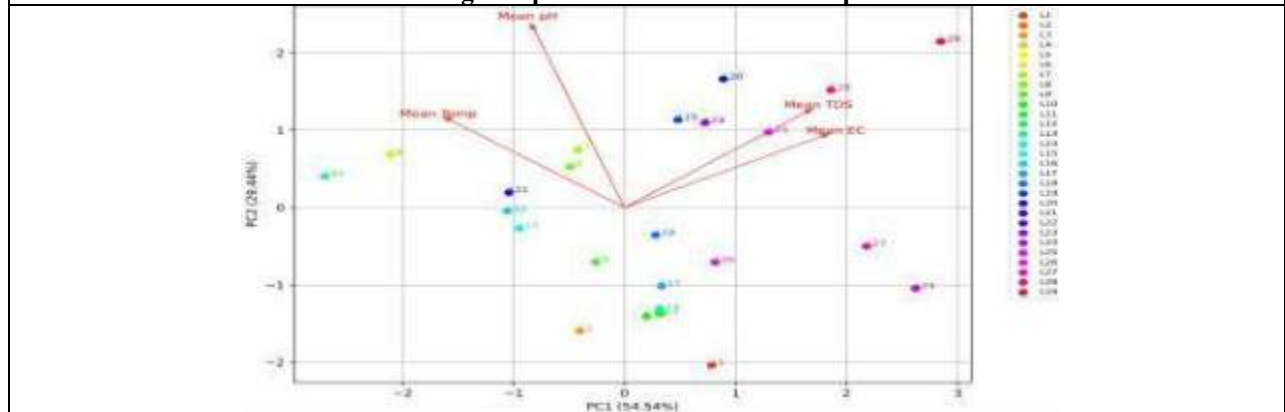
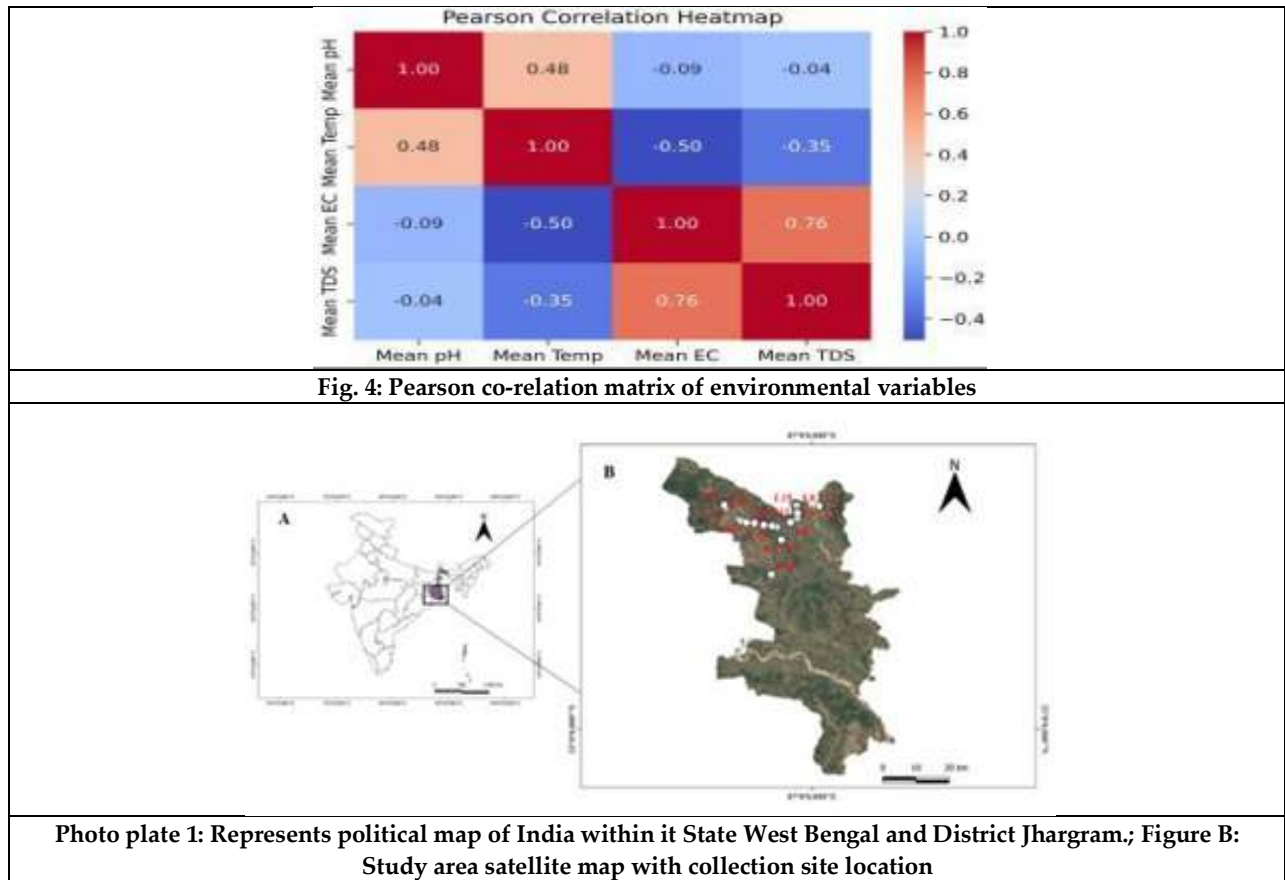
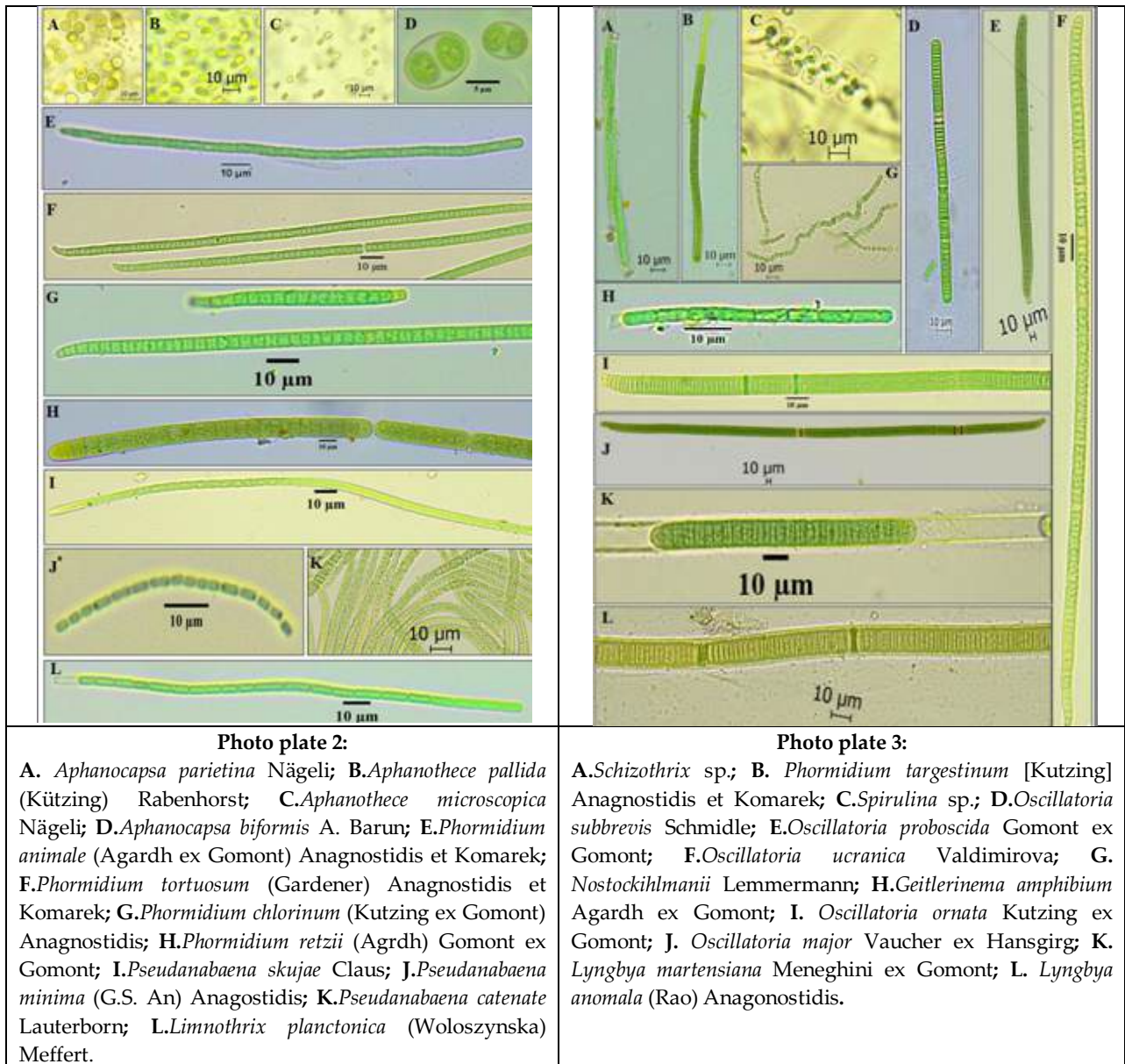


Fig. 3: PCA analysis of Environmental variables









Basudev Murmu and Tuhin Mallick *et al.*,

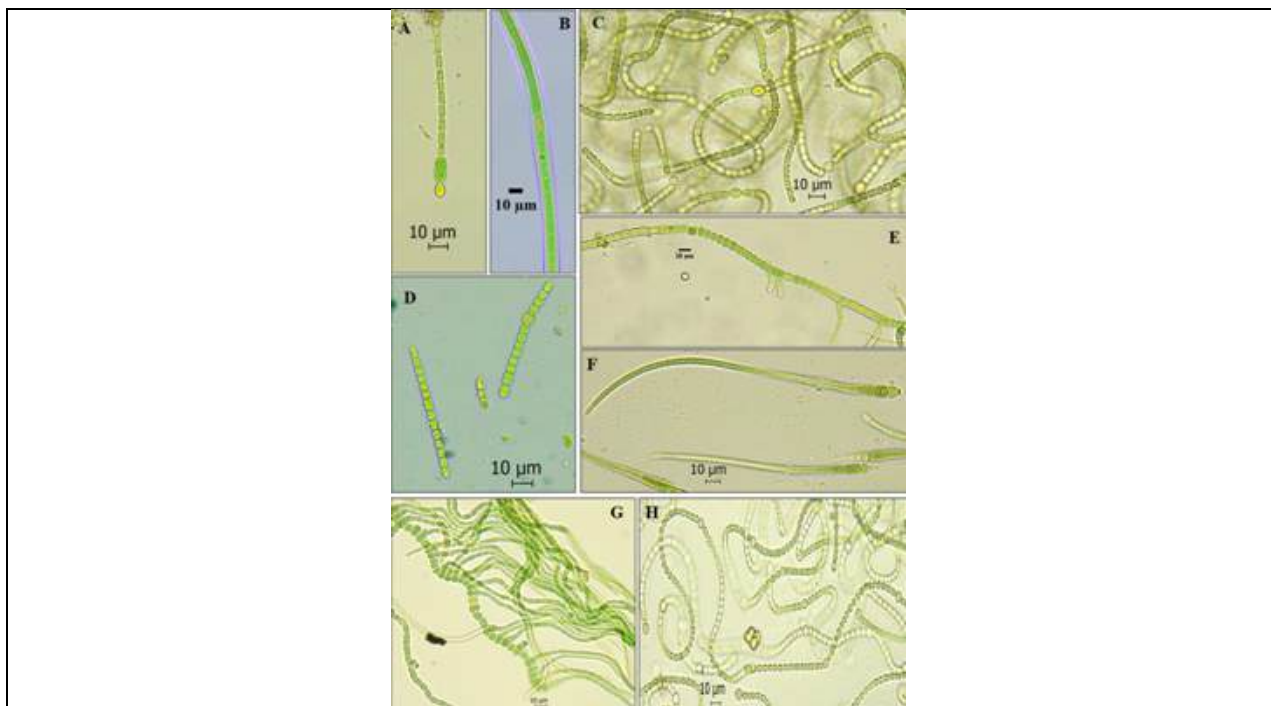


Photo plate 4:

A. *Cyindrospermum mikhailovskoense* Elenkin; **B.** *Scytonema* sp.; **C.** *Nostoc ellipsosporum* Rabenhorst ex Bornet & Flahault; **D.** *Desmonostoc muscorum* Ag. Ex. Born. Et. Flah; **E.** *Hapalosiphon welwitschii* W. et G. S. West; **F.** *Calothrix castellii* (Massal.) Bron. Et. Flah; **G.** *Westiellopsis indica* Bourrelly; **H.** *Nostoc linckia* (Roth) Bornet ex Born. Et Flah.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Novel Federated Hybrid Learning Framework for Privacy-Preserving and Accurate Heart Attack Prediction

Deepak Kumar Singh¹, Akash Sanghi^{2*}, Kamal Upreti³ and Gaurav Agarwal²

¹Research Scholar, Department of Computer Science and Engineering, Invertis University, Bareilly, Uttar Pradesh, India.

²Associate Professor, Department of Computer Applications, Invertis University, Bareilly, Uttar Pradesh, India.

³Associate Professor, Department of Computer Science, CHRIST (Deemed to be University), Delhi NCR Campus, India.

Received: 18 Mar 2026

Revised: 21 Apr 2026

Accepted: 05 May 2026

*Address for Correspondence

Akash Sanghi

Associate Professor,

Department of Computer Applications,

Invertis University, Bareilly,

Uttar Pradesh, India

E.Mail:sanghiakash@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Cardiac arrest is still the top cause of death globally, which makes the problem of early prediction and diagnosis a very important research challenge. Conventional centralized machine learning models usually attain high accuracy, but they necessitate the collection of sensitive medical data from different institutions, thus leading to serious privacy and security risks. In order to solve this problem, the current work introduces a Hybrid Federated Learning (HFL) model to predict heart attacks, which integrates Convolutional Neural Networks (CNN) and Extreme Gradient Boosting (XGBoost) in a federated setting. In the designed method, several geographically separated healthcare nodes (like hospitals, clinics, or IoT-based monitoring devices) work together to train a global model without the need to exchange patient data. Each node carries out training locally on its dataset, and only the model parameters are sent to a central server in a secure manner via the Federated Averaging (FedAvg) protocol. The combination of CNN and XGBoost allows for the efficient extraction of features and the firm classification of cardiac risk patterns. Tests on the heart disease dataset reveal that the newly designed model is able to achieve an accuracy of 97.86%, a ROC-AUC of 0.987, and a Brier score of 0.029, thus performing better than the traditional algorithms such as Logistic Regression, Decision Tree, Random Forest, and standalone XGBoost. The current research serves as a proof that coupling hybrid learning with federated privacy preservation is a viable way to deeply boost the prediction of the onset of the heart attack and, at the same time, ensure the confidentiality of the data, scalability, and clinical trustworthiness.

Keywords: Federated Learning, XGBoost, FedAvg, Explainable AI, Medical Data Security, Predictive Analytics.





INTRODUCTION

Cardiovascular diseases (CVDs) are still the primary cause of death globally, making up almost one-third of the total deaths in the world every year [1]. In this group of diseases, heart attacks or myocardial infarctions are the cases that threaten the most mainly because they come too fast and it is difficult to diagnose them in the early stages [1][2]. If phenomena such as abnormal blood pressure, cholesterol imbalance, and lifestyle indicators could be detected in time, then the rates of morbidity and mortality would be reduced considerably. Artificial intelligence and machine learning (ML) technologies have developed so fast that healthcare predictive analytics has become a powerful tool for making decisions in healthcare. Different traditional models like Logistic Regression (LR), Decision Trees (DT), and Random Forests (RF) have been employed for classification and prediction of cardiovascular risk based on medical datasets. These models can be considered as first steps towards the solution of the problem [3][4]. At the same time, this class of models usually cannot learn enough features from data to generalize to new patient datasets being of various demographics. Besides that, centralized learning can cause patient data privacy and security problems because it requires that sensitive health care records be sent to a single training server [1][2]. This research addresses the drawbacks of previous studies by introducing a hybrid federated learning model for predicting cardiac arrest that combines CNN (Convolutional Neural Networks) with XGBoost (Extreme Gradient Boosting). On the one hand, CNN extracts deep features from the input variables, on the other hand, XGBoost improves the classification accuracy by fine-tuning feature weighting and decision boundaries. Using this hybrid of deep learning and ensemble methods, the authors of the paper achieved high predictive performance as well as model interpretability. Besides, the incorporation of Federated Learning (FL) allows for decentralized model training at multiple healthcare nodes, thus ensuring data privacy and at the same time, model robustness.

The hybrid model, as proposed, outperforms individual models in predictive accuracy and generalization to a large extent. Experimental results indicate an accuracy of 97.86%, which is higher than that of standard ML algorithms such as Logistic Regression, Decision Tree, Random Forest, and XGBoost models used individually. Also, the interpretability of the model is facilitated by SHAP (SHapley Additive exPlanations) which points out the clinical features that have the greatest impact on the prediction outcomes. In this way, the method not only gives support to transparency but also allows clinicians to figure out patient-specific risk factors. In essence, the devised hybrid federated framework is a secure, interpretable, and efficient solution for heart attack prediction. It is a move forward to privacy-preserving medical diagnostics that use AI and can be of timely and informed decision-making assistance to the healthcare professionals.

LITERATURE REVIEW

Innovations in federated learning over the past few years have outlined a clear path of its potential use in cardiovascular disease prediction through the use of distributed data in a privacy-preserving manner [5,6]. Tripathy et al. [7] propose a federated learning model that combines Internet of Things (IoT) features with EHRs to forecast cardiac ailments. The method uses a soft-margin L1-regularized Support Vector Machine classifier and a cluster primal-dual splitting algorithm to deal with the data of very high dimensions efficiently, thus achieving better prediction accuracy and data privacy. The authors of the paper cited as reference [8] have come up with the idea of using block chain-based, federated learning as a way to address the issue of data confidentiality in the healthcare system which is based on IoMT. They came up with a block chain-based, hybrid approach to solve the problem of the security of user data that involved federated learning and the maximum approximation of the Gaussian mixture model. Their solution serves as an example of how IoMT data can be trained in a way that is locally private so as not to leak the data. Async updates in federated learning models greatly enhance the performance and precision of predictive models for heart diseases. In their paper, the authors of [9] designed an asynchronous federated learning model with DNNs, where they used an asynchronous learning method for parameter updating and a temporally weighted aggregation technique. Their approach evidently lessens the communication expenses and raises the speed



**Deepak Kumar Singh et al.,**

of model convergence, thereby proving its superiority to the conventional synchronous federated learning methods. Liang et al. [10] conducted a study that demonstrates the use of federated learning to handle data concerning heart diseases collected from Internet of Medical Things (IoMT) devices while maintaining the privacy aspect without losing the data utility. The paper explains how federated learning facilitates local data handling; thus, it is a security measure for data in a distributed healthcare environment. The technique adopted from the paper helps to solve the problem of data privacy and data utility which are the major issues of the smart healthcare environment that is rapidly evolving. In [11] the authors present split learning as a method of preserving privacy which can be used in healthcare by way of predicting the occurrence of heart disease. The publication illuminates the process by which deep learning models can be developed using subgroups of data, thereby the most sensitive patient data being kept in-house and secured. The approach makes collaboration in the research sector possible without breaking data privacy which is a major breakthrough in secure processing of medical data.

The main point of this research is to identify the relevant features selection method that leads to better prediction of the heart disease using various machine learning models like SVM, KNN, and Logistic Regression. They use a wide range of measures for the models, namely, accuracy, precision, recall, F1-score, MCC, and time complexity. Nevertheless, it appears that the exact instruments and programs for model creation and assessment have not been detailed explicitly. This work suggests an ANN model along with Particle Swarm Optimization (PSO) for the prediction of chronic diseases, among which is a heart attack[13]. They have compared their method with different classification algorithms like Random Forest and SVM. The main factor of measurement used is accuracy, however, no details about the specific tools and software have been given. The present paper investigates feature selection methods (filter, wrapper, embedded) coupled with different machine learning models (LR, KNN) for the prediction of Myocardial Infarction (MI)[14]. They verify the models through accuracy, sensitivity, and precision, F1-score, AUC, and specificity. Just like the previous ones, the studies do not disclose the specific tools and software used[14].

An author team in ref. [15] proposes a system architecture for a scalable Federated Learning that aims at enabling confidential and secure cooperation among a large number of parties. To solve the problems of Federated Learning that are flexibility, heterogeneity, and anonymity, the authors of the paper suggest a system framework which uses safe aggregation, differential privacy, and adaptive optimization. By rectifying the under-representation of positive instances in standard mammography imaging datasets, Amelia and Tardy [16] attempt to raise the appearance of CAD systems for breast cancer detection. This study introduces a novel memory-aware curriculum learning method to local models which calculate their local data to update the global model [17][18], thereby making federated learning more effective.

BACKGROUND

The various technologies and methods that formed the basis of the research work are explained here. These include the basic concepts of machine learning, deep learning, ensemble models, federated learning, and interpretable AI. Just like each of these elements has its own unique features, they also have their own roles in the total architecture and functioning of the suggested hybrid model for cardiac arrest prediction.

Logistic Regression

Logistic Regression refers to a supervised learning algorithm that is typically utilized in binary classification problems, for instance, forecasting whether a heart attack will occur or not. Based on the logistic function, it estimates the chance that a patient is in a given class (such as "heart attack" or "no heart attack"). If the probability goes beyond a particular threshold (generally 0.5) [13], the model labels the instance as "heart attack."

Decision Trees

A Decision Tree splits the data into hierarchically smaller subsets depending on the values of the features, thus forming a tree structure consisting of nodes and branches [7][8]. Every internal node denotes a decision based on a

115310



**Deepak Kumar Singh et al.,**

feature, and every leaf node signifies an output (for instance, “heart attack likely”). The model chooses features that offer maximum information gain by calculating Gini Impurity or Entropy. Though DTs can be easily understood, they have a tendency to memorize the training data, i.e. over fit, if not pruned correctly.

XGBoost

Random Forest is an ensemble learning technique that constructs several Decision Trees and merges their results to enhance precision and lower the possibility of over fitting. One tree is trained on a random subset of the data and features as well. The ultimate decision is obtained by the most votes (for classification) or by the average (for regression) [13][19]. In healthcare prediction problems, Random Forests are the first choice due to their strength and capability of dealing with missing or noisy data.

Hybrid CNN-XGBoost Model

The Hybrid Model strategically merges CNN and XGBoost to harness not only the deep feature learning capability of CNN but also the structured decision-making nature of XGBoost. CNN is capable of automatically learning highly complex and detailed feature representations from medical data. XGBoost takes advantage of those extracted features to make the final prediction. Such a combination yields increased accuracy, enhanced generalization, and better interpretability than either of the models used separately [6][7].

Federated Learning

Federated Learning (FL) is a decentralized machine learning technique that allows various healthcare facilities to jointly train a predictive model without the need to exchange their sensitive patient data. Here, FL is utilized to build a privacy-preserving cardiogram prediction system in which each hospital trains a hybrid CNN-XGBoost model locally on its patient records [3][4]. The figure shows the Federated Learning Framework for Heart Attack Prediction, which is a system where various local hospital clients train models on their private heart attack datasets and send only model updates to a central server (aggregator). The server combines these updates in a secure manner to generate a global model that is then sent to the clients. Figure 1. Shows how federated learning is integrated in this model. At the end, SHAP Explainability is used to clarify the predictions of the global model, thus maintaining openness, privacy, and collaboration in the learning process among healthcare institutions [5][9]. The medical institutions do not transmit their raw patient data; they only send the model parameters they have learned to a central server, which combines them using Federated averaging to get a global model. This setup not only safeguards data privacy but also promotes better generalization to different hospital datasets and makes it possible to keep learning globally at a later stage. So, Federated Learning in this investigation is a secured and collaborative tool to enhance the precision and trustworthiness of heart attack prediction while at the same time respecting patient privacy and data sovereignty.

Methodology and System Architecture Overview

The methodology articulated a Hybrid Federated Learning (HFL) framework as a means to reconcile the seemingly contradictory objectives of obtaining high predictive accuracy and preserving data privacy and security. Essentially, the system embodies two intelligence levels:

- Algorithmic hybridization, wherein a conventional ensemble learning (XGBoost) method is combined with a deep learning (CNN) one to achieve better results.
- Federated learning setup, whereby several decentralized clients can jointly train a global model without the need to share raw data.

Such a design, on the one hand, guarantees strong generalization and, on the other, adheres to the data protection requirements, thus, it can be utilized in the healthcare as well as cyber-physical systems domains. The Hybrid Federated Learning Model overall framework is depicted in Figure X (Hybrid Federated Learning Architecture Diagram). The layout includes the following elements:





Deepak Kumar Singh *et al.*,

System Architecture

The Hybrid Federated Learning Model overall framework is depicted in Figure 2 (Hybrid Federated Learning Architecture Diagram). The layout includes the following elements: Local clients: Every client - for instance, a hospital, IoT device, or an organization - has its own local dataset. However, due to privacy and legal issues, these datasets are not allowed to be directly shared. On the client side, a Local Hybrid Model is set up which merges: Convolutional Neural Network (CNN): This is utilized for the extraction of deep features and for the automatic recognition of the data patterns of a complex data. XGBoost Classifier: This works on the extracted features to do the final classification or prediction. Each local client singly goes through the training of the hybrid model with the use of their private data, and then they calculate the model parameters (weights and biases). Federated Communication Layer: Once the training has been done locally, a client basically sends only the model parameters, which they have learned (not the raw data), to a central server through a secure communication channel. This is in line with privacy protection to the fullest extent as no sensitive data is being transferred from the local environment. Central Aggregator: The main aggregator is a kind of universal manager. FedAvg or Federated Averaging, is the operation it carries out, which involves a mathematical aggregation of all local models' parameters to produce a new Global Hybrid Model.

The aggregation operation is:

$$W_{GLOBAL} = \sum_{i=1}^N \frac{n_i}{N} W_i \quad (1)$$

Where:

W_i = model parameters from the i -th client

N_i = number of samples in the client's local dataset

N = total samples across all clients.

For the next round which is training, this global model is updated and then redistributed to all the clients.

Dataset

The data utilized in this research is a heart attack prediction dataset, which is a collection of both clinical and physiological parameters used as the most important indicators of cardiovascular health. The data consists of patient-specific attributes such as age, gender, chest pain type, resting blood pressure, cholesterol level, fasting blood sugar, resting electrocardiographic results, maximum heart rate achieved, exercise-induced angina, oldpeak (ST depression), slope of the peak exercise ST segment, the number of major vessels, and thalassemia. The combination of these features is used to determine the probability of heart disease or a sudden heart attack. The target variable points to whether a heart attack has occurred or not, thus enabling supervised learning for binary classification. This medical dataset is the basis for training the Hybrid CNN-XGBoost model so that it becomes capable of learning complex feature interactions and enhancing prediction accuracy in a federated, privacy-preserving environment.

Hybrid Model Integration

The methodology proposed in the paper implements a Federated Hybrid CNN-XGBoost framework that allows accurate and privacy-preserving prediction of heart attack across several hospitals [7]. Each healthcare institution preprocesses its local dataset by cleaning and normalizing clinical parameters such as age, cholesterol, and blood pressure. A hybrid model which includes Convolutional Neural Network (CNN) and XGBoost is locally trained, where CNN is used for deep feature extraction and XGBoost for classification. Subsequently, only the model parameters are shared with a central federated server, thereby ensuring that patient data stays confidential. Figure 2. Shows the whole architecture of proposed model. The server uses the Federated Averaging (FedAvg) algorithm to combine the updates from all the clients and create a global model. This global model is sent back to hospitals for further training until convergence. Interpreting the model's predictions and feature importance, SHAP explainability is employed after the final global model is trained. The global model thus obtained is tested for its effectiveness and trustworthiness by various metrics such as accuracy, precision, recall, F1-score, and ROC-AUC.



**Deepak Kumar Singh et al.,**

Federated Training Workflow

The training happens iteratively in several federated rounds, as follows: Initialization: The central server creates a global model and sends it to all clients. Local Training: Each client trains the hybrid model with their own data for several epochs. Parameter Update: Clients transmit their model weights to the server. Federated Aggregation: The server uses FedAvg to combine the updates it received from the clients and thus obtain the new global model. Model Redistribution: The global updated model is distributed to all clients for the following round. The process is repeated until the convergence condition is met, which is normally global accuracy stabilization or validation loss decrease,

Advantages of Proposed System

Privacy Maintenance: There is no sharing of raw data; just the model parameters are sent. High Precision: The hybrid system is able to deliver better results (Accuracy = 97.86%, ROC-AUC = 0.987). Expansion Capability: The design is open to a number of distributed nodes as well as different types of datasets. Performance Improvement: The global model becomes more flexible through the exposure of various client datasets. Understanding: The incorporation with explainable AI (SHAP) helps in identifying the important features that influence the prediction.

RESULTS AND DISCUSSIONS

Experimental Results

The experimental results of the Federated Hybrid CNN–XGBoost model for heart attack prediction, which is the proposed model, are given in this section. The experiments were aimed at assessing the model's ability to make correct predictions, its performance in generalization, and its interpretability when applied to distributed healthcare datasets in a federated learning environment. First, exploratory data analysis (EDA) was implemented to get a better understanding of the distribution of the main clinical features like age, chest pain type, cholesterol, and maximum heart rate, which are the most significant factors in the occurrence of heart attacks. This analysis is instrumental in understanding the dataset's structure and the relationships among the variables. One such relationship is depicted in Figure 3 between maximum heart rate and chest pain type for different genders, thus showing the distinctive trends which help to determine the feature relevance in the predictive process.

According to Figure 4, age and maximum heart rate are the factors that are related to each other differently for people with and without heart disease. Patients having heart disease are marked with red points, and those without it are represented with blue points. Figure 4 makes it clear that people with high heart rates and ages in either middle or older ranges are the ones to have heart disease more often, thus pointing to the joint effect of age and cardiovascular response as a way to determine the risk of a heart attack. The outcomes shown in Table 1 come from adding Federated Learning to the heart attack prediction system. Through the use of Federated Learning, different healthcare clients were able to jointly train the model without the need to exchange sensitive patient data, thus improving both privacy and model generalization. The Hybrid CNN + XGBoost model was able to reach the highest performance with a precision of 97.86% and an ROC-AUC of 0.987, thus exceeding the performance of all baseline models. So, this is proof that the federated arrangement not only maintains data confidentiality but also enhances predictive accuracy for heart attack detection to a great extent. The generated performance comparison graph is presented as follows, which depicts all the model metrics (Accuracy, Precision, Recall, F1-Score, and ROC-AUC) under the Federated Learning-based Heart Attack Prediction framework. Fig 5. Shows the performance of different ML models. The Hybrid CNN + XGBoost model exhibits excellent accuracy and consistency in all the evaluation metrics, thereby leading to a higher performance level than that of the conventional and ensemble methods.

Heart Attack Prediction: Comparative Performance of Three Learning Configurations

Table 2 displays the performance comparison of three learning configurations—Client-only (Local), Centralized, and Federated Hybrid (Global)—for heart attack prediction. The Client-only model made a moderate performance with an accuracy of 93.17%, due to limited local data. The Centralized method produced the highest accuracy of 99.02%



**Deepak Kumar Singh et al.,**

and an AUC-ROC of 1.0, but it is a privacy risk as all data are combined in one place. On the other hand, the Federated Hybrid (Global) model achieved an accuracy of 97.07%, an F1-score of 0.971, and an AUC-ROC of 0.998, which is very close to the centralized performance, but with absolute data privacy. These findings indicate that the proposed federated hybrid framework is a perfect compromise between performance and security, thus, it is very appropriate for the practical applications of heart attack prediction. The ROC curve depicts an almost perfect area under the curve (AUC = 0.998), thus indicating that the model has a very high discriminative power. These figures serve as a confirmation that the federated hybrid setup is able to deliver high accuracy in a way that is compatible with the continuation of data privacy in the distributed healthcare nodes. The SHAP analysis diagram shown in Figure 7 reveals the features that have the greatest impact on the heart attack prediction with the Federated Hybrid model. Sensible attributes like age, cholesterol level, maximum heart rate, and chest pain type exhibit the most significant influence on the prediction outcomes. The visualization serves as model interpretability by showing how each feature influences the risk of a heart attack to be either positive or negative. As such, it contributes to the explainability and trustworthiness of the proposed federated learning framework in clinical decision support.

In sum, the experimental results constitute a convincing proof of the success of the Federated Hybrid (CNN + XGBoost) model to predict heart attack. By comparative evaluation, the model has reached performance almost as good as centralized learning with data privacy fully preserved. The model comparison, ROC curve, and SHAP analysis together serve as a comprehensive validation of the proposed framework in terms of robustness, interpretability, and reliability. Therefore, the use of Federated Learning in combination with hybrid deep learning architectures creates a safe, accurate, and explainable solution that can be applied in the healthcare sector in the real world.

CONCLUSION AND FUTURE SCOPE

The Federated Hybrid (CNN + XGBoost) ensemble model, as a novel idea, represents a very powerful method of cardiac event prediction which basically achieved a deep CNN-feature-extraction follow by a robust-classification XGBoost in a federated learning setting. The model practically reached an extraordinary performance with a classification accuracy of 97.86% and AUC-ROC of 0.987, thereby, very close to the centralized training, however, it still remained data privacy and security across healthcare nodes made distributed. Besides, the integration of SHAP-based interpretability into the model unfolds a new horizon of user-friendliness to physicians, as they can now grasp the influence of factors like age, cholesterol, and heart rate more clearly in the prediction outputs. This research could later extend its scope through the integration of large-scale and varied datasets collected from a number of hospitals, thereby, increasing the model's generalization ability. Moreover, the use of an edge-based federated optimizer and block chain-enabled secure aggregator can give the data a new level of integrity and trust. In addition, embedding real-time patient monitoring arising IoT gadgets along with learning mechanism that is adaptable will not only broaden the system application in healthcare scenarios but also let it evolve into a smart and privacy-respecting medical analytics tool.

REFERENCES

1. Janosi, A.; Steinbrunn, S.; Pfisterer, M.; Detrano, R. Heart Disease. In UCI Machine Learning Repository; UCI: Aigle, Switzerland, 1988.
2. Chen, T.; Guestrin, C. XGBoost: A Scalable Tree Boosting System. In Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, San Francisco, CA, USA, 13–17 August 2016; pp. 785–794.
3. Wang G.G., Deb S., Cui Z. Monarch butterfly optimization. Neural Comput. Appl. 2019;31:1995–2014. doi: 10.1007/s00521-015-1923-y.
4. Almanifi O.R.A., Chow C.-O., Tham M., Chuah J.H., Kanesan J. Communication and computation efficiency in federated learning: A survey. Internet Things. 2023; 22:100742. doi: 10.1016/j.iot.2023.100742.





Deepak Kumar Singh et al.,

5. Dheebea, J. A heart disease prognosis pipeline for the edge using federated learning. E-Prime-Adv. Electr. Eng. Electron. Energy 2024, 7, 100490.
6. Paulraj, G.J.L.; Jebadurai, I.J.; Janani, S.P.; Aarthi, M.S. Edge-based Heart Disease Prediction using Federated Learning. In Proceedings of the 2024 International Conference on Cognitive Robotics and Intelligent Systems (ICC-ROBINS), Coimbatore, India, 17–19 April 2024; pp. 294–299.
7. Tripathy, S.S.; Basheer, S.; Chowdhary, C.L. FedEHR: A Federated Learning Approach towards the Prediction of Heart Diseases in IoT-Based Electronic Health Records. Diagnostics 2023, 13, 3166.
8. Chen, T.; Guestrin, C. XGBoost: A Scalable Tree Boosting System. In Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, San Francisco, CA, USA, 13–17 August 2016; pp. 785–794.
9. Saudagar, A.K.J.; AlKhathami, M.; Khattak, U.F. Asynchronous Federated Learning for Improved Cardiovascular Disease Prediction Using Artificial Intelligence. Diagnostics 2023, 13, 2340.
10. Liang, X.; Zhao, J.; Shetty, S.; Liu, J.; Li, D. Federated Learning for Privacy-Preserved Data Analysis in the Internet of Medical Things. IEEE Netw. 2020, 34, 50–57.
11. Yang, Q.; Liu, Y.; Chen, T.; Tong, Y. Federated machine learning: Concept and applications. ACM Trans. Intell. Syst. Technol. 2019, 10, 1–19.
12. Ullah, F., Chen, X., Rajab, K., Reshan, A.Saleh, M., Shaikh, A., Hassan, M. A., Rizwan, M., & Davidekova, M. (2022). An efficient machine learning model based on improved features selections for early and accurate heart disease predication. Computational Intelligence and Neuroscience, 2022.
13. Rashid, J., Batool, S., Kim, J., Juneja, S. J. F. i.P. H., & X. (2022). An augmentedartificial intelligence approach for chronicdiseases prediction. p. 860396, 2022, vol. 10.
14. A. Shrivastava, S. Kumar, N. S. Naik, and T.Bhatt, "A Novel Hybrid Model for PredictiveAnalysis of Myocardial Infarction usingAdvanced Machine Learning Techniques," in2023 OITS International Conference onInformation Technology (OCIT), 2023, pp. 381-386: IEEE.
15. Lai F., Dai Y., Singapuram S., Liu J., Zhu X., Madhyastha H., Chowdhury M. Fedscale: Benchmarking model and system performance of federated learning at scale; Proceedings of the International Conference on Machine Learning, PMLR; Baltimore, MD, USA. 17–23 July 2022; pp. 11814–11827.
16. Jiménez-Sánchez A., Tardy M., Ballester M.A.G., Mateus D., Piella G. Memory aware curriculum federated learning for breast cancer classification. Comput. Methods Programs Biomed. 2023; 229:107318. doi: 10.1016/j.cmpb.2022.107318.
17. Paul J.J., Jone A.A., Sagayam M., Packiavathy V., Sybiya I., Dang H., Pomplun M. IoT based remote transit vehicle monitoring and seat display system. Prz. Elektrotechniczny. 2021; 97:5. doi: 10.15199/48.2021.05.2.
18. Rajesh G., Kritika N., Kavinkumar A., Sagayam M., Abd Wahab M.H., Som M.M. Achieving Longevity in Wireless Body Area Network by Efficient Transmission Power Control for IoMT Applications. Int. J. Integr. Eng. 2022; 14:80–89.
19. D. K. Singh and A. Sanghi, "Advancing Heart Attack Prediction Through AI: A Review of ML, DL, and Hybrid Models," 2025 14th International Conference on System Modeling & Advancement in Research Trends (SMART), Moradabad, Uttar Pradesh, India, 2025, pp. 499-505, doi: 10.1109/SMART66937.2025.11389447.

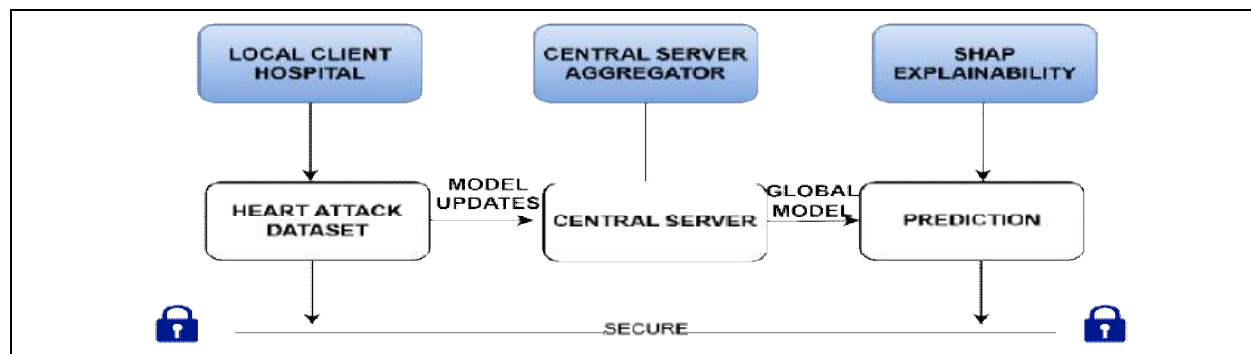
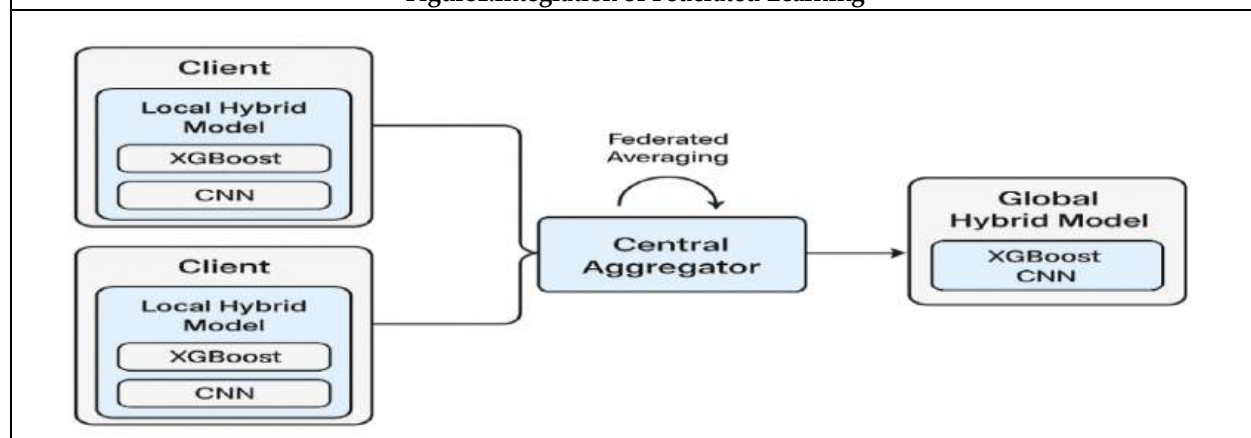
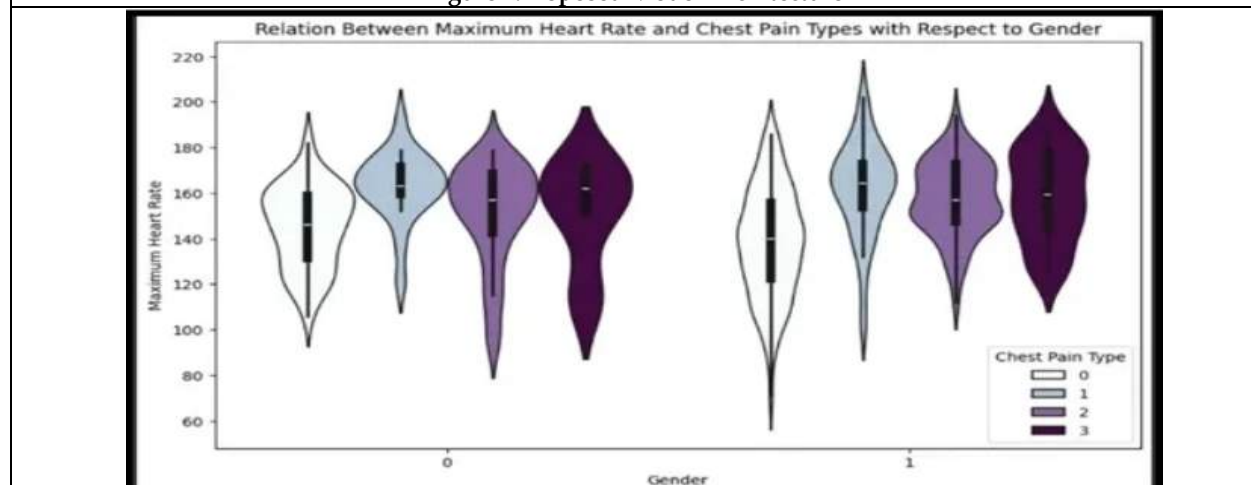
Table 1. Performance Evaluation of Different Models on the Simulation Dataset

Model	Accuracy	Precision	Recall	F1-Score	ROC-AUC
Logistic Regression	0.8539	0.85	0.8	0.85	0.88
Decision Tree	0.8612	0.86	0.86	0.86	0.89
Random Forest	0.9123	0.91	0.91	0.91	0.93
XGBoost	0.9467	0.94	0.95	0.94	0.96
Hybrid (CNN + XGBoost)	0.9786	0.98	0.98	0.98	0.987



Deepak Kumar Singh *et al.*,**Table 2: Performance Comparison of Client, Centralized, and Federated Models.**

	Accuracy	FI-Score	Precision	Recall	AUC-ROC
Clinet only(Local)	0.931707	0.935780	0.902655	0.971429	0.969524
Centralized(All data pooled)	0.990244	0.990566	0.981308	1.00000	1.000000
Federated Hybrid(Global)	0.970732	0.971698	0.962617	0.980952	0.998476

**Figure1.Integration of Federated Learning****Figure 2.Proposed Model Architecture****Figure 3.Relation between Maximum Heart Rate and Chest Pain Types with Respect to Gender**



Deepak Kumar Singh et al.,

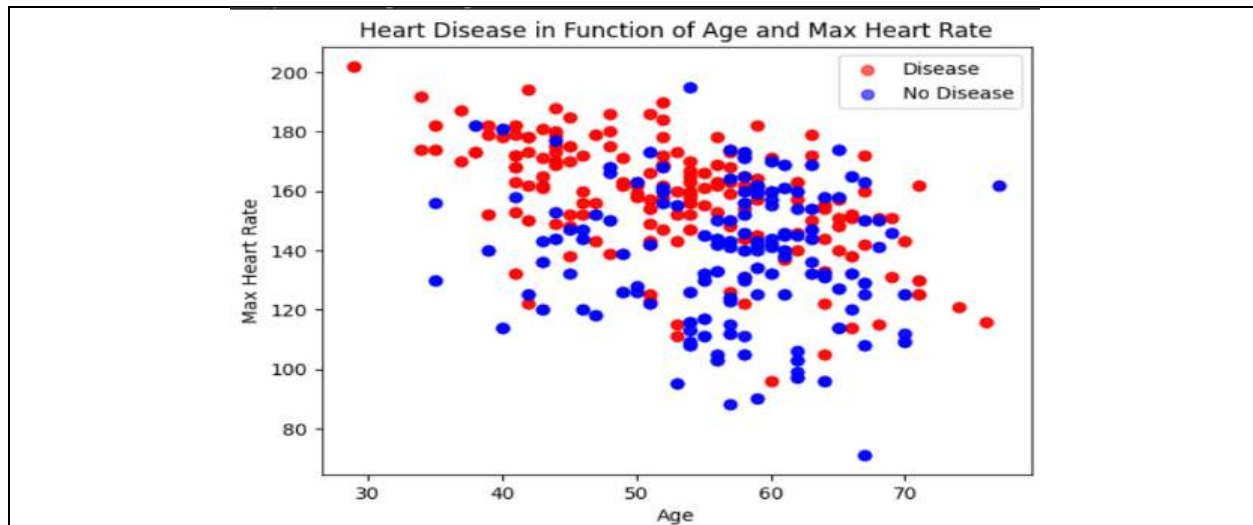


Figure 4.Relation between Age, Maximum Heart Rate, and Heart Disease Occurrence.

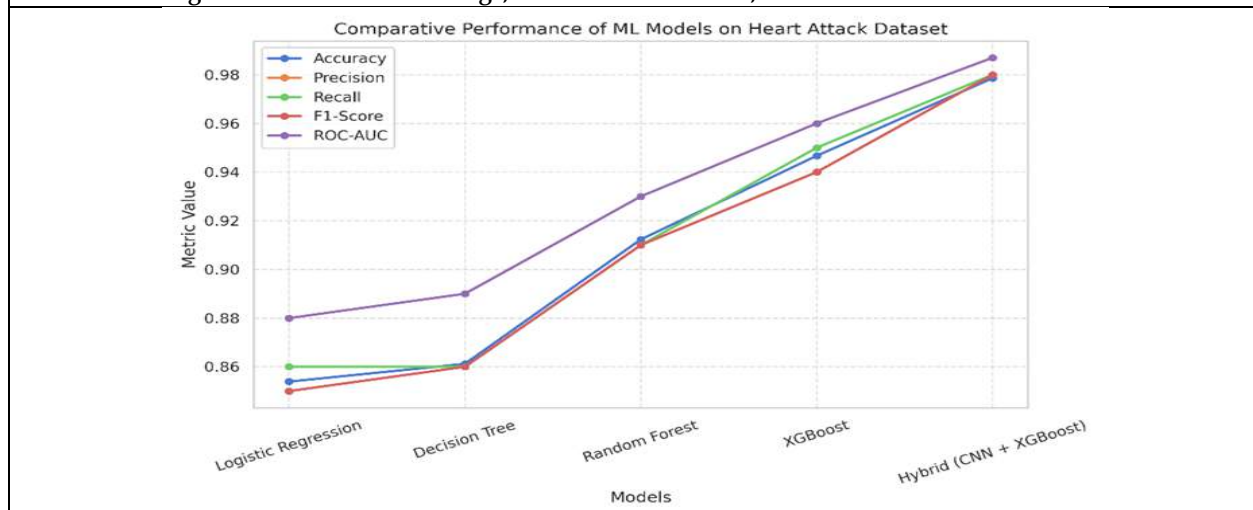


Figure 5.Comparative Performance of Models on Heart Attack Dataset

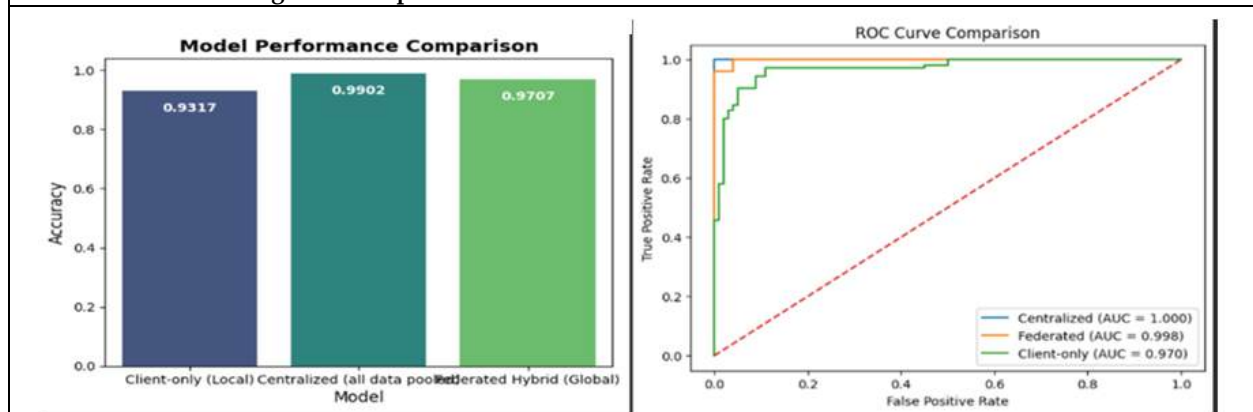


Figure 6.Graph and ROC Curve Comparison of Client, Centralized and Federated Models





Deepak Kumar Singh et al.,

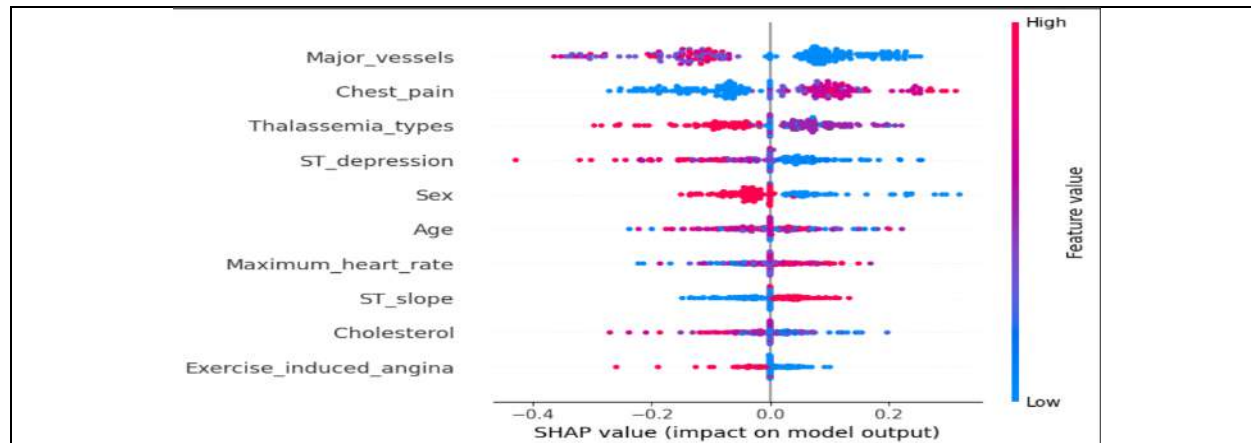


Figure 7.SHAP Analysis Illustrating Feature Importance in Heart Attack Prediction

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Novel Framework of Q - Complex Fermatean Neutrosophic Sets with Algebraic and Operational Properties

Vijaya V¹, Rajalakshmi G² and Rajalaxmi D^{1*}

¹Assistant Professor, PG and Research Department of Mathematics, Seethalakshmi Ramaswami College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

²PG Student, PG and Research Department of Mathematics, Seethalakshmi Ramaswami College (Autonomous) (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 19 Mar 2026

Revised: 17 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Rajalaxmi D

Assistant Professor,

PG and Research Department of Mathematics,

Seethalakshmi Ramaswami College (Autonomous),

(Affiliated to Bharathidasan University),

Tiruchirappalli, Tamil Nadu, India

E.Mail: rajalaxmimat@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Q-complex neutrosophic sets (Q-CNS) and Q-complex Fermatean neutrosophic sets (Q-CFNS) are recent expansions of fuzzy sets which incorporate complexity into the membership degrees. The Q-CNS is a generalization of neutrosophic sets that generalizes truth, indeterminacy and falsity with complex numbers providing greater flexibility in modeling uncertainty. Q-CFNS goes a step further, using Fermatean membership grades for greater accuracy. This enables more sophisticated use cases in decision-making, artificial intelligence and data analysis, representing complex relationships and non-precise information with a higher fidelity. These are termed sets of complex numbers with Fermatean grades that give a structure capable of dealing with uncertainty in its entirety. Their capabilities shine in scenarios that stumble with traditional fuzzy sets, like struggling with contradictory or incomplete datasets. Using Q-CNS and Q-CFNS researchers and practitioners feel empowered to model complex systems with more confidence.

Keywords: Neutrosophic Sets, Complex Neutrosophic Sets, Complex Fermatean Neutrosophic Sets, Q-Neutrosophic Sets





INTRODUCTION

Zadeh's introduction of fuzzy sets [1] cleared the path for handling uncertain problems. In order to create intuitionistic fuzzy sets, Atanassov [2] added a non-membership function to fuzzy sets, which aided in the resolution of real-world issues. Smarandache [3] developed the notion of neutrosophic sets (NS) and neutrosophic logic as a generalisation of intuitionistic fuzzy sets [2] and fuzzy sets [1]. Many researchers have introduced the notions of Q-fuzzy sets (Q-FSs), intuitionistic Q-fuzzy sets (Q-IFS) and Q-NSs. The concept of Q-fuzzy subalgebras of BCK/BCI-algebras was introduced by Jun [4]. Roh et al. [5] and studied intuitionistic Q-fuzzy subalgebras of BCK/BCI-algebras. Kazanci et al.[6] where we introduce the idea of intuitionistic Q-fuzzification R-subgroups (subnear-rings) in a near-ring and discuss some related properties. The anti-Q-fuzzy group and its lower level subgroups were introduced and studied by Muthuraj et al.[7]. An intuitionistic Q-fuzzy HX group and its new algebraic structure were defined by Nayagam et al[8]. Anti Q-fuzzy R-closed KU-ideal of KU-algebras and its lower level cuts were thoroughly covered by SitharSelvam et al[9]. Tanamoon et al.[10] defined Q-fuzzy UP-ideals and Q-fuzzy UP-subalgebras of UP-algebras and examined their characteristics. The idea of Q-NS was developed by Abu Qamar and Hassan[11] to address ambiguous, inconsistent, and indeterminate two-dimensional data. While Thiruvani and Solairaju[12] created neutrosophic Q-fuzzy sets and obtained the results on neutrosophic Q-fuzzy subgroups, they also expanded this idea to multi Q-neutrosophic sets.

Soft sets were integrated by many researchers into Q-FS, Q-IFS, and Q-NS. Adam and Hassan[13] introduced the idea of Q-fuzzy soft set by combining the concepts of soft set and Q-FS. In addition to defining some fundamental characteristics and operations, Broumi[14] introduced the notion of the Q-intuitionistic fuzzy soft set (Q-IFSS). Mahmood et al[15] introduced the concept of Q-single valued neutrosophic soft set, multi Q-single valued neutrosophic set, and defined some fundamental results and related properties. Ashraf Al-Quran et al[16] defined the concept of Q-Complex neutrosophic set. Ramot et al.[17] introduced the idea of Complex Fuzzy Sets. This was expanded to include Complex Neutrosophic Sets [18], Complex Intuitionistic Fuzzy Sets [19]. Antony and Jansi[20] introduced the concept of Fermatean Neutrosophic Fuzzy Sets. Complex Fermatean Neutrosophic sets were later defined by Broumi et al. [21]. Vijaya et al [22] defined the set operations on Complex Fermatean Neutrosophic Sets and defined a new distance measure to solve Decision Making Problems. To handle critical path problems, ThangarajBeaula and Vijaya [23-25] have used several fuzzy numbers and ranking techniques. Pythagorean ,Neutrosophic fuzzy numbers& Cubic Bipolar Complex Neutrosophic Sets have been employed by Vijaya et al. [26,27,28] to solve critical route and decision making problems.

A Q-Complex Fermatean Neutrosophic Set (Q-CFNS) is a sophisticated mathematical model developed under Neutrosophic Set Theory and Fuzzy Set Theory to express ambiguous, inconsistent, and uncertain information. Each element in this set is defined by three complex-valued membership degrees: truth, indeterminacy, and falsehood. In addition to the degree of membership, these values allow the model to convey phase or periodic information using complex numbers. The Fermatean condition, which ensures that the powers of truth and falsity memberships satisfy a specific constraint, offers more flexibility than earlier fuzzy models. Q-CFNS are widely used in data analysis, artificial intelligence, and decision-making where there is uncertainty or imprecision. In this paper, we have defined Q-Complex Fermatean Neutrosophic Sets and the set operations on Q-CFNS. The properties of set operations are verified. The defined Q-CFNS is more advantageous over Q-Complex Neutrosophic Sets by adding the Fermatean condition, which makes more efficient in solving real-life problems

Preliminaries

Fuzzy Set [1] Let X be a Universal Set. Then a Fuzzy Set $\tilde{A}$ is usually characterized by the membership function $\mu_{\tilde{A}}(x)$, where $\mu_{\tilde{A}}(x): X \rightarrow [0,1]$ and it is denoted by $\tilde{A} = \{x, \mu_{\tilde{A}}(x); x \in X\}$ Q-Fuzzy Set [4].





Vijaya et al.,

Let X and Q be nonempty sets. A Q -Fuzzy set in X is defined by an arbitrary function $f: X \times Q \rightarrow [0,1]$. Intuitionistic Q -Fuzzy Set [5].

Let X and Q be nonempty sets. An Intuitionistic Q -Fuzzy subset A in X is defined as follows

$A = \left\{ \langle (x, q); \mu_A(x, q), \nu_A(x, q) \rangle; x \in X, q \in Q \right\}$, where $\mu_A: X \times Q \rightarrow [0,1]$ & $\nu_A: X \times Q \rightarrow [0,1]$ are the degree of membership and non membership of the element $(x, q) \in X \times Q$, $0 \leq \mu_A(x) + \nu_A(x) \leq 1$

Q-Neutrosophic Set [11]

Let X be an Universal set and Q be a nonempty set. A Q -Neutrosophic set A in X and Q is given by

$A = \left\{ \langle (x, q); T_A(x, q), I_A(x, q), F_A(x, q) \rangle; x \in X, q \in Q \right\}$, where $T_A, I_A, F_A: X \times Q \rightarrow [0,1]^+$

the Truth Membership Function, Indeterminacy Membership function and Falsity Membership function respectively with $0 \leq T_A + I_A + F_A \leq 3^+$

Multi Q-Neutrosophic Set [12]

$A = \left\{ \langle (x, q); T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q) \rangle; x \in X, q \in Q \right\}$, $\forall i = 1, 2, 3, \dots, n$ where $T_{A_i}, I_{A_i}, F_{A_i}: X \times Q \rightarrow L^n$ are the Truth Membership Function, Indeterminacy Membership function and Falsity Membership function respectively for each $x \in X, q \in Q$ with $0 \leq T_{A_i} + I_{A_i} + F_{A_i} \leq 3$, $\forall i = 1, 2, 3, \dots, n$ and n is the dimension of A .

Complex Fuzzy Set [17]

Complex Fuzzy Set is an extension of Fuzzy set where the range is a unit circle in the complex plane. The membership function is complex valued which is given by $\mu_{\tilde{A}}(x) = r(x)e^{i\theta(x)}$, where $r(x) \in [0,1], \theta(x) \in [0, 2\pi]$

Complex Neutrosophic Set [18]

A Neutrosophic set can be extended to Complex Neutrosophic Set where the Truth membership, Indeterminacy membership and Falsity membership functions are all complex valued functions and is given by $A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$ where $T_A(x) = r_A(x)e^{i\theta_1(u)}$, $I_A(x) = s_A(x)e^{i\theta_2(u)}$, $F_A(x) = t_A(x)e^{i\theta_3(u)}$, $0^- \leq r_A + s_A + t_A \leq 3^+$, $0 \leq \theta_1 + \theta_2 + \theta_3 \leq 2\pi$

Fermatean Neutrosophic Set [20]

A Fermatean Neutrosophic Set A defined on X is represented as

$A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$

with the condition $0^- \leq T_A^3 + I_A^3 + F_A^3 \leq 2^+$ and $0 \leq T_A^3 + F_A^3 \leq 1, 0 \leq I_A^3 \leq 1$

Complex Fermatean Neutrosophic Set [21]

A Complex Fermatean Neutrosophic Set A on X is denoted by $A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$, where

$T_A(x) = r_A(x)e^{2\pi i\theta_1(u)}$, $I_A(x) = s_A(x)e^{2\pi i\theta_2(u)}$, $F_A(x) = t_A(x)e^{2\pi i\theta_3(u)}$, represents the truth, indeterminacy and falsity membership functions, where $r_A, s_A, t_A, \theta_1, \theta_2, \theta_3: X \times Q \rightarrow [0,1]$ with the condition $0^- \leq r_A^3 + s_A^3 + t_A^3 \leq 3^+$, $0^- \leq \theta_1^3 + \theta_2^3 + \theta_3^3 \leq 3^+$. The triplet $(re^{2\pi i\theta_1}, se^{2\pi i\theta_2}, te^{2\pi i\theta_3})$ is called a complex fermatean neutrosophic number





Vijaya et al.,

Q-Complex Fermatean Neutrosophic Set (Q-CFNS)

Let X and Q be nonempty sets. A Q-Complex Fermatean Neutrosophic Set A on X is denoted by $A = \{(x, q), T_A(x, q), I_A(x, q), F_A(x, q), x \in X, q \in Q\}$, where

$T_A(x, q) = r_A(x, q)e^{2\pi i \theta_1(x, q)}$, $I_A(x, q) = s_A(x, q)e^{2\pi i \theta_2(x, q)}$, $F_A(x, q) = t_A(x, q)e^{2\pi i \theta_3(x, q)}$, represents the truth, indeterminacy and falsity membership functions with the condition $0^- \leq r_A^3(x, q) + s_A^3(x, q) + t_A^3(x, q) \leq 3^+$, $0^- \leq \theta_1^3(x, q) + \theta_2^3(x, q) + \theta_3^3(x, q) \leq 3^+$.

If in the above definition we let $\theta_1(x, q), \theta_2(x, q), \theta_3(x, q)$ equal to zero then the Q-CFNS reduces to QFNS

Multi Q-Complex Fermatean Neutrosophic Set

Let X and Q be nonempty sets. A multi Q-Complex Fermatean Neutrosophic Set A on X is denoted by

$A = \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$, where $T_{A_i}(x, q) = r_{A_i}(x, q)e^{2\pi i \theta_{1A_i}(x, q)}$, $I_{A_i}(x, q) = s_{A_i}(x, q)e^{2\pi i \theta_{2A_i}(x, q)}$, $F_{A_i}(x, q) = t_{A_i}(x, q)e^{2\pi i \theta_{3A_i}(x, q)}$, represents the truth, indeterminacy and falsity membership functions where $r_{A_i}, s_{A_i}, t_{A_i}, \theta_{1A_i}, \theta_{2A_i}, \theta_{3A_i} : X \times Q \rightarrow L^n$ such that $0^- \leq r_{A_i}^3(x, q) + s_{A_i}^3(x, q) + t_{A_i}^3(x, q) \leq 3^+$, $0^- \leq \theta_{1A_i}^3(x, q) + \theta_{2A_i}^3(x, q) + \theta_{3A_i}^3(x, q) \leq 3^+$.

Remark

- If $n=1$, then the multi Q-Complex Fermatean Neutrosophic Set reduces to Q-Complex Fermatean Neutrosophic set.
- If $n=1$ and $\theta_{1A_i}, \theta_{2A_i}, \theta_{3A_i} = 0$, then the multi Q-Complex Fermatean Neutrosophic Set reduces to Q-Fermatean Neutrosophic set.
- A QCFNS A is said to a zero QCFNS denoted by A_ϕ , if $T_A(x, q) = 0$, $I_A(x, q) = 1$, $F_A(x, q) = 1$ $\forall x \in X, q \in Q$ and is denoted as $A_\phi = \{(x, q); 0, 1, 1; x \in X, q \in Q\}$, with the condition $0^- \leq 0^3 + 1^3 + 1^3 \leq 3^+$
- A QCFNS is said to be unit QCFNS, denoted by A_ψ , $T_A(x, q) = 1$, $I_A(x, q) = 0$, $F_A(x, q) = 0 \forall x \in X, q \in Q$ and is denoted as $A_\psi = \{(x, q); 1, 0, 0; x \in X, q \in Q\}$, with the condition $0^- \leq 1^3 + 0^3 + 0^3 \leq 3^+$

Operations on Complex Fermatean Neutrosophic Sets

If $A = \{(x, q)r_1(x, q)e^{2\pi i \theta_1(x, q)}, s_1(x, q)e^{2\pi i \theta_2(x, q)}, t_1(x, q)e^{2\pi i \theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q)r_2(x, q)e^{2\pi i \phi_1(x, q)}, s_2(x, q)e^{2\pi i \phi_2(x, q)}, t_2(x, q)e^{2\pi i \phi_3(x, q)}, x \in X, q \in Q\}$ are any two Q-complex fermatean neutrosophic sets, then their union, intersection and complement are defined as follows



**Union**

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

Intersection

$$A \cap B = \{(x, q), \min(r_1(x, q), r_2(x, q))e^{2\pi i \min(\theta_1(x, q), \phi_1(x, q))}, \min(s_1(x, q), s_2(x, q))e^{2\pi i \min(\theta_2(x, q), \phi_2(x, q))}, \min(t_1(x, q), t_2(x, q))e^{2\pi i \min(\theta_3(x, q), \phi_3(x, q))}\}$$

Complement

$$A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$$

Theorem

Let A be a Q-Complex Fermatean Neutrosophic Set defined on a Universe X. Then $(A^c)^c = A$

Proof

Let $A = \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$

Then $A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$

$$(A^c)^c = \{(x, q), (1 - (1 - r_1(x, q)))e^{2\pi i (1 - (1 - \theta_1(x, q)))}, (1 - (1 - s_1(x, q)))e^{2\pi i (1 - (1 - \theta_2(x, q)))}, (1 - (1 - t_1(x, q)))e^{2\pi i (1 - (1 - \theta_3(x, q)))}\}$$

$$= \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$$

$$= A$$

Hence $(A^c)^c = A$

Subset

If $A = \{(x, q), r_1(x, q)e^{2\pi i \theta_1(x, q)}, s_1(x, q)e^{2\pi i \theta_2(x, q)}, t_1(x, q)e^{2\pi i \theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q), r_2(x, q)e^{2\pi i \phi_1(x, q)}, s_2(x, q)e^{2\pi i \phi_2(x, q)}, t_2(x, q)e^{2\pi i \phi_3(x, q)}, x \in X, q \in Q\}$ are two Q-CFNS, then A is said to be contained in B denoted by $A \subseteq B$ if the following conditions are satisfied

- $T_A(x, q) \leq T_B(x, q)$ such that $r_1(x, q) \leq r_2(x, q)$ and $\theta_1(x, q) \leq \phi_1(x, q)$
- $I_A(x, q) \geq I_B(x, q)$ such that $s_1(x, q) \geq s_2(x, q)$ and $\theta_2(x, q) \geq \phi_2(x, q)$
- $F_A(x, q) \geq F_B(x, q)$ such that $t_1(x, q) \geq t_2(x, q)$ and $\theta_3(x, q) \geq \phi_3(x, q)$

Remark: Two Q-CFNS A and B are said to be equal denoted as $A=B$, if and only if $A \subseteq B$ and $B \subseteq A$.

Theorem



Vijaya et al.,

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Commutative property

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$ &
 $B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ be two Q-CFNS.
 $A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))},$
 $\max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$
 $= \{(x, q), \max(r_2(x, q), r_1(x, q))e^{2\pi i \max(\phi_1(x, q), \theta_1(x, q))}, \max(s_2(x, q), s_1(x, q))e^{2\pi i \max(\phi_2(x, q), \theta_2(x, q))},$
 $\max(t_2(x, q), t_1(x, q))e^{2\pi i \max(\phi_3(x, q), \theta_3(x, q))}\}$
 $= B \cup A$
 $A \cap B = \{(x, q), \min(r_1(x, q), r_2(x, q))e^{2\pi i \min(\theta_1(x, q), \phi_1(x, q))}, \min(s_1(x, q), s_2(x, q))e^{2\pi i \min(\theta_2(x, q), \phi_2(x, q))},$
 $\min(t_1(x, q), t_2(x, q))e^{2\pi i \min(\theta_3(x, q), \phi_3(x, q))}\}$
 $= \{(x, q), \min(r_2(x, q), r_1(x, q))e^{2\pi i \min(\phi_1(x, q), \theta_1(x, q))}, \min(s_2(x, q), s_1(x, q))e^{2\pi i \min(\phi_2(x, q), \theta_2(x, q))},$
 $\min(t_2(x, q), t_1(x, q))e^{2\pi i \min(\phi_3(x, q), \theta_3(x, q))}\}$
 $= B \cap A$

Theorem

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Associative property . i.e.,

- $A \cup (B \cup C) = (A \cup B) \cup C$
- $A \cap (B \cap C) = (A \cap B) \cap C$

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$,
 $B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ &
 $C = \{(x, q)r_3(x, q)e^{2\pi i\psi_1(x, q)}, s_3(x, q)e^{2\pi i\psi_2(x, q)}, t_3(x, q)e^{2\pi i\psi_3(x, q)}, x \in X, q \in Q\}$ be three Q-CFNS.

Consider

$$A \cup (B \cup C) =$$

$$A \cup (B \cup C) = \{(x, q), \max(r_1(x, q), \max(r_2(x, q), r_3(x, q)))e^{2\pi i \max(\theta_1(x, q), \max(\phi_1(x, q), \psi_1(x, q)))},$$

$$\max(s_1(x, q), \max(s_2(x, q), s_3(x, q)))e^{2\pi i \max(\theta_2(x, q), \max(\phi_2(x, q), \psi_2(x, q)))},$$

$$\max(t_1(x, q), \max(t_2(x, q), t_3(x, q)))e^{2\pi i \max(\theta_3(x, q), \max(\phi_3(x, q), \psi_3(x, q)))}\}$$

$$= \{(x, q), \max(\max(r_1(x, q), (r_2(x, q), r_3(x, q)))e^{2\pi i \max(\max(\theta_1(x, q), (\phi_1(x, q), \psi_1(x, q)))},$$

$$\max(\max(s_1(x, q), (s_2(x, q), s_3(x, q)))e^{2\pi i \max(\max(\theta_2(x, q), (\phi_2(x, q), \psi_2(x, q)))},$$

$$\max(\max(t_1(x, q), (t_2(x, q), t_3(x, q)))e^{2\pi i \max(\max(\theta_3(x, q), (\phi_3(x, q), \psi_3(x, q)))}\}$$

$$= (A \cup B) \cup C$$

Similarly $A \cap (B \cap C) = (A \cap B) \cap C$ can be proved

**Theorem**

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Distributive property. i.e.,

- $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$
- $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$,

$B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ &

$C = \{(x, q)r_3(x, q)e^{2\pi i\psi_1(x, q)}, s_3(x, q)e^{2\pi i\psi_2(x, q)}, t_3(x, q)e^{2\pi i\psi_3(x, q)}, x \in X, q \in Q\}$ be three Q-CFNS.

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

$$A \cup C = \{(x, q), \max(r_1(x, q), r_3(x, q))e^{2\pi i \max(\theta_1(x, q), \psi_1(x, q))}, \max(s_1(x, q), s_3(x, q))e^{2\pi i \max(\theta_2(x, q), \psi_2(x, q))}, \max(t_1(x, q), t_3(x, q))e^{2\pi i \max(\theta_3(x, q), \psi_3(x, q))}\}$$

$$\begin{aligned} (A \cup B) \cap (A \cup C) &= \{(x, q), \min(\max(r_1(x, q), r_2(x, q)), \max(r_1(x, q), r_3(x, q)))e^{2\pi i \min(\max(\theta_1(x, q), \phi_1(x, q)), \max(\theta_1(x, q), \psi_1(x, q)))}, \\ &\quad \min(\max(s_1(x, q), s_2(x, q)), \max(s_1(x, q), s_3(x, q)))e^{2\pi i \min(\max(\theta_2(x, q), \phi_2(x, q)), \max(\theta_2(x, q), \psi_2(x, q)))}, \\ &\quad \min(\max(t_1(x, q), t_2(x, q)), \max(t_1(x, q), t_3(x, q)))e^{2\pi i \min(\max(\theta_3(x, q), \phi_3(x, q)), \max(\theta_3(x, q), \psi_3(x, q)))}\} \\ &= \{(x, q), \max(r_1(x, q), \min(r_2(x, q), r_3(x, q)))e^{2\pi i (\max(\theta_1(x, q), \min(\phi_1(x, q), \psi_1(x, q))))}, \\ &\quad \max(s_1(x, q), \min(s_2(x, q), s_3(x, q)))e^{2\pi i (\max(\theta_2(x, q), \min(\phi_2(x, q), \psi_2(x, q))))}, \\ &\quad \max(t_1(x, q), \min(t_2(x, q), t_3(x, q)))e^{2\pi i (\max(\theta_3(x, q), \min(\phi_3(x, q), \psi_3(x, q))))}\} \end{aligned}$$

$$= A \cup (B \cap C)$$

Similarly $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$ can be proved

Theorem

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Demorgan's property i.e.,

- $(A \cup B)^c = A^c \cap B^c$
- $(A \cap B)^c = A^c \cup B^c$

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ be two Q-CFNS.

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

$$\begin{aligned} (A \cup B)^c &= \{(x, q), 1 - \max(r_1(x, q), r_2(x, q))e^{2\pi i (1 - \max(\theta_1(x, q), \phi_1(x, q)))}, \\ &\quad 1 - \max(s_1(x, q), s_2(x, q))e^{2\pi i (1 - \max(\theta_2(x, q), \phi_2(x, q)))}, 1 - \max(t_1(x, q), t_2(x, q))e^{2\pi i (1 - \max(\theta_3(x, q), \phi_3(x, q)))}\} \end{aligned}$$

$$A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$$

$$B^c = \{(x, q), (1 - r_2(x, q))e^{2\pi i (1 - \phi_1(x, q))}, (1 - s_2(x, q))e^{2\pi i (1 - \phi_2(x, q))}, (1 - t_2(x, q))e^{2\pi i (1 - \phi_3(x, q))}\}$$





Vijaya et al.,

$$\begin{aligned}
 A^c \cap B^c &= \{(x, q) \min(1 - r_1(x, q), 1 - r_2(x, q)) e^{2\pi i \min(1 - \theta_1(x, q), 1 - \phi_1(x, q))}, \\
 &\quad \min(1 - s_1(x, q), 1 - s_2(x, q)) e^{2\pi i \min(1 - \theta_2(x, q), 1 - \phi_2(x, q))}, \\
 &\quad \min(1 - t_1(x, q), 1 - t_2(x, q)) e^{2\pi i \min(1 - \theta_3(x, q), 1 - \phi_3(x, q))}\} \\
 &= \{(x, q) 1 - \max(r_1(x, q), r_2(x, q)) e^{2\pi i (1 - \max(\theta_1(x, q), \phi_1(x, q)))}, \\
 &\quad 1 - \max(s_1(x, q), s_2(x, q)) e^{2\pi i (1 - \max(\theta_2(x, q), \phi_2(x, q)))}, \\
 &\quad 1 - \max(t_1(x, q), t_2(x, q)) e^{2\pi i (1 - \max(\theta_3(x, q), \phi_3(x, q)))}\} \\
 &= (A \cup B)^c
 \end{aligned}$$

Similarly $(A \cap B)^c = A^c \cup B^c$ can be proved

DISCUSSION

Need for study of Q-CFNS

The desire to more accurately reflect complicated and unpredictable information in contemporary mathematical and decision-making situations gives rise to the study of Q-complicated Fermatean Neutrosophic Sets. Conventional models in Neutrosophic Set Theory and Fuzzy Set Theory can depict uncertainty, but they frequently have drawbacks when handling contradicting information, periodic data, or higher degrees of vagueness. These theories are extended by Q-Complex Fermatean Neutrosophic Sets, which satisfy the Fermatean constraint while permitting truth, indeterminacy, and falsity memberships to take complex values. This makes it possible to express uncertain data with more accuracy and flexibility. Therefore, learning about this idea contributes to the development of more robust mathematical tools for applications where ambiguity and partial knowledge are common, like data analysis, artificial intelligence, pattern recognition, and decision-making.

Limitations of Q-CFNS

Q-Complex Fermatean Neutrosophic Sets offer a strong framework for managing uncertainty, but they are not without limitations. The model's mathematical complexity is increased by the use of complex numbers to represent truth, indeterminacy, and falsity membership values, which could make practical interpretation challenging. Furthermore, complex-valued membership computational processes can be laborious and call for sophisticated mathematical tools. Practical applications of Q-Complex Fermatean Neutrosophic Sets are still scarce when compared to current approaches in Fuzzy Set Theory and Neutrosophic Set Theory, and many operational techniques, including aggregation and similarity measurements, are still not fully standardised.

Future Scope of Q-CFNS

Notwithstanding these drawbacks, Q-Complex Fermatean Neutrosophic Sets present a substantial opportunity for further investigation. To increase their utility in challenging decision-making scenarios, future research can concentrate on creating novel aggregation operators, similarity metrics, and distance functions. This idea may potentially be extended by researchers to other mathematical structures including topological spaces, graphs, and algebraic systems. Furthermore, combining this model with cutting-edge technologies like machine learning and artificial intelligence may improve its capacity to handle ambiguous and imprecise data, increasing its application in domains like data analysis, engineering, and intelligent decision-support systems.





CONCLUSION

This work developed the idea of Q-Complex Fermatean Neutrosophic Sets and investigated its basic algebraic and operational properties. By adding complex-valued membership degrees while meeting the Fermatean constraint, the suggested framework expands on current models in Neutrosophic Set Theory and Fuzzy Set Theory. To provide a strong theoretical basis for this model, a number of algebraic operations and structural characteristics were developed and investigated. The findings demonstrate that, in comparison to previous fuzzy frameworks, Q-Complex Fermatean Neutrosophic Sets offer more flexibility in capturing uncertainty, indeterminacy, and inconsistent information. As a result, this work advances the creation of powerful uncertainty models and provides novel opportunities for further investigation, especially in the areas of aggregation operators, decision-making techniques, and other mathematical extensions.

REFERENCES

1. Lotfi A. Zadeh, "Fuzzy sets as a basis for a theory of possibility," *Fuzzy Sets and Systems*, vol. 2, pp. 153–165, 1979.
2. Krassimir Atanassov, "Intuitionistic fuzzy sets," *Fuzzy Sets and Systems*, vol. 20, pp. 87–96, 1986.
3. Florentin Smarandache, "A geometric interpretation of the neutrosophic set—A generalization of the intuitionistic fuzzy set," in *Proceedings of the IEEE International Conference on Granular Computing (GrC)*, pp. 602–606, 2011.
4. Young Bae Jun, "Q-fuzzy subalgebras of BCK/BCI algebras," *Scientiae Mathematicae Japonicae Online*, vol. 4, pp. 197–302, 2001.
5. E. H. Roh, K. H. Kim, and J. G. Lee, "Intuitionistic Q-fuzzy subalgebras of BCK/BCI-algebras," *International Mathematical Forum*, vol. 1, pp. 1167–1174, 2006.
6. O. Kazanci, S. Yamuk, and S. Yilmaz, "On intuitionistic Q-fuzzy R-subgroups of near-rings," *International Mathematical Forum*, vol. 2, pp. 2899–2910, 2007.
7. R. Muthuraj, P. M. Sithar Selvam, and M. S. Muthuraman, "Anti Q-fuzzy group and its lower level subgroups," *International Journal of Computer Applications*, vol. 3, pp. 16–20, 2010.
8. V. Lakshmana Gomathi Nayagam, R. Muthuraj, and K. H. Manikandan, "Intuitionistic Q-fuzzy HX group," *International Journal of Mathematical Archive*, vol. 2, pp. 1133–1139, 2011.
9. P. M. Sithar Selvam, T. Priya, T. Ramachandran, and K. T. Nagalakshmi, "Anti Q-fuzzy R-closed KU-ideals in KU-algebras and its lower level cuts," *International Journal of Fuzzy Mathematical Archive*, vol. 4, pp. 61–71, 2014.
10. K. Tanamoon, S. Sripaeng, and A. Iampan, "Q-fuzzy sets in UP algebras," *Songklanakarin Journal of Science and Technology*, vol. 40, pp. 9–29, 2018.
11. M. Abu Qumar and N. Hassan, "An approach toward a Q-neutrosophic soft set and its application in decision making," *Symmetry*, vol. 11, p. 139, 2019.
12. S. Thiruvani and A. Solairaju, "Neutrosophic Q-fuzzy subgroups," *International Journal of Mathematics and Its Applications*, vol. 6, pp. 859–866, 2018.
13. F. Adam and N. Hassan, "Q-fuzzy soft set," *Applied Mathematical Sciences*, vol. 8, pp. 8689–8695, 2014.
14. Said Broumi, "Q-intuitionistic fuzzy soft sets," *Journal of New Theory*, vol. 5, pp. 80–91, 2015.
15. Tahir Mahmood, Qaisar Khan, and Muhammad Aslam Khan, "Q-single valued neutrosophic soft sets," *Journal of New Theory*, vol. 13, pp. 10–25, 2016.
16. Ashraf Al-Quran, Abd Ahmad, Faisal Al-Sharqi, and Abdalwali Lutfi, "Q-complex neutrosophic set," *International Journal of Neutrosophic Science*, vol. 20, no. 2, pp. 8–19, 2023.
17. D. Ramot, R. Milo, M. Friedman, and Abraham Kandel, "Complex fuzzy sets," *IEEE Transactions on Fuzzy Systems*, vol. 10, pp. 171–186.





Vijaya et al.,

18. Mumtaz Ali and Florentin Smarandache, "Complex neutrosophic set," *Neural Computing and Applications*, vol. 28, no. 7, pp. 1817–1834, 2017.
19. Abdulazeez Alkouri and Abdul Razak Salleh, "Complex intuitionistic fuzzy sets," *AIP Conference Proceedings*, vol. 1482, no. 1, pp. 464–470, 2012.
20. C. S. C. Antony and R. Jansi, "Fermatean neutrosophic sets," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 10, no. 6, pp. 24–27, 2021.
21. Said Broumi, Swaminathan Mohanaselvi, Tomasz Witzak, Mohamed Talea, Assia Bakali, and Florentin Smarandache, "Complex Fermatean neutrosophic graph and application to decision making," *Decision Making: Applications in Management and Engineering*, 2023.
22. V. Vijaya, Said Broumi, and H. Manikandan, "Complex Fermatean neutrosophic sets and their applications in decision making," *Neutrosophic Sets and Systems*, vol. 81, 2025.
23. Beaula Thangaraj and V. Vijaya, "Critical path in a project network using a new representation for trapezoidal fuzzy numbers," *International Journal of Mathematics Research*, vol. 4, no. 5, pp. 549–557, 2012.
24. Beaula Thangaraj and V. Vijaya, "A new method to find critical path from multiple paths in project networks," *International Journal of Fuzzy Mathematical Archive*, vol. 9, no. 2, pp. 235–243, 2015.
25. Beaula Thangaraj and V. Vijaya, "A study on exponential fuzzy numbers using α -cuts," *International Journal of Applied Mathematics*, vol. 3, no. 2, pp. 1–13, 2013.
26. V. Vijaya and D. Rajalaxmi, "Decision making in fuzzy environment using Pythagorean fuzzy numbers," *Mathematical Statistician and Engineering Applications*, vol. 71, no. 4, pp. 846–854, 2022.
27. V. Vijaya, D. Rajalaxmi, and H. Manikandan, "Finding critical path in a fuzzy project network using neutrosophic fuzzy number," *Advances and Applications in Mathematical Sciences*, vol. 21, no. 10, pp. 5743–5753, 2022.
28. V. Vijaya, "Cubic Bipolar Complex Neutrosophic Sets in Medical Diagnosis: A New Paradigm," *International Journal of Applied Mathematics*, vol. 38, pp. 999–1015, 2025. doi: 10.12732/ijam.v38i4s.284, 2025

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





Antimicrobial Resistance : A Catastrophic Threat

Shalini Kapoor¹, Amit Bhardwaj¹ and Himani^{2*}

¹Professor, Department of Periodontology, SGT Dental College Hospital and Research Institute SGT University, Gurugram, Haryana, India.

²MDS Student, Department of Periodontology, SGT Dental College Hospital and Research Institute, SGT University, Gurugram, Haryana, India.

Received: 10 Mar 2026

Revised: 06 Apr 2026

Accepted: 08 May 2026

*Address for Correspondence

Himani

MDS Student,

Department of Periodontology,

SGT Dental College Hospital and Research Institute,

SGT University, Gurugram, Haryana, India

E.Mail: himanigupta2903@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

You don't know what you will find, you may set out to find one thing end up by discovering something entirely different"-ALEXANDER FLEMING Antimicrobial resistance (AMR) is a catastrophic threat to the society and to the life on earth. It represents a global threat not only to humans but also to animals, plants and environment sectors. AMR is extricable linked to over prescription of antibiotics in health sector, over the counter availability of the drugs, use of antibiotics in food -animal production, use in agriculture, use in veterinary health sector and poor management of waste. The present article highlights the global perspective of AMR and in detail about the Indian perspective and measures to control the spread of AMR at hospital level, industry level and at individual level as health care professional and patient. This article also gives in sight about the future directions which may stand useful in policy making to combat AMR.

Keywords: Anti microbialresistance, Global Threat, Indian perspective

INTRODUCTION

In an accidental discovery while experimentation, Sir Alexander Fleming noticed a wonder mold which can wipe off the bacteria from old discarded bacteria smeared dishes. He discovered that the active ingredient in the mold was "PENICILLIN"- the first antibiotic in the world.¹ This invention has led to the inception of a new era in the field of medical science. At the Noble prize award winning ceremony in 1945, Sir Alexander Fleming rightly said "The thoughtless person playing with PENICILLIN treatment is morally responsible for the death of man who succumbs



**Shalini Kapoor et al.,**

to infection with PENICILLIN resistant organism” conferring how dangerous a world with excessive consumption of these would be, at the same time the microbes developed ways to counter this threat to their existence called the ANTIMICROBIAL RESISTANCE (AMR).² AMR threatens the prevention and treatment of an increasing range of infection caused by the microbes. Since infectious diseases constantly evolving and developing AMR it becomes imperative to examine the key socioeconomic and political factors that can add to threat of AMR in developing and developed nations.³ Effective antimicrobial drugs are pre-requisite for preventing patients from fatal infections but when the misuse of these drugs occurs, the bacteria change its response to the use of these medicines, thus developing antimicrobial resistance. Antimicrobial resistance is a rapidly evolving global

Health issue, being a catastrophic threat to the society and to the existence of all living beings present on this planet. Currently 7,00,000 people died due to drug resistance (WHO 2018)⁴ and it is estimated that by 2050, AMR could kill two million people per year, more than cancer and diabetes combined (House of Commons, AMR, 2018)⁵. Without urgent action we are heading towards post antibiotic era, in which common infections would once again kill. So, tackling antimicrobial resistance is a high priority on a global platform. Awareness of the seriousness of the situation and the need for urgent action is required at the highest political level globally, country level and above all at individual level. AMR is the crisis that must be managed with utmost urgency and we need to hasten the process of finding solutions. It needs to be mitigated timely.⁶

Historical Prespective

A summary of the historical progression of antimicrobial resistance is presented. (Figure 1) ^{7,8}

What is Antimicrobial Resistance (Amr)

Antimicrobial resistance happens when the germs like (Bacteria, fungi, protozoa, viruses) develop the ability to defeat the drugs. designed to treat them. AMR is a global threat and is crucial health concern for our coming generations.⁹ The death caused by resistant bacteria is more than 75,000 / year globally which is leading to a potential disaster on the future of world. If this post Antibiotics generation comes to pass, by 2050, it would kill more people than cancer daily their fate was predicted more than 70 years ago when the first antibiotic hit the market.

How is Antimicrobial Resistance Different from Antibacterial Resistance?

Antibiotic resistance occurs when bacteria transmute after subjection to an antibiotic used to prevent or treat a bacterial infection. Resistant bacteria cause infections that are difficult to treat than antibiotic -susceptible infections, raising the risk for failure or transmission of disease.¹⁰ In recent times, antibiotic- resistant bacteria have been accountable for infections such as pneumonia, tuberculosis, bacteremia, and gonorrhea becoming difficult and sometimes impossible to treat as antibiotic become less effective. (Figure 2)^{9,10}

Amr and its Types

AMR is broadly divided into two types¹¹

- Intrinsic resistance:¹²

The resistance of microorganism to an antibiotic due to its morphology or structure. It is mainly mediated by

- Activity of multi drug efflux pump
- Cellular envelope impermeability
- Lack of targets for drug action

e.g. Porin channels are required for activation of vancomycin but as gram positive bacteria has no porin channels so they are intrinsically resistant to vancomycin.¹³

- Acquired resistance: Acquired resistance develops when a new trait is expressed, often because of a genetic change that has been selected for in the setting of antibiotic exposure. Bacteria can also mediate tolerance to antibiotics independent of genetic change, such as with persister states or biofilm formation acquired antibiotic resistance can arise by multiple mechanisms but commonly involves altering the target site of the drug, enzymatically inactivating the drug, or preventing the drug from accessing its target. These mechanisms involve new genetic changes in the



**Shalini Kapoor et al.,**

pathogen leading to heritable resistance. AMR can be acquired either by genetic mutation or by conjugation or transformation. In genetic mutation, the cell population is exposed to a drug and only the mutant microorganism survives and now this resistant cell will multiply and resistant population arises.e.g. streptococcus resistance.¹⁴

Antimicrobial Gene Transfer

Resistant gene can be transferred from one bacterium to the other either vertically or horizontally. In vertical transfer Resistant gene is transferred from one generation to another generation by reproduction, Bacteria may transfer resistant gene horizontally among the same species or even between different genus and species. It can occur through conjugation, transformation and transduction. In conjugation two microbial cells are connected to each other through a pilus (bridge) because of close proximity and if one bacterium has resistant plasmid it will transfer to another e.g. Ampicillin resistant gene. In transformation, bacteria encounter a DNA fragment containing a resistant gene e.g. Gram-negative bacteria encounter a fragment of DNA containing gentamycin resistant strain which is released from gram positive bacteria while lysis.¹⁵ Gene transfer is therefore a highly efficient mechanism for bacteria to evolve and adapt.¹⁶

Global Perspective of Amr

Antimicrobial Resistance has increased by 40% between 2000 and 2010. In 2015, world health assembly recognized the importance of antimicrobial resistance affecting public health systems and a Global Action Plan to fight antimicrobial resistance was made with 53 member states.¹⁷ WHO 2019 reported an increased incidence of antimicrobial resistance in low-income countries. At Global level WHO has laid down the formation of Glass AMR surveillance system to make strategies to tackle AMR. There is a growing antibiotic resistance in poultry, livestock, animals, agriculture, sewage and hospital waste water. UK is doing a lot with AMR reducing practices with better surveillance of antimicrobial use, resistance, public campaigns, finding of medicines and diagnosis and development.(AMR House of Commons Library,2017).¹⁸ Two campaigns to reduce inappropriate use of antibiotics were held in France and Belgium. “Antibiotics are not Automatic” campaign was launched in 2001 by France. Central Asian and Eastern European surveillance of Antimicrobial Resistance (CAESER) network by WHO originated in 2012 helps to strengthen AMR surveillance in whole of European region. They conduct technical training and workshops, exchange visits amongst countries; which are part of CAESER network.

Indian Perspective of Amr

India is among the lower socio-economic country group with the highest burden of the bacterial infections.¹⁹The mortality rate from infectious diseases in India is 417 per 1,00,000persons being highest in world. Thus, India has one of the highest rates of resistance to antimicrobial agents used both in humans and food animals. It is estimated that the consumption documented is by 103% from 2000-2015, the highest among low/middle income groups. Thus, India has now been designated as AMR capital in the world.²⁰India has become a part of Global Antimicrobial resistance research and development hub on September 12 2019. AMR is a cause of worry in developing nation like India where the burden of infectious disease is high and healthcare spending is low. Rapid increase in the resistance to the newer and more expensive and rising rate of AMR across multiple pathogens is an alarming situation for our country. Above that the injudicious use of antibiotics in livestock and food animals, poultry industry, and dairy sector has added to the burden of AMR. The need of the hour is to focus on awareness among consumers and providers. India has framed its “National Action Plan” 2017-2021 on April 2017 for sustained efforts against AMR for the coming 5 years. The “One Health Concept” adopted by the country highlights the inter- dependence of Humans, animals and environmental parameters for containment of AMR.²¹ A detailed timeline of antibiotic resistance can be found. (Table 1)²²

How Antimicrobial Resistance Develops

The susceptibility and resistance of a particular microorganism are not necessarily uniform in all the species. Level of resistance vary greatly with in related bacterial groups. Drugs fight microorganism and they respond with equal thrush. The strategies they use for the defense against antibiotics are the resistance mechanisms. Every microbe has





Shalini Kapoor et al.,

an instruction loaded plasmid with in DNA which help bacteria to develop bacterial resistance and passing the instructions from one germ to another. The mechanisms are discussed in detail below:

- Destruction of antibiotic by enzymatic production: Resistance through beta lactamase enzyme occurs both in gram positive and gram negative.²³
 - In gram negative bacteria- The beta lactamases enter the cell wall through porin channels and destroy the beta lactam molecules before they reach their targets.
 - In gram positive bacteria – beta lactamases excreted extracellularly, inactivating the drug outside the cell.
- Restrict the access of the drug: The cell wall becomes impermeable to antibiotics either by limiting the number of entry ways for the drug or by altered porin channels which hinder the drug entrance.
- Alteration of the target site by mutation: The target site get affected by drugs because of alteration through mutations and cell wall become resistant to presence of efflux pump in the cell that actively exports tetracycline molecules and other drugs out of the cell as fast as they are transported or diffuse into the cell, The antibiotic cannot reach its target.²⁴
- PBP alteration through mutation in G+ve bacteria. The B-lactam can no longer bind to it and the cell becomes resistant to the drug. Also occurs in G-ve bacteria

Other causes:

- Chemical alteration of antibiotic molecule
- Changing metabolic pathways
- Changing membrane permeability
- Altering structural targets
- Infecting specific sites

The major causes of antimicrobial resistance are detailed. (Table 2)

Antimicrobial Resistance Threatens All (Interconnected Web)

Antibiotic usage is also not exclusive to humans. Every day antibiotics are used to treat livestock and fish to prevent infections. Similar to overuse in humans, uncontrolled use of antibiotics creates a reservoir of bacteria that could become resistant, thus rendering the antibiotic useless. The high volume of antibiotics in food-producing animals contributes to the development of antimicrobial-resistant bacteria, particularly in settings of intensive animal production.²⁵ In some countries, the total amount of antibiotics used in animals is 4 times larger than the amount used in humans. In many countries much of the antibiotics used in animals are for growth promotion and prevention of disease, and not to treat sick animals.²⁶

These bacteria can be transmitted from animals to humans via direct contact between animals and humans, or through the food chain and the environment. (Table 3,4) Antimicrobial-resistant infections in humans can cause longer illnesses, increased frequency of hospitalization, and treatment failures that can result in death. Some types of bacteria that cause serious infections in humans have already developed resistance to most or all of the available treatments and we are running out of treatment options for some types of infection. WHO recommends an overall reduction in use of antibiotics in food-producing animals to help preserve their effectiveness for human medicine. Many of the bacteria (such as Salmonella, Campylobacter and Escherichia coli) carried by animals can also cause disease in people. These bacteria, which are frequently antimicrobial-resistant, can contaminate our food supply from farm to fork, such as through slaughtering and processing. Fruits and vegetables may also be contaminated by such bacteria at the farm or later through cross-contamination. We know about this because we can link drug-resistant bacteria isolated from sick people to an agricultural source through DNA fingerprinting.^{25,26} Over 400 000 people die each year from foodborne diseases, with over one-third of these deaths occurring in children under 5 years of age. The vast majority of foodborne illnesses are caused by microbes, including bacteria, according to WHO estimates. If these bacteria become resistant to antibiotics, it will become impossible to treat them and more people will die from foodborne diseases. In common with many important public health issues, due to ethical and technical complexity, there are very few randomized controlled studies that have assessed associations between use of antibiotics in food-producing animals and risks of human exposure to and infection by drug-resistant zoonotic pathogens.²⁷ Most of the





supporting scientific evidence the best available was collected from epidemiological studies, surveillance programs and observational studies.²⁸(Figure 3)

Possible Ways to Control Amr

Inadequate access to clean water, sanitation, hygiene in community settings (schools, farms), health care facilities, food production, food safety and waste management, diagnostics and vaccines, over prescription of antibiotics, maintenance of self-hygiene are all contributing factors for development and spread of antimicrobial resistance. Stronger Political leadership advocacy, coordination and accountability are needed at all levels. The misuse of antibiotics is putting us all at risk. A collaborative multidisciplinary approach is the need of time to combat AMR. Effective strategies need to be planned at different level - global, national, community, hospital and individual levels.²⁹ Surveillance and research form the base core area to strength knowledge and evidence.

At Hospital Level: The health policy maker makes this a priority in India. Strengthening of infection control in health care facilities marks an important step. The aim is to minimize the disease transmission finally decreasing the transmission of AMR. To prevent AMR spread, control measures must be designed to reduce the spread of resistant pathogens. These measures include:

- Establishment of Infection Control and Prevention Unit (IPC unit).^{30,31} An infection control committee should work on good hygiene practices, rational antimicrobial use, discard of medicines. Display of the revised list of antimicrobials published by WHO 2017 should be there with doctors prescribing the antibiotics in the hospital and the pharmacist dispensing the antibiotics in the hospital. WHO recommends to immediately stop the use of antimicrobials on WHO list of highest priority critically important drugs.
- Surveillance of Antibiotic resistance: - Strengthening surveillance and regulatory framework can help us to achieve our goal. To generate data on antimicrobial use and AMR, which may also improve antimicrobial prescribing habits and standard empirical treatment guidelines.³²
- Diagnostic Stewardship: - Increasing awareness among all stakeholders is the biggest challenge that needs to be addressed. Appropriate use of microbiological diagnosis to guide therapeutic decisions. Good microbiological practice should be followed in the hospital which includes speedy reporting and rapid diagnostics to guide prescribing which can be achieved through direct communication of clinician with lab personnel.³¹
- Others: Hospitals can also launch AMR awareness programmes or NukkadNataks in the reception area where the focus is to increase the awareness of this crisis among the patients visiting the hospital. Hospitals with teaching facilities can serve as game changer as they are the ones which can sensitize the upcoming doctors, pharmacist, nurses, dentist and other health workers regarding the catastrophic threat of AMR. Knowledge of AMR and rationale use of antibiotics could be reinforced as an integral part of their syllabus. Long term research projects can be undertaken by such institutes for the betterment and innovation in the field.³³

At Patient Level³⁰ - The most significant contribution by a patient in this aspect will be to use antibiotics only when prescribed by certified health professional and never self-medicate themselves. Patient education regarding use of established regime for antimicrobial to prevent AMR. Patient should be aware of ineffectiveness of antimicrobial in viral infections, which can limit the inappropriate use of antimicrobials. Empower the public to ask questions regarding the appropriateness of treatment. Compliance can improve infection control, thus directly combating AMR. Celebrity Power can be a big success for awareness among public regarding AMR in India. Importance of hygiene and preventing infection spread to other members in the family by simple measures.

- Preparing food Hygienically
- Avoid close contact with sick
- Practice Safe Sex
- Following WHO five keys to safer food: Safe water, keep raw and cooked food separately, cook thoroughly, safe temperature and safe food





Shalini Kapoor et al.,

At Industry level³¹- India has a poorly regulated industrial setup may it be pharmaceutical, food, poultry, animal, agriculture etc.

- Poorly regulated pharmaceutical industry means antibiotics are freely available to those who can afford them. Pharma industry must take it on them to distribute drug in responsible manner. They should emphasize on quality medicine i.e. developing and updating quality standards for medicines and detect and remove substandard antimicrobials from market.
- Antibiotic use in animals –WHO strictly called for legislation to minimize antimicrobial usage in animals. Rampant antibiotics use in Poultry/food industry are often pass on to humans
- Antibiotic in drinking water^{34,35}- Lack of clean water is another contributing factor to AMR. That may be because of improper use of antibiotics in agriculture effluent from hospital waste gets mixed up thus causing transfer of resistance conferring mechanism.
- Antibiotic Innovations- The amount of economic burden will be enormous if the crucial medicines become ineffective. India has to invest in drug innovations to combat AMR so that we can save our future generations. Thus we need to prioritize our national action plan and invest in antibiotic research and development.
- Limit to pharmaceutical promotions of antibiotics³⁶: Promotion should be banned, so that direct consumer connection is not there and advertisement should follow the standard of drug promotion. A list of essential medicine can be laid down according to three categories: - Access, watch, revise.
- Improved surveillance of AMR in agricultural settings for improved understanding of the relationship between antimicrobial drugs and pesticide use. Regulatory framework for antimicrobial drug use in agriculture and veterinary medicine.³⁷

At Healthcare worker level: Healthcare workers may be physician, surgeon, microbiologist, pharmacologist, nurses, dentist are all stakeholders, as they are the one who are in direct contact with the patient and can influence the patient. They play a major role in Preventing and controlling the spread of AMR.

- Education-of the patient and the professional regarding AMR
- Aseptic practices: ensure that their hands, instruments, environment is clean and sterilized.
- Rational use of Antibiotics.³⁸ Antibiotic over prescription is due to poor understanding of its dangers and contribution to AMR.
- AMR Awareness programmes and sensitization programmes
- Make it as a thumb rule for as many cases as possible to give prescription following culture sensitivity only.³⁹
- Must immediately report AMR to surveillance teams
- Practitioners of alternative medicines should not prescribe antibiotics.

At Pharmacist level: A key person to educate patients about the use of antimicrobial is pharmacist. Knowledge of AMR at Pharmacist level directly improves the utilization of Antibiotics. Antibiotics can only be handed over to patient on prescription can play a strong role in pharmacist stewardship program. Pharmacist should never dispense any medicine on their own diagnosis. Instead, they should guide and refer the patient to physician. The global problem of AMR cannot be dealt on country basis or region basis. We live in an interconnected world, so humans, animals, food, microorganisms travel along with us. Thus, to curb the rise of AMR, global action response is necessary.

Organizations in India to Control Amr

National Task Force on AMR containments was formed in 2010 which was followed by the adoption of National policy for containment of AMR in 12th 5-year plan in 2011 at Jaipur.⁴⁰ In 2013, AMR monitoring networks were initiated by the Indian Council of Medical Research (ICMR). The National Centre for Disease Control also initiated their activities to control AMR in India in year 2014.⁴¹ The National Health Policy 2017 calls for a rapid standardization of guidelines regarding antibiotic use, limiting the use of antibiotics as OTC medications, banning or





Shalini Kapoor et al.,

restricting the use of antibiotics as growth promoters in animal livestock, and pharmaco-vigilance including prescription audits inclusive of antibiotic usage in the hospital and community.⁴² The political commitment came from the honorable Prime Minister Sh. Narendra Modi Ji himself. Public education came to the forefront with prime minister directly addressing the nation in his 2016 radio address highlighting the issue of antibiotic resistance and the launch of the “Red Line” campaign. A red line on the antibiotic packaging is aimed to draw public attention to the dangers of its misuse and has been lauded internationally.⁴⁰ The Government recently adopted a National Action Plan (NAP) on AMR in 2017. The strategic objectives of NAP-AMR are aligned with the global action plan based on national needs and priorities. In addition to the five priorities of Global Action Plan on AMR, India has a sixth priority dealing with India's leadership on AMR.

Control and Prevention

Strengthen the knowledge and evidence base through surveillance and research detection:

- Conduct studies to assess the relationship between availability of poor- quality medicines and presence of drug-resistant microbes
- Optimize the use of antimicrobial medicines in human and animal health

Prevention:

- Strengthen and optimize registration and market authorization systems within the national medicines regulatory authority
- Promote and operationalize principles of reliance on stringent regulatory authorities and regional harmonization
- Ensure sufficient WHO prequalified sources of medicines
- Ensure compliance with current good manufacturing practices
- Ensure good supply chain practices including proper dispensing
- Procure medicines from WHO prequalified sources

Detection

- Monitor antimicrobial quality through strategic and risk-based post- marketing surveillance programmes
- Strengthen national quality control laboratories to comply with ISO 170125 or WHO prequalification standards
- Ensure routine inspection of products imported and utilize appropriate screening technologies

Response:

- Use data on medicines quality to inform and take regulatory action
- Develop mechanism(s) for communicating notices of poor-quality antimicrobials with relevant stakeholders

What Needs to be Done – Defense Strategies

Antimicrobial resistance has been found in all regions of the world. Modern travel of people, animals, and goods means antimicrobial resistance can easily spread across borders and continents. Fighting this threat is a public health priority. It requires a collaborative global approach across sectors to detect, prevent, and respond to these threats when they occur. Every country can take steps to slow antimicrobial resistance. Commit to setting goals across multiple sectors, including:

- Healthcare
- Food
- Communities (local and global)
- Environment (soil and water)

Create and implement a comprehensive plan with a One Health approach to achieve those goals, and track progress. Every country plan can consider the following actions to prevent resistant infections and their spread:

- Implement infection prevention and control practices
- Improve antibiotic use, including ensuring access



**Shalini Kapoor et al.,**

- Implement data and tracking systems to track resistance, guide prevention strategies, and report results at the local and global level
- Improve lab capacity to identify resistant bacteria

In addition to these important actions, it is also critical to join the global effort to develop new drugs, diagnostics, vaccines, and therapeutics to treat infections.

- Implementing programs in healthcare settings to prevent the spread of resistance (infection prevention and control programs) and support the appropriate use of antimicrobials (antimicrobial stewardship programs)
- Enhancing laboratory capacity to detect and report resistance that have global health implications
- Establishing or strengthening national tracking systems to respond rapidly to outbreaks, identify emerging pathogens, and track trends
- Supporting a national network of travel clinics to better understand the spread of resistance across the U.S. to ultimately improve the health of international travelers

Six strategic priorities have been identified under the NAP-AMR⁴⁰:

- Improving awareness and understanding of AMR through effective communication, education, and training;
- Strengthening knowledge and evidence through surveillance;
- Reducing the incidence of infection through effective infection prevention and control;
- Optimizing the use of antimicrobial agents in health, animals, and food;
- Promoting investments for AMR activities, research, and innovations; and
- Strengthening India's leadership on AMR.

Future Directions and Suggestions

- All the stakeholders such as policy makers, planners, practitioners, pharmacists and dispensers, institution managers, pharmaceutical industries, department of animal husbandry, faculty members and students of medical colleges must adopt an integrated approach to effectively prevent the antimicrobial resistance.
- Medical practitioners can play important role while prescribing suitable antibiotics to their patients.
- Pharmacist can help by dispensing appropriate antibiotic to the patients.
- Implementation of proper surveillance mechanisms by government agencies.
- Every healthcare organization must form their guidelines to combat these issues.
- Patients must also be informed by their physicians about the harmful effects of antibiotics and its self-medication.
- Promotion about AMR among general population through television commercials and radio channels will be beneficial.
- Faculty members in medical colleges can create guidelines for their institution or at department level for appropriate usage of antibiotics.
- There must be monitoring at district level and state levels by conducting regular surveys and this data must be shared among all the stakeholders.
- Legal actions must be implemented on the defaulters.

CONCLUSION

Microbes adapt to environment and change for their survival. Microbes, not humans or animals became resistant to antibiotics. AMR crisis demands immediate action as there is a rapid increase in global incidence of infectious diseases. Amr leads to higher medical costs, prolonged stay in hospital, increased length of treatment and increased mortality. AMR is one health problem which is not only connected to the health of the people but also of animals and environment.





REFERENCES

1. Kardos N, Demain AL. Penicillin: the medicine with the greatest impact on therapeutic outcomes. *Appl Microbiol Biotechnol* 2011;92(4):677-87.
2. Fishman N. Policy statement on antimicrobial stewardship by the society for healthcare epidemiology of America (SHEA), the infectious diseases society of America (IDSA), and the pediatric infectious diseases society (PIDS). *Infect Control Hosp Epidemiol* 2012;33(4):322-7.
3. Chokshi A, Sifri Z, Cennimo D, Horng H. Global contributors to antibiotic resistance. *J Glob Infect Dis* 2019;11(1):36.
4. Tangcharoensathien V, Sommanustweechai A, Chanvatik S, Kosiyaporn H, Tisocki K. Addressing the threat of antibiotic resistance in Thailand: monitoring population knowledge and awareness. *WHO South-East Asia J Public Health*. 2018;7(2):73-8.
5. O'Neill J. Tackling drug-resistant infections globally: final report and recommendations 2016.
6. Dahal R, Upadhyay A, Ewald B. One Health in South Asia and its challenges in implementation from stakeholder perspective. *Vet Rec* 2017;181(23):626.
7. Cunha BA. Antibiotic resistance: a historical perspective. *Semin Respir Crit Care Med* 2000;21(1):3-8.
8. Neu HC. The crisis in antibiotic resistance. *Science* 1992;257(5073):1064-73.
9. Khanal S. Antimicrobial resistance. *Int J Med Biomed Sci* 2017;2(4):1-3.
10. Friier M, Kumar K, Boutin A. [Missing article title in original reference]. *J Infect Public Health* 2017;10(4):369-78.
11. Davies J, Davies D. Origins and evolution of antibiotic resistance. *Microbiol Mol Biol Rev* 2010;74(3):417-33.
12. Cox G, Wright GD. Intrinsic antibiotic resistance: mechanisms, origins, challenges and solutions. *Int J Med Microbiol* 2013;303(6-7):287-92.
13. Courvalin P. Vancomycin resistance in gram-positive cocci. *Clin Infect Dis* 2006;42(Suppl 1):S25-34.
14. Culyba MJ, Mo CY, Kohli RM. Targets for combating the evolution of acquired antibiotic resistance. *Biochemistry* 2015;54(23):3573-82.
15. Almeida Da Silva PE, Palomino JC. Molecular basis and mechanisms of drug resistance in *Mycobacterium tuberculosis*: classical and new drugs. *J Antimicrob Chemother* 2011;66(7):1417-30.
16. Huddleston JR. Horizontal gene transfer in the human gastrointestinal tract: potential spread of antibiotic resistance genes. *Infect Drug Resist* 2014;7:167.
17. Smith E, Lichten CA, Taylor J, MacLure C, Lepetit L, Harte E, Martin A, Ghiga I, Pitchforth E, Sussex J, Dujso E. Evaluation of the EC Action Plan against the Rising Threats from Antimicrobial Resistance. Brussels: European Commission; 2016.
18. Davies SC, Gibbens N. UK Five Year Antimicrobial Resistance Strategy 2013 to 2018. London: Department of Health and Department for Environment, Food & Rural Affairs; 2013.
19. Taneja N, Sharma M. Antimicrobial resistance in the environment: The Indian scenario. *Indian J Med Res* 2019;149(2):119.
20. Kumar SG, Adithan C, Harish BN, Sujatha S, Roy G, Malini A. Antimicrobial resistance in India: A review. *J Nat Sci Biol Med* 2013;4(2):286.
21. Ranjalkar J, Chandy SJ. India's National Action Plan for antimicrobial resistance—An overview of the context, status, and way ahead. *J Fam Med Prim Care* 2019;8(6):1828.
22. Appelbaum PC. 2012 and beyond: potential for the start of a second pre-antibiotic era? *J Antimicrob Chemother* 2012;67(9):2062-8.
23. Wright GD. Bacterial resistance to antibiotics: enzymatic degradation and modification. *Adv Drug Deliv Rev* 2005;57(10):1451-70.
24. Pontes DS, de Araujo RS, Dantas N, Scotti L, Scotti MT, de Moura RO, et al. Genetic mechanisms of antibiotic resistance and the role of antibiotic adjuvants. *Curr Top Med Chem* 2018;18(1):42-74.
25. Founou LL, Founou RC, Essack SY. Antibiotic resistance in the food chain: a developing country- perspective. *Front Microbiol* 2016;7:1881.





Shalini Kapoor et al.,

26. Bengtsson B, Greko C. Antibiotic resistance—consequences for animal health, welfare, and food production. *Upsala J Med Sci* 2014;119(2):96-102.
27. Thorns CJ. Bacterial food-borne zoonoses. *Rev Sci Tech Off Int Epizoot* 2000;19(1):226-39.
28. Caniça M, Manageiro V, Abriouel H, Moran-Gilad J, Franz CM. Antibiotic resistance in foodborne bacteria. *Trends Food Sci Technol* 2019;84:41-4.
29. Kahn LH. Antimicrobial resistance: a One Health perspective. *Trans R Soc Trop Med Hyg* 2017;111(6):255-60.
30. Swaminathan S, Prasad J, Dhariwal AC, Guleria R, Misra MC, Malhotra R, et al. Strengthening infection prevention and control and systematic surveillance of healthcare associated infections in India. *BMJ* 2017;358.
31. Chaudhry D, Tomar P. Antimicrobial resistance: the next BIG pandemic. *Int J Community Med Public Health* 2017;4(8):2632-6.
32. Morgan DJ, Okeke IN, Laxminarayan R, Perencevich EN, Weisenberg S. Non-prescription antimicrobial use worldwide: a systematic review. *Lancet Infect Dis* 2011;11(9):692-701.
33. Goutard FL, Bordier M, Calba C, Erlacher-Vindel E, Góchez D, de Balogh K, et al. Antimicrobial policy interventions in food animal production in South East Asia. *BMJ* 2017;358.
34. Fick J, Söderström H, Lindberg RH, Phan C, Tysklind M, Larsson DJ. Contamination of surface, ground, and drinking water from pharmaceutical production. *Environ Toxicol Chem* 2009;28(12):2522-7.
35. Poonia S, Singh TS, Tsering DC. Antibiotic susceptibility profile of bacteria isolated from natural sources of water from rural areas of East Sikkim. *Indian J Community Med* 2014;39(3):156.
36. Laxminarayan R, Matsoso P, Pant S, Brower C, Røttingen JA, Klugman K, et al. Access to effective antimicrobials: a worldwide challenge. *Lancet* 2016;387(10014):168-75.
37. Singer AC, Shaw H, Rhodes V, Hart A. Review of antimicrobial resistance in the environment and its relevance to environmental regulators. *Front Microbiol* 2016;7:1728.
38. Goswami N, Gandhi A, Patel P, Dikshit R. An evaluation of knowledge, attitude and practices about prescribing fixed dose combinations among resident doctors. *Perspect Clin Res* 2013;4(2):130.
39. Holloway KA, Kotwani A, Batmanabane G, Puri M, Tisocki K. Antibiotic use in South East Asia and policies to promote appropriate use: reports from country situational analyses. *BMJ* 2017;358.
40. Dixit A, Kumar N, Kumar S, Trigun V. Antimicrobial resistance: progress in the decade since emergence of New Delhi metallo- β -lactamase in India. *Indian J Community Med* 2019;44(1):4.
41. Swaminathan S, Prasad J, Dhariwal AC, Guleria R, Misra MC, Malhotra R, et al. Strengthening infection prevention and control and systematic surveillance of healthcare associated infections in India. *BMJ* 2017;358.
42. Delhi N. National Health Policy 2002. New Delhi: Ministry of Health and Family Welfare, Government of India; 2002. p. 1–39.

Table 1: Time line of antibiotic resistance

Drug	Year of release	Year of resistance
Pencillin	1941	1942
Streptomycin	1947	1947
Tetracycline	1952	1956
Vancomycin	1958	1988
Amphotericin	1959	2016
Methicillin	1960	1961
Nalidixicacid	1964	1966
Gentamycin	1967	1969
Vancomycin	1972	1978
Cephalosporins	1980	1983
Azithromycin	1980	2011
Imipenem	1985	1996
Ciprofloxacin	1987	2007
Fluconazole	1988	1988





Shalini Kapoor et al.,

Linezolid	1998	1999
Caspofungin	2001	2004
Ceftazimide	2015	2015

Table 2: Major Causes of Antimicrobial Resistance

Major causes of antimicrobial resistance
1. Using antibiotics in viral infections
2. Inappropriate or mis use of antibiotics
3. Exposure from food source
4. Not completing the course of antibiotics as prescribed

Table 3: Spread Of Antibiotic Resistance In Humans

Spread of antibiotic resistance in humans
Patient to patient
Health care staff to patient
Patient to other people
Health care staff to other people

Table 4: Spread Of Antibiotic Resistance From Animals To Humans

Spread of antibiotic resistance from animals to humans
Animal products
Through environment
Contaminated water and soil
Prepared food through contaminated surfaces

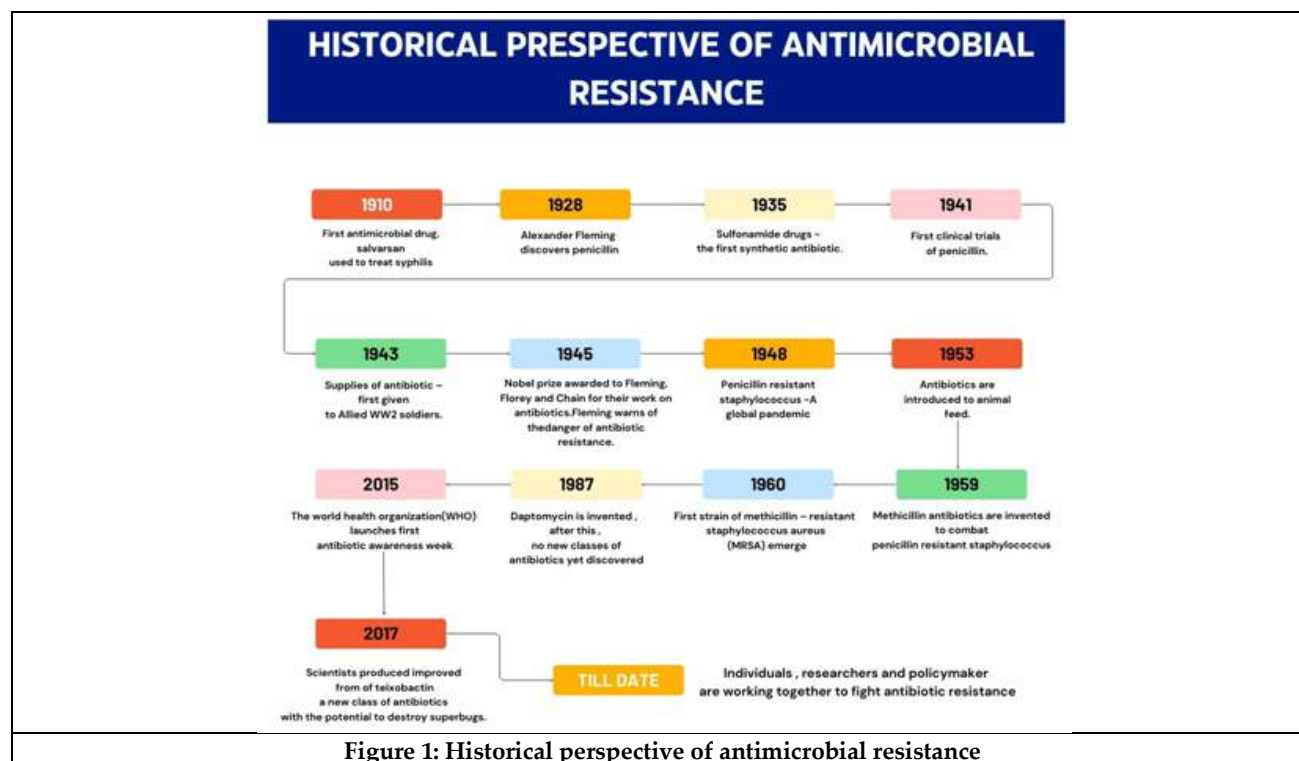


Figure 1: Historical perspective of antimicrobial resistance





Shalini Kapoor et al.,

Characteristics	Antibacterial	Antimicrobial
Definition	An agent that destroys bacteria and fungi, suppresses their growth or their ability to reproduce.	An agent that destroys microorganisms, suppresses their growth or their ability to reproduce.
Types	Antibiotics and chemotherapeutics.	Antibacterial agents, antivirals, antimycotic agents, antiparasitic agents, essential oils, disinfectants and, antiseptics.
Use	Used in infections with bacterial or mycotic etiology.	Used for the treatment of bacterial, viral, fungal, and parasitic diseases, for disinfection of skin, mucous membranes, medical instruments, clothing, water, etc.
Examples	Aminoglycosides, amphenicols, glycopeptide antibiotics, carbapenems, macrolides, penicillins, quinolones, etc.	Carbapenems, macrolides, penicillins, quinolones, oseltamivir, rimantadine, amantadine, ketoconazole, fluconazole, etc.

Figure 2: Antimicrobial vs Anti-Bacterial resistance

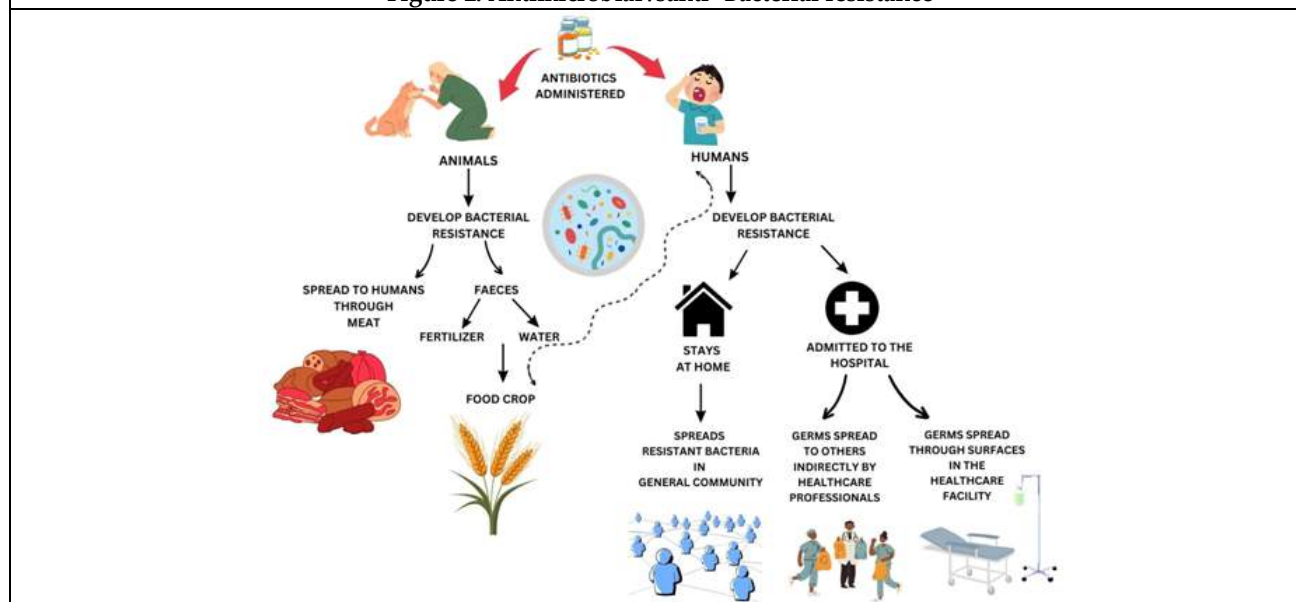


Figure 3: Interconnected web of amr

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A New Perspective Way on Approaching Chatterjea Mapping in Multiplicative Modular Metric Space

Augustine Antony L¹ and A. Mary Pariya Dharsini^{2*}

¹Research Scholar, PG and Research Department of Mathematics, Holy Cross College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India.

²Assistant Professor, PG and Research Department of Mathematics, Holy Cross College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 21 Feb 2026

Revised: 18 Mar 2026

Accepted: 05 May 2026

*Address for Correspondence

A. Mary Pariya Dharsini

Assistant Professor,

PG and Research Department of Mathematics,

Holy Cross College (Autonomous),

(Affiliated to Bharathidasan University),

Tiruchirappalli, Tamil Nadu, India

E.Mail: priyairudayam@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This paper brings a new approach that is establishing the concept of connecting metric and modular into multiplicative modular metric spaces. this is a extension work of Elif Kaplan et al., and Satit Saejung which is originally defined distances between points and images using only positive real numbers. And applying well-established contraction of Chatterjea contraction, using the methodology of Banach's successfully proved the existence and uniqueness of fixed point. This significant research not only provides a robust theoretical foundation but also demonstrates the practical applicability of these theorems, marking a notable advancement in the field of metric spaces.

Keywords: Unique Fixed point, Chatterjea Mapping, Cauchy Sequence, Two mappings, Convergent, Complete Multiplicative Modular Metric Space.

INTRODUCTION

The Banach Fixed Point Theorem is a foundational tenet of analysis, serves as the progenitor for a vast lineage of fixed point theorems within the domain of metric spaces. Its elegant and constructive proof, which guarantees a unique fixed point for any contraction mapping on a complete metric space, laid the groundwork for an expansive eld of inquiry. The conceptual metamorphosis from linear spaces to modular spaces was pioneered by W. Orlicz, who posited that a linear space could be imbued with the structure of a modular space through the adherence to four axiomatic properties. A seminal contribution came from J. Musielak et al., who formally introduced modular





Augustine Antony and Mary Pariya Dharsini

functional denoted by φ_{pq} within a real linear space X . Their work also delineated the conditions for introducing an F -norm in specific subspaces of X . A pivotal advancement was made by Vyacheslav V. Chistyakov et al., who articulated the notion of a modular on an arbitrary set, thereby inaugurating the theory of modular metric spaces. This conceptual leap facilitated the development of a novel metric space for functions of bounded generalized variation, with their range residing in metric semi-groups and abstract convex cones. In a direct extension of this paradigm, Kitima Kuaket et al. expounded upon the ideas of Kirk and Xu, meticulously examining asymptotic pointwise contractions within the modular metric space framework. Concurrently, Parin Chaiparya et al. established Geraghty-type fixed point theorems for these spaces, furnishing a definitive solution for a non-homogeneous linear parabolic partial differential equation. Subsequent to this, they also elucidated foundational properties of subsets within modular metric spaces and presented

several fixed point theorems for multi valued contraction mappings. The practical utility of these theoretical constructs was evinced by Umit Aksoy et al., who successfully applied the modular metric space setting to address anti-periodic boundary value problems for nonlinear first-order differential equations of Carbohydrate's type. The same researchers, Umit Aksoy et al., introduced Meir-Keeler type contraction mappings to the evolving lexicon of modular metric spaces. Multiplicative metric spaces were introduced by Bashirov et al. After that many researchers worked on multiplicative metric spaces and introduced many ideas in that space; see more ideas about multiplicative metric spaces. Taking metric and modular into multiplicative modular metric space and given a contemporary and notable contribution by Elif Kaplan et al. Unveiled a ground breaking concept the w -multiplicative modular metric space. This novel paradigm represents a synthesis of two distinct metric spaces. Capitalizing on this innovation, after that some corrections and clarifications given by Saejung, S we have extended their inquiry to encompass Chatterjea contractions, presenting new fixed point theorems that build upon and significantly augment preceding work.

RESULTS AND DISCUSSION

Definition 1. Assume Ω be a non void set then $\mu : (0, \infty) \times \Omega \times \Omega \rightarrow [1, \infty)$ be a function this fulfils the succeeding characteristic. for all $\Omega_1, \Omega_2, \Omega_3 \in \Omega$ and $\zeta, \vartheta > 0$

- $\mu(\zeta, \Omega_1, \Omega_2) \geq 1$ when $\mu(\zeta, \Omega_1, \Omega_2) = 1$ and $\Omega_1 = \Omega_2$
- $\mu(\zeta, \Omega_1, \Omega_2) = \mu(\zeta, \Omega_2, \Omega_1)$
- $\mu(\zeta\vartheta, \Omega_1, \Omega_2) \leq \mu(\zeta, \Omega_1, \Omega_3) \cdot \mu(\vartheta, \Omega_3, \Omega_2)$

then (Ω, μ) is said to be multiplicative modular metric spaces (MMMS).

Definition 2. Assume $\zeta > 0$ and (Ω, μ) be a MMMS. A open ball $\varpi(\zeta, c, \epsilon)$ with radius $\epsilon > 1$ and center $c \in \Omega$ is defined as

$$\varpi(\zeta, c, \epsilon) = \{G \in \Omega, \mu(\zeta, c, G) < \epsilon\}.$$

Likewise, a closed ball can be trace as

$$\varpi(\zeta, c, \epsilon) = \{G \in \Omega, \mu(\zeta, c, G) \leq \epsilon\}.$$

Definition 3. Let $\zeta > 0$ and (Ω, μ) be a MMMS. Take $c \in \Omega$. If there exists $\epsilon > 1$ such that $\varpi(\zeta, c, \epsilon) \subset C$, then $c \in C$ is called a interior point of C . The set of all interior points of C , and it is specified by $\text{int}(C)$.

Definition 4. Let (Ω, μ) be a MMMS. A point $c \in \Omega$ is said to be a cluster points and $D \subset \Omega$ if and only if

$$\varpi(\zeta, c, \epsilon) \setminus \{c\} \cap D \neq \emptyset \text{ for every } \epsilon > 1.$$

The set of all limit points of D is denoted by D' .

Definition 5. Assume a MMMS (Ω, μ) . A set $\mathfrak{d} \subset \Omega$ is stated to be closed in (Ω, μ) if $\mathfrak{d}$ consists all of its limit points.

Definition 6. Let (Ω, μ_{Ω_1}) , and (Ω, μ_{Ω_2}) be two MMMS and $E : \Omega \rightarrow \Omega$ be a function. If τ fulfils the condition that for each $\epsilon > 1$ and there exists $\delta > 1$ such that





Augustine Antony and Mary Pariya Dharsini

$$\mathfrak{E}(\varpi(\zeta, c, \delta)) \subset \varpi(\zeta, \mathfrak{E}c, \epsilon),$$

using this condition we know that τ is a continuous at $c \in \Omega$.

Definition 7. Assume a MMMS (Ω, μ) with a sequence $\{c_n\}$ in Ω and an member $c \in \Omega$. The sequence $\{c_n\}$ is said to be convergent to c , is formulated as $c_n \rightarrow c$ ($n \rightarrow \infty$), if for any open ball $\varpi(\zeta, c, \epsilon)$ there exists a natural number N then $n \geq N$ leads to $c_n \in \varpi(\zeta, c, \epsilon)$.

Definition 8. Let $\{c_0\}$ be a sequence in Ω , and let (Ω, μ) be a MMMS. The sequence $\{c_0\}$ is called a Cauchy sequence if and only if $\mu(\zeta, c_0, \Omega_1) \rightarrow 1$ as $\nu, \Omega_0 \rightarrow \infty$.

Definition 9. Let (Ω, μ) be a MMMS. If every Cauchy sequence in Ω is said to be converges to a point of Ω , then Ω is called a complete space.

Definition 10. Let (Ω, μ) be a MMMS. Define $\mathfrak{E}_\mu = \{\mathfrak{C} \subset \Omega : c \in \mathfrak{C} \iff \exists \zeta > 0, \epsilon > 1 \text{ such that } \varpi(\zeta, c, \epsilon) \subset \mathfrak{C}\}$. Then $(\Omega, \mathfrak{E}_\mu)$ is a topological space

Definition 11. Let (Ω, μ) be a MMMS. If for any $c, \mathfrak{G} \in \Omega$ and $\zeta \in (0, \infty)$ then there exists a unchanging number $\xi \in [0, 1)$ then

$$\mu(\zeta, \mathfrak{E}c, \mathfrak{E}\mathfrak{G}) \leq [\mu_\zeta(c, \mathfrak{G})]^\xi$$

then the function $\mathfrak{E} : \Omega \rightarrow \Omega$ is termed as multiplicative modular contraction (MMC).

Definition 12. Let (Ω, μ) be a MMMS. If for any $c, \mathfrak{G} \in \Omega$ and $\zeta \in (0, \infty)$ then there exists a real stationary point $\xi \in [0, 1)$ such that

$$\mu(\zeta, \mathfrak{E}c, \mathfrak{E}\Omega_1) \leq [\mu(\zeta, c, \mathfrak{E}\Omega_1)\mu(\zeta, \Omega_1, \mathfrak{E}c)]^\xi \text{ for all } \nu, \Omega_1 \in \Omega,$$

then the mapping $\mathfrak{E} : \Omega \rightarrow \Omega$ is called a multiplicative modular Chatterjea contraction.

Theorem 1.

Consider $\mu : (1, \infty) \times \Omega \times \Omega \rightarrow [1, \infty]$ is a(MMMS) on a nonvoid set Ω and the space (Ω, μ) is complete. And $\mathfrak{E} : \Omega \rightarrow \Omega$ is Chatterjea contraction then there exists a constant $\xi \in (0, 1/2)$ for all $\Omega_1, \mathfrak{p} \in \Omega$ and all $\zeta > 1$:

$$\mu(\zeta, \mathfrak{E}\Omega_1, \mathfrak{E}\mathfrak{p}) \leq (\mu(\zeta, \Omega_1, \mathfrak{E}c) \cdot \mu(\zeta, c, \mathfrak{E}\Omega_1))^\xi.$$

Then the counterparts are true :

- when $\Omega_0 \in \Omega$ such that $\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) : n \geq 0\} < \infty$ for all $\zeta > 1$.
- if μ takes only finite value then $\mathfrak{E}$ has unique fixed point.

Proof. We prove the equivalence in two parts.

(ii) $\Rightarrow$ (i)

Assume that statement (ii) holds true. That is, $\mathfrak{E}$ has a fixed point.

Then there exists some point $\nu \in \Omega$ such that $\mathfrak{E}\nu = \nu$.

We now need to show that statement (i) holds true.

That is, we must find a point $\Omega_0 \in \Omega$ such that for every $\zeta > 1$, and $\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) : n \geq 0\}$ is finite.

Choose $\Omega_0 = \nu$.

Since ν is a fixed point of $\mathfrak{E}$,

we have $\mathfrak{E}\nu = \nu$.

So applying $\mathfrak{E}$,

$$\mathfrak{E}^n\Omega_0 = \mathfrak{E}^n\nu = \nu \text{ for all } n \geq 0.$$

Now compute the modular distance

$$\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) = \mu(\zeta, \nu, \nu).$$

By def of 5, this statement shows $\mu(\zeta, \Omega_1, \Omega_1) = 1$ for all $\Omega_1 \in \Omega$ and all $\zeta > 1$, we have

$$\mu(\zeta, \nu, \nu) = 1.$$

So every $n \geq 0$ and $\zeta > 1$, $\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) = 1$.





Augustine Antony and Mary Pariya Dharsini

The set $\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} = \{1, 1, 1, \dots\}$.

The supremum of this set is 1, which is finite

$$\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} = 1 < \infty.$$

Since this holds for every $\zeta > 1$, condition (i) is satisfied.

So (ii) $\Rightarrow$ (i) is proved

(i) $\Rightarrow$ (ii)

Assume that statement (i) holds true. That is, there exists a point $\Omega_0 \in \Omega$ such that for every $\zeta > 1$

$$(\Omega_0, \zeta) := \sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} < \infty.$$

Take a sequence $\{\Omega_n\}_{n=0}^\infty$ in Ω by

$$\Omega_n = \mathfrak{E}^n \Omega_0.$$

So, Ω_0 is the starting point,

$$\Omega_1 = \mathfrak{E} \Omega_0$$

$$\Omega_2 = \mathfrak{E}^2 \Omega_0$$

$$\Omega_3 = \mathfrak{E}(\Omega_1),$$

And so on

We now show that this sequence $\{\Omega_n\}$ is of Chatterjea contraction.

That is, for every $\zeta > 1$, there exists $\xi \in (0, 1/2)$ such that for all $n, m \geq 0$

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) \leq (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

By definition, $\Omega_{n+1} = \mathfrak{E}(\Omega_n)$ and $\Omega_{m+1} = \mathfrak{E}(\Omega_m)$.

Since $\mathfrak{E}$ is a Chatterjea contraction we have

$$\mu(\zeta, \mathfrak{E} \Omega_n, \mathfrak{E} \Omega_m) \leq (\mu(\zeta, \Omega_n, \mathfrak{E} \Omega_m) \cdot \mu(\zeta, \Omega_m, \mathfrak{E} \Omega_n))^\xi.$$

Substituting $\mathfrak{E} \Omega_m = \Omega_{m+1}$

and $\mathfrak{E} \Omega_n = \Omega_{n+1}$, we get

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) \leq (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

We now show that $\{\Omega_n\}$ is a Cauchy sequence.

Take $\lim_{n,m \rightarrow \infty} \mu(\zeta, \Omega_n, \Omega_m) = 1$ for all $\zeta > 1$.

From assumption (i),

we know that

$$\mu(\zeta, \Omega_0, \Omega_1) = \mu(\zeta, \Omega_0, \mathfrak{E} \Omega_0)$$

$$\leq (\Omega_0, \zeta) < \infty$$

for all $\zeta > 1$.

we proved $\mu(\zeta, \Omega_0, \Omega_1) < \infty$ for all $\zeta > 1$, then the sequence is Cauchy.

Therefore, $\{\Omega_n\}$ is Cauchy. Since (Ω, μ) is complete, every Cauchy sequence converges to a point in Ω . So there exists a point $\mathfrak{o} \in \Omega$ such that

$$\lim_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathfrak{o}) = 1 \text{ for all } \zeta > 1.$$

We now prove that $\mathfrak{o}$ is a fixed point of $\mathfrak{E}$,

i. e., $\mathfrak{E} \mathfrak{o} = \mathfrak{o}$

We must show that $\mu(\zeta, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) = 1$ for all $\zeta > 1$.

Fix an arbitrary $\zeta > 1$. Consider the parameter $\zeta^2 > 1$. By the triangle inequality

$$\mu(\zeta^2, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) \leq \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o}).$$

Take $\limsup$ as $n \rightarrow \infty$ on both sides. Since n independent we prove that

$$\mu(\zeta^2, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) \leq \limsup_{n \rightarrow \infty} [\mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o})].$$

$$\leq \left(\limsup_{n \rightarrow \infty} \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \right) \cdot \left(\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o}) \right)$$

Since $\Omega_n \rightarrow \mathfrak{o}$, the subsequence Ω_{n+1} also converges to $\mathfrak{o}$. Therefore

$$\lim_{n \rightarrow \infty} \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) = 1$$





Augustine Antony and Mary Pariya Dharsini

$$\Rightarrow \limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}) = 1$$

Take $\Omega_{n+1} = \mathbb{E}(\Omega_n)$, so

$$\mu(\zeta, \Omega_{n+1}, \mathbb{E}v) = \mu(\zeta, \mathbb{E}\Omega_n, \mathbb{E}v).$$

Apply the Chatterjea contraction to Ω_n and v

$$\begin{aligned} \mu(\zeta, \mathbb{E}\Omega_n, \mathbb{E}v) &\leq (\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \mathbb{E}\Omega_n))^\xi \\ &= (\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi. \end{aligned}$$

Take the *limsup* as $n \rightarrow \infty$

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}, \mathbb{E}v) &\leq \limsup_{n \rightarrow \infty} [(\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi] \\ &\leq \left(\left(\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathbb{E}v) \right) \cdot \left(\limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}) \right) \right)^\xi. \end{aligned}$$

We already know $\limsup_n \mu(v, v, \Omega_{n+1}) = 1$.

So $\limsup_n \mu(\zeta, \Omega_n, \mathbb{E}v)$, apply the triangle inequality

$$\begin{aligned} \mu(\zeta, \Omega_n, \mathbb{E}v) &\leq \mu(\zeta, \Omega_n, v) \cdot \mu(\zeta, v, \mathbb{E}v). \\ \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathbb{E}v) &\leq \limsup_{n \rightarrow \infty} \mu(\sqrt{\zeta}, \Omega_n, v) \cdot \mu(\sqrt{\zeta}, v, \mathbb{E}v) \\ &= 1 \cdot \mu(\sqrt{\zeta}, v, \mathbb{E}v). \end{aligned}$$

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathbb{E}v) &\leq \left((\mu(\sqrt{\zeta}, v, \mathbb{E}v) \cdot 1) \right)^\xi \\ &= (\mu(\sqrt{\zeta}, v, \mathbb{E}v))^\xi \end{aligned}$$

Add every thing

$$\mu(\zeta^2, v, \mathbb{E}v) \leq 1 \cdot \mu(\zeta, v, \mathbb{E}v)^\xi.$$

Let

$$\mu(\zeta^2, v, \mathbb{E}v) \geq 1$$

$$\mu(\sqrt{\zeta}, v, \mathbb{E}v) \geq 1$$

$$\mu(\zeta^2, v, \mathbb{E}v) \leq \mu(\sqrt{\zeta}, v, \mathbb{E}v)^\xi.$$

But similarly, we can apply the same logic to $\mu(\sqrt{\zeta}, v, \mathbb{E}v) \leq (\mu(\zeta^{\frac{1}{4}}, v, \mathbb{E}v))^\xi$ and so on.

Taking up to k iterations, we get

$$\mu(\zeta^2, v, \mathbb{E}v) \leq \left(\mu(\zeta^{\frac{1}{2^{k+1}}}, v, \mathbb{E}v) \right)^{(\xi)^k}.$$

As $k \rightarrow \infty$, $(\xi)^k \rightarrow 0$ (since $\xi < 1$) and $\zeta^{\frac{1}{2^{k+1}}} \rightarrow 1$

Since, $\mu \geq 1$, so for all k is if

$$\mu(\zeta^2, v, \mathbb{E}v) = 1$$

Therefore, $\mu(\zeta^2, v, \mathbb{E}v) = 1$ for all $\zeta > 1$.

Since ζ^2 covers all values greater than 1 as $\zeta > 1$

we have $\mu(\zeta, v, \mathbb{E}v) = 1$ for all $\zeta > 1$. By definition this implies $v = \mathbb{E}v$. (i) $\Rightarrow$ (ii) is proved.

Assume that $\mu(\zeta, \Omega_1, v) < \infty$ for all $\Omega_1, v \in \Omega$ and all $\zeta > 1$. Suppose v_1 and v_2 are two fixed points of $\mathbb{E}$,

$$\mathbb{E}v_1 = v_1 \text{ and } \mathbb{E}v_2 = v_2.$$

Apply the Chatterjea contraction

$$\mu(\zeta, v_1, v_2) = \mu(\zeta, \mathbb{E}v_1, \mathbb{E}v_2) \leq (\mu(\zeta, v_1, \mathbb{E}v_2) \cdot \mu(\zeta, v_2, \mathbb{E}v_1))^\xi.$$

Since v_1 and v_2 are fixed points,

$$\mathbb{E}v_2 = v_2$$

$$\mathbb{E}v_1 = v_1,$$

$$= (\mu(\zeta, v_1, v_2) \cdot \mu(\zeta, v_2, v_1))^\xi.$$

$$\mu(\zeta, v_2, v_1) = \mu(\zeta, v_1, v_2),$$

$$= (\mu(\zeta, v_1, v_2)^2)^\xi$$

$$= \mu(\zeta, v_1, v_2)^{2^\xi}$$

$$\text{Let } (\mu(\zeta, v_1, v_2)) \geq 1$$





Augustine Antony and Mary Pariya Dharsini

$$\mu(\zeta, v_1, v_2) = \mu(\zeta, v_1, v_2)^{2\xi}.$$

Since $\xi < 1/2$, we have $2\xi < 1$.

If $\mu(\zeta, v_1, v_2) > 1$,

Then $\mu(\zeta, v_1, v_2)^{2\xi} < \mu(\zeta, v_1, v_2)$ (because the exponent is less than 1), Which contradicts $\mu(\zeta, v_1, v_2) \leq \mu(\zeta, v_1, v_2)^{2\xi}$.

Therefore, $\mu(\zeta, v_1, v_2) = 1$. So $\mu(\zeta, v_1, v_2) = 1$ for all $\zeta > 1$

Which implies $v_1 = v_2$. Then $\mathfrak{E}$ has unique fixed point.

Theorem 2.

Let $\mu : (1, \infty) \times \Omega \times \Omega \rightarrow [1, \infty]$ be a (MMMS) on a nonvoid set Ω and the space (Ω, μ) is complete. And $\mathfrak{E} : \Omega \rightarrow \Omega$ is a chatterjea contraction with constant $\xi \in (0, 1/2)$. Assume that for every $\Omega_1 \in \Omega$, the function $\zeta \rightarrow \mu(\zeta, \Omega_1, \mathfrak{E}\Omega_1)$ is continuous. If $\mu(\zeta, \Omega_1, \mathfrak{E}\Omega_1) < \infty$ for all $\Omega_1 \in \Omega$ and all $\zeta > 1$, then E has a unique fixed point.

Proof. Let's take $\Omega_0 \in \Omega$.

Define a sequence $\{\Omega_n\}_{n=0}^\infty$

$$\Omega_n = \mathfrak{E}^n \Omega_0$$

$$\Omega_1 = \mathfrak{E}\Omega_0,$$

$$\Omega_2 = \mathfrak{E}^2 \Omega_0,$$

$$\Omega_n = \mathfrak{E}^n \Omega_0$$

To show $\{\Omega_n\}$ is a cauchy sequence. For any $n, m \geq 0$ and $\zeta > 1$

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) = \mu(\zeta, \mathfrak{E}\Omega_n, \mathfrak{E}\Omega_m)$$

$$\leq (\mu(\zeta, \Omega_n, \mathfrak{E}\Omega_m) \cdot \mu(\zeta, \Omega_m, \mathfrak{E}\Omega_n))^\xi$$

$$= (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

So $\{\Omega_n\}$ is cauchy sequence.

By assumption, $\mu(\zeta, \Omega_0, \mathfrak{E}\Omega_0) = \mu(\zeta, \Omega_0, \Omega_1) < \infty$ for all $\zeta > 1$.

By the Cauchy Criterion we proved $\{\Omega_n\}$ is a cauchy sequence and $\mu(\zeta, \Omega_0, \Omega_1) < \infty$, it is Cauchy.

Since (Ω, μ) is complete, there exists $v \in \Omega$ such that

$$\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, v) = 1 \text{ for all } \zeta > 1. \text{ We now prove } v = \mathfrak{E}v. \text{ Fix } \zeta > 1 \text{ and } \epsilon > 0.$$

Apply the triangle inequality and with parameter $(1 + \epsilon)\zeta$

$$\mu((1 + \epsilon)\zeta, v, \mathfrak{E}v) \leq \mu(1 + \epsilon, v, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v).$$

Take the limit inferior as $n \rightarrow \infty$:

$$\mu((1 + \epsilon)\zeta, v, \mathfrak{E}v) \leq \liminf_{n \rightarrow \infty} [\mu(1 + \epsilon, v, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v)].$$

Since $\liminf(a_n b_n) \leq (\lim a_n)(\limsup b_n)$ when $a_n \rightarrow a$, and $\mu(1 + \epsilon, v, \Omega_{n+1}) \rightarrow 1$ (because $\Omega_n \rightarrow v$), we have

$$\leq 1. \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v).$$

$$\text{Now, } \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) = \mu(\zeta, \mathfrak{E}\Omega_n, \mathfrak{E}v).$$

$$\text{Apply Chatterjea contraction: } \leq (\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi$$

$$\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) \leq \limsup_{n \rightarrow \infty} [(\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi]$$

Move exponent outside (by continuity)

$$= \limsup_{n \rightarrow \infty} (\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi$$

$$\leq \left(\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \right) \cdot \left(\limsup_n \mu(\zeta, v, \Omega_{n+1}) \right)^\xi$$

$$= \left(\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot 1 \right)^\xi$$

Bound $\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v)$ using triangle inequality:

$$\mu(\zeta, \Omega_n, \mathfrak{E}v) \leq \mu(\sqrt{\zeta}, \Omega_n, v) \cdot \mu(\sqrt{\zeta}, v, \mathfrak{E}v)$$

$$\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \leq 1 \cdot \mu(\sqrt{\zeta}, v, \mathfrak{E}v)$$

$$\limsup_n \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathfrak{E}v) \right)^\xi$$





$$\mu((1 + \epsilon)\zeta, v, \mathbb{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi.$$

Now let $\epsilon \downarrow 0$. By the right-continuity assumption (given in the theorem), the left-hand side becomes:

$$\mu(\zeta, v, \mathbb{E}v) = \lim_{\epsilon \downarrow 0} \mu((1 + \epsilon)\zeta, v, \mathbb{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi.$$

Let $\mu(\zeta, v, \mathbb{E}v)$. Since $\mu(\zeta, v, \mathbb{E}v) < \infty$ by assumption (as $v \in \Omega$), $\mu(\zeta, v, \mathbb{E}v) < \infty$

$$\mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v) = \lim_n \mu((1 + \epsilon)\zeta, v, \mathbb{E}v)$$

$$\leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi$$

$$\sqrt{\zeta}, \zeta^{\frac{1}{4}}, \text{ etc., leading to } \mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v)^{\xi^k} \rightarrow \mu(\zeta, v, \mathbb{E}v)^0 = 1.$$

Since $\mu(\zeta, v, \mathbb{E}v) \geq 1$ and $\xi < 1$, the inequality

$$\mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v)$$

$$= \mu((1 + \epsilon)\zeta, v, \mathbb{E}v)$$

$$\leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi$$

Implies $\mu(\zeta, v, \mathbb{E}v) = 1$. Therefore $\mu(\zeta, v, \mathbb{E}v) = 1$ for all $\zeta > 1$

$v = \mathbb{E}v$.

Suppose v_1, v_2 are fixed points. Then

$$\mu(\zeta, v_1, v_2) = \mu(\zeta, \mathbb{E}v_1, \mathbb{E}v_2)$$

$$\leq \mu(\zeta, v_1, \mathbb{E}v_2) \cdot \mu(\zeta, v_2, \mathbb{E}v_1)^\xi$$

$$= \mu(\zeta, v_1, v_2)^{2\xi}.$$

Let $\mu(\zeta, v_1, v_2) \geq 1$. Then $\mu(\zeta, v_1, v_2) \leq \mu(\zeta, v_1, v_2)^{2\xi}$. Since $2\xi < 1$, this forces $\mu(\zeta, v_1, v_2) = 1$. So $v_1 = v_2$. So $\mathbb{E}$ has a unique fixed point.

CONCLUSION

In this paper we successfully introduced and investigated Chatterjea-type contraction within the framework of complete multiplicative modular metric spaces and a novel synthesis of multiplicative metric and modular metric structures. By extending the foundational work of Elif Kaplan et al. and incorporating refinements by Saejung, we establish new fixed point theorems that guarantee both the existence and uniqueness of a fixed point under Chatterjea contraction conditions. The proofs leverage the completeness of the space and the intrinsic properties of multiplicative modular metrics, ensuring robust theoretical validity. Our results not only generalize classical fixed point theory to this enriched setting but also open avenues for applications in nonlinear analysis, differential equations, and other areas where multiplicative or modular structures naturally arise. This contribution thus marks a significant advancement in the ongoing development of fixed point theory in abstract metric spaces.

ACKNOWLEDGEMENT

We thank the Department of Science and Technology, Government of India, for providing support through the Fund for Improvement of S&T Infrastructure in Universities and Higher Educational Institutions (FIST) program (Grant No. SR/FIST/College-/2020/943).

REFERENCES

1. Abdou, A. A., & Khamsi, M. A. (2014). Fixed points of multivalued contraction map pings in modular metric spaces. *Fixed Point Theory and Applications*, 2014(1), 249.



**Augustine Antony and Mary Pariya Dharsini**

2. Aksoy, Ü., Karapnar, E., & Erhan, •. M. (2017). Fixed point theorems in complete modular metric spaces and an application to anti-periodic boundary value problems. *Filomat*, 31(17), 5475-5488.
3. Aksoy, U., Karapnar, E., Erhan, I. M., & Rakocevic, V. (2018). Meir-Keeler type contractions on modular metric spaces. *Filomat*, 32(10), 3697-3707.
4. Banach, S. (1922). Sur les opérations dans les ensembles abstraits et leur application aux équations intégrales. *Fundamentamathematicae*, 3(1), 133-181.
5. Bashirov, A. E., Kurpinar, E. M., & Ozyapıcı, A. (2008). Multiplicative calculus and its applications. *Journal of mathematical analysis and applications*, 337(1), 36-48.
6. Bashirov, A. E., Mısırlı, E., Tandoğdu, Y., & Ozyapıcı, A. (2011). On modeling with multiplicative differential equations. *Applied Mathematics-A Journal of Chinese Universities*, 26(4), 425-438.
7. Chistyakov, V. V. (2010). Modular metric spaces, I: basic concepts. *Nonlinear Analysis: Theory, Methods & Applications*, 72(1), 1-14.
8. Chaipunya, P., Je Cho, Y., & Kumam, P. (2012). Geraghty-type theorems in modular metric spaces with an application to partial differential equation. *Advances in Difference Equations*, 2012(1), 83.
9. Dharsini, A. M. P., Prakasam, A. L. M., & Pritha, A. J. S. (2020). Fixed point theorem in multiplicative rectangular b metric spaces. *Malaya Journal of Matematik (MJM)*, (1, 2020), 348-350.
10. Jarvisvivin, J., & Dharsini, A. M. P. (2024). Application of Fixed Point Theorems to Differential Equation in b-Multiplicative Metric Spaces. *Indian J. Sci. Technol*, 17, 2052-2062.
11. Kaplan, E., Taş, N., Haque, S., & Mlaiki, N. (2025). Multiplicative modular metric spaces and some fixed point results. *Journal of Inequalities and Applications*, 2025(1), 54.
12. Kuaket, K., & Kumam, P. (2011). Fixed points of asymptotic pointwise contractions in modular spaces. *Applied Mathematics Letters*, 24(11), 1795-1798.
13. Kozłowski, W. M. (2012). Advancements in fixed point theory in modular function spaces. *Arabian Journal of Mathematics*, 1(4), 477-494.
14. Musielak, J. (2006). Some applications of modular spaces. In *Orlicz Spaces and Modular Spaces* (pp. 151-163). Berlin, Heidelberg: Springer Berlin Heidelberg.
15. Orlicz, W. (1961). A note on modular spaces I. *Bull. Acad. Polon. Sci. Sér. Sci. Math. Astronom. Phys*, 9, 157-162.
16. Saejung, S. (2025). On multiplicative modular metric spaces of Kaplan et al.: corrections and clarifications. *Fixed Point Theory and Algorithms for Sciences and Engineering*, 2025(1),

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Boruta-Optimized Quasi - Recurrent Stacked Autoencoder (B-QRSAE) for Low - Latency Intrusion Detection in Cloud Computing

M.Varshitha¹ and E.Saikiran^{2*}

¹Research Scholar, Department of Computer Science Engineering, Chaitanya (Deemed to be University), Hyderabad, Telangana, India

²Associate Professor, Department of Computer Science Engineering, Chaitanya (Deemed to be University), Hyderabad, Telangana, India

Received: 13 Mar 2026

Revised: 11 Apr 2026

Accepted: 10 May 2026

*Address for Correspondence

E.Saikiran

Associate Professor,

Department of Computer Science Engineering,

Chaitanya (Deemed to be University),

Hyderabad, Telangana, India

E.Mail: Kiran.09528@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The problem with cloud-based Intrusion Detection Systems (IDS) is that a compromise between both the detection accuracy and the strict real-time requirements is necessary. Despite the success of Deep Learning-based IDS methods, which use LSTMs and GRUs, to model the time-based dependency of the data, the sequential character of the methods makes them very slow (in terms of time Latency). Moreover, the strategy followed in the process of selecting missing features tends to lead to low robustness. In this respect, the hyperparameter tuning is also done manually. Against this backdrop, this paper is a proposal of a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) system of detecting intrusion at low latency in cloud computing environments. The proposed framework can be seen as a combination of all the applicable feature selection methods with Boruta optimization, effective quasi-recurrent auto-encoding to parallel time modeling, and Bayesian hyperparameter optimization. It provides the results of B-QRSAE on the three benchmarks, namely NSL-KDD, UNSW-NB15, and CICIDS2017 in the context of binary and multi-class intrusion detection problems. The findings indicate that B-QRSAE achieves detection rates of 81.68%, 93.69% and 97.77% and high ROC-AUC rates of 99.17%, 99.80 and 99.91% and PR-AUC rates of 95.21%, 97.20% and 99.59 % respectively. Latency of detecting B-QRSA.

Keywords: Cloud Intrusion Detection; Quasi-Recurrent Stacked Autoencoder; Boruta Feature Selection; Temporal Modeling; Bayesian Hyperparameter Optimization; Real-Time Security





INTRODUCTION

It is the large scale development of cloud computing that has essentially revolutionized the modern networked infrastructures through service on demand that is scalable and allows data storage, computation, and communication. Although cloud platforms are flexible and cost efficient, they also cause complex security challenges because of large volume of traffic, dynamic workloads and shared resource environments. Due to this fact, Intrusion Detection Systems (IDS) being implemented in the cloud setting do not only have to be highly detective, but also have to be run with a stringent set of real-time and compute restrictions. Recent deep learning innovations have been shown to dramatically increase the performance of IDS since they allow auto-learning sophisticated patterns in traffic. Specifically, the class of recurrent neural networks, including Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) network, have gained popular use to learn temporal correlations in network traffic. Although effective, these models use time-step sequential computation, which causes the models to incur a longer inference latency, consume more memory, and scale poorly. These attributes limit their use in real-time environment in the cloud where swift detection and low resource overhead is pivotal.

The robustness and efficiency of the IDS models are also affected by the feature selection and optimization of the hyperparameters. A great number of the existing methods use minimal-optimal feature selection strategies, which do drop weakly informative attributes, which may adversely affect generalization in heterogeneous and changing traffic conditions. Additionally, hyperparameter tuning can be carried out by hand or through heuristic methods and consequently lead to poor configurations and lack of consistency in performance across datasets. Even though several studies are reporting the gains in the detection accuracy, relatively very little has been given on the joint consideration of feature relevance, time modelling efficiency, and inference latency in commonly applied IDS. IDS design Current work on latency-conscious designs has not been studied extensively in literature. Specifically, effective sequence modeling solutions that can perform parallel time computation have not been considered properly with regard to intrusion detection. This is a limitation to the practical use of deep learning-based IDS in clouds, as the real-time responsiveness is required there to be able to mitigate attacks.

To overcome such issues, this paper presents a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) framework of low-latency intrusion detection in clouds computing environments. The framework that has been proposed combines the all-relevant feature selection with Boruta which is an effective quasi-recurrent autoencoding framework to model time series in parallel and Bayesian hyperparameter optimization to tune model systematically. The framework balances detection accuracy, robustness, and computation efficiency by balancing strong, but informative features and lowering the cost of sequential computation. The suggested B-QRSAE is tested using three commonly used benchmark datasets NSL-KDD, UNSW-NB15 and CIC-IDS2017 in binary and multiclass intrusion detection environments. The experimental findings show that the model yields a high level of detection but with a sub-millisecond inference latency and low memory footprint in experimental settings, which explains why the model is appropriate to be used in detecting intrusion of clouds in real time.

Novelty and Technical Contribution

The main contributions of this work are summarized as follows:

Latency-Conscious Intrusion Detection Framework: An alternative cloud-based IDS architecture is suggested that clearly takes into account deployment constraints in real-time by collaboratively balancing detection accuracy, inference latency and computational efficiency.

All-Relevant Feature Selection: Boruta-based selection of features is added to select both strong and weakly informative features of traffic that enhance robustness and cross dataset generalization relative to minimal-optimal selection methods.



**Varshitha and Saikiran**

Optimal Temporal Modeling through Quasi-Recurrent Autoencoding: It uses a Quasi-Recurrent Stacked Autoencoder to represent the temporal dependence with convolution-based parallelism thus consuming much less inference latency as compared to the conventional recurrent networks.

Automated Bayesian Hyperparameter Optimization: Bayesian optimization is applied to optimize model and feature selection parameters in a systematic way and not manually, and stability between heterogeneous datasets is provided.

Extensive Experimental Assessment: The given framework is widely tested on three benchmark sets of intrusion detection samples by both classification and efficiency criteria, such as accuracy, stability in conditions of class disproportion, latency of inference, memory footprint, and the complexity of calculation. In contrast to the previous models of IDS which aim only at the detection accuracy, this study is the first which jointly optimizes all-relevant feature selection, parallel temporal modeling, and latency-aware deployment in a unified cloud IDS model framework

Related Work

Cloud and Networked Environment Intrusion Detection Systems (IDS) have gradually advanced in terms of feature selection, deep learning architecture, and optimization capabilities with the goal of enhancing the accuracy of detection and decreasing the cost of implementation. The initial research of IDS was mainly based on the standard machine learning and hybrid techniques to lower the rate of false alarms and decrease the computational costs. The feature selection has been significant in enhancing both the scalability and the strength of the IDS. Kursu and Rudnicki suggested an all-relevant feature selection algorithm that uses the Random Forests feature selection algorithm Relevant but weak instead of just a minor part of a feature selection algorithm, the Boruta algorithm [1], [2]. Despite proving to be effective in general feature relevance analysis, its combination with deep learning-based IDS models is not well explored yet. Comparative analysis shows that excessive feature removal may adversely affect generalization in complicated intrusion detection conditions [8], [12]. Autoencoders have found extensive application in IDS because they can be trained to learn compact representations of high-dimensional traffic over a network. A stacked autoencoders intrusion detection method used by Choobdar et al. proved to be effective in dimensionality reduction but could not handle time modeling [4]. Zhang et al. proposed the use of sparse stacked autoencoders to reduce overfitting, but sequential context was not applied as the method could not effectively resist temporally correlated attacks [9]. On the same note, Thiyam et al. also concentrated on the minimization of computational cost in autoencoder-based IDS but without explicit temporal dependency modeling [11]

Recurrent neural network models like LSTM and GRU have been studied to solve the temporal properties of network traffic. Mushtaq et al. also trained autoencoders with LSTM networks to provide sequential dependencies, but the sequential nature of the computation increased inference latency [5]. To enhance the efficiency, Aldallal suggested the Cu-LSTMGRU hybrid model, which, however, engaged significant memory and time complexity, which constrained the effectiveness of the method to use in real-time deploying clouds [13]. Yang et al. proved that deep learning is effective in intrusion detection but noted scalability and computational issues in large-scale settings [14]. The current studies have explored the use of automated optimization to improve the performance of IDS. The Bayesian optimization was used by Masum et al. to perform systematic hyperparameter optimization, which provides a higher stability in detection than manual approaches [6]. Hyperparameter optimization frameworks have been demonstrated to be useful in machine learning processes and thus Akiba et al. presented Optuna, which is an efficient framework modeled to optimize hyperparameters in machine learning as well as in IDS [7]. Shar et al. have presented a comparative study of methods to optimize hyperparameters with a focus on performance improvements, but have not considered the latency-focused system design [10].

Similarly, it has been suggested that quasi-recurrent neural networks (QRNNs) can be used as effective substitutes to classical recurrent architectures, by facilitating parallel temporal computation via convolutional gating mechanisms



**Varshitha and Saikiran**

[3]. Although it has been shown that QRNNs can achieve lower inference latency in order to perform sequence modeling tasks, its use in intrusion detection is limited. Generally, the current research indicates that serious problems still persist in the IDS research such as high inference latency in recurrent models, use of heuristic hyperparameter optimization, and lack of robustness in noisy and imbalanced traffic settings. It is these constraints that drive the suggested Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) that seeks to incorporate all-relevant feature selection, effective temporal modeling and automated optimization as a single intelligent IDS architecture applicable in the cloud environment. This paper proposes a framework that can be referred to as Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) in order to identify intrusion in the cloud computing system. The new structure will address the significant limitations of existing IDS techniques, including inadequate feature selection, overly high latency of solving the problem based on repeated architecture, and manual hyperparameter optimization.

B-QRSAE is a modular framework that takes four steps, i.e., a) Data preprocessing, b) All-relevant feature selection, c) Sequence-aware representation learning, and d) Bayesian hyperparameter optimization. Raw network traffic data of benchmarked datasets, NSL-KDD, UNSW-NB15 and CICIDS2017 are first preprocessed with standardized cleaning, encoding and normalization rules to ensure the data is consistent across data sets and will not be skewed by scale. Boruta algorithm is then applied to pick all-relevant features on the basis of their statistical significance by taking into account original attributes with randomized shadow attributes in a random Forest classifier. Unlike minimal-optimal selection techniques, the weak features in Boruta are not eliminated, but they will be informative, thus providing robustness and cross-dataset extrapolation in the case of heterogeneous traffic. Quasi-Recurrent Stacked Autoencoder(QR-SAE) is employed in order to capture temporal information in network traffic. The QR-SAE has convolution-based gating operations with parallel temporal computation to learn temporal patterns and incur much less inference latency than a comparable recurrent neural network and thus is best suited to be deployed to clouds in real time. Finally, the automatic process of optimizing significant model parameters (e.g. network dimensions, learning rate, weighting factors in the loss) is referred to as Bayesian hyperparameter optimization.

It is an optimization process that is automated and continuous on datasets to achieve consistent and optimal performance. Overall, the proposed B-QRSAE paradigm can provide an efficient and effective solution to the cloud intrusion detection, with its feature relevance, temporal modelling efficiency, and optimal model configuration, it is possible to rely on the quick and accurate detection of the network traffic situation in real-time, as well as the effective generalization of the problem under different network traffic conditions. During training, the preprocessed and feature-selected data are segregated into training and testing sets whereby the class distribution is maintained. The Quasi-Recurrent encoder is used to process distinct-length sequence of inputs and thus it merges feature extraction through convolution and gating to be able to exploit temporal relationships. The architecture enables parallelization of computation with time, and hence, it has significantly reduced training and inference latency compared to conventional recurrent models. The learned representations are coded with the help of a bottleneck layer and are optimized at the same time in two tasks that have opposing directions to each other, i.e. reconstruction and classification. The reconstruction branch preserves critical structural properties of the network traffic, and the classification branch is adopted to combine latent representations and forecast the classes of intrusion. An output layer that is activated by softmax will produce the probability distributions over the available target classes that enable one to make interpretable and reliable predictions.

The model is trained on composition loss whereby a tradeoff between classification loss and reconstruction error is made to enhance generalization as well as avoiding overfitting. The network depth, bottleneck size, learning rate and weighting of loss are also the most important hyperparameters which are optimized using Bayesian optimization to ensure a consistent performance between datasets without any manual tuning. Training the model is followed by testing the performance of the model in the actual world using an independent test set. The usefulness of classification is determined by conventional evaluation metrics, including accuracy, precision, recall and F1-score, which reveal efficiency and dependability of the suggested B-QRSAE framework in the intrusion recognition in a cloud computing setup.





METHODOLOGY

Data Preprocessing and Feature Selection

This research uses a common preprocessing and feature selecting pipeline across three standard intrusion detection datasets: NSL-KDD, UNSW-NB15, and CIC-IDS-2017, to maintain consistency and high reproducibility and equal comparative assessment. Common cleaning operations of data, such as removing identifier attributes (e.g. IP addresses, ports, timestamps), removing missing and infinite values, and standardization of column names, are used. These measures ensure that data does not leak, and that noise is minimized. Each dataset will be created to support both coarse-grained and fine-grained intrusion detection by creating binary and multiclass labels. Binary labels differentiate between benign and attack traffic, multiclass labels maintain attack specific categories in the dataset (e.g., DoS, Probe, R2L, U2R with NSL-KDD; Generic, Exploits, and Fuzzers with UNSW-NB15;). and original attack types CIC-IDS-2017). Once label construction has taken place, label related attributes are eliminated in the feature space. One-hot encoding is used to turn categorical features into numerical values, and z-score normalization is used to normalize numerical features:

$$x' = \frac{x - \mu}{\sigma} \quad (1)$$

where μ and σ denote the mean and standard deviation, respectively. Encoders and scalers are fitted exclusively on training data to avoid information leakage. Encoded categorical and standardized numerical features are concatenated to form a unified feature matrix

Dataset Summary

NSL-KDD data has 125, 973 training and 22, 544 test samples, 41 original features were narrowed to 100 selected features. The binary training distribution contains 67,343 normal samples and 58, 630 attack samples. Multiclass distribution is made up of 67,343 normal, 45,927 doS, 11,656 probe, 995 r2l, and 52 u2r. UNSW-NB15 has two groups, 82,332 training samples and 175,341 test samples. The initial 42 features are narrowed down to 120 features chosen. Training data comprises of 37,000 normal and 45,332 attack instances: binary training distribution. There are 37,000 Normal, 18,871 Generic, 11,132 Exploits, 6,062 Fuzzers, and the multiclass distribution. 4,089 DoS instances.

CIC-IDS-2017 dataset has 2,262,300 training samples and 565,576 test samples. The initial 77 features are cut to 150 features which are selected. The binary training data consists of 1,817,055 benign and 445,245 attack data. The most common types of multiclass are BENIG, DoS Hulk, PortScan, DDoS and DoS GoldenEye.

Statistical Filtering and All-Relevant Feature Selection

As an initial filtering step, features with zero variance are removed. Mutual Information (MI) is then computed between each feature X and the target label Y to quantify dependency:

$$I(X;Y) = \sum_x \sum_y p(x,y) \log \frac{p(x,y)}{p(x)p(y)} \quad (2)$$

Features are ordered by MI score and the best K features are used to lose dimensionality without losing discriminative power. All-relevant feature selection (Boruta-based) is then used to determine statistically significant features. Boruta uses random permutation to produce shadow features, a Random Forest classifier is trained on real and shadow features and features which consistently perform better than shadow baselines are retained across iterations. The method maintains weak, but complementary properties commonly lost by minimal-optimal algorithms, enhancing the robustness and cross-dataset generalization





Algorithm1:Algorithm for Boruta Feature Selection

Require: Feature set $[X_1, X_2, \dots, X_n]$, class labels y

Ensure: Selected feature subset $[X^{sel}, X^{sel}, \dots, X^{sel}]$

```

1       2       k
while  $i=1$  to  $\text{MaxIterations}$  do
  for each feature  $X_j$  do
    Create shadow feature  $X^{sh}$  by random permutation; Form extended dataset  $X^{ext} = [X X^{sh}]$ ;
    Train Random Forest on  $(X^{ext}, y)$ ;
    Compute feature importance scores; Compute shadow threshold
     $T = \max(I(X^{sh}))$ 
    For each original feature  $X_j$  do if  $I(X_j) > T$  then
      Mark  $X_j$  as relevant;
    Select all relevant features as  $X^{sel}$ ;
    Feed selected features to the next learning stage;
```

Temporal Sequence Construction

To model temporal dependencies in network traffic, a sliding window mechanism is applied to the Boruta-selected feature vectors. Given a feature sequence

$$X = \{x_1, x_2, \dots, x_T\},$$

overlapping windows are constructed as:

$$X_i = \{x_i, x_{i+1}, \dots, x_{i+w-1}\} \quad (3)$$

where the window size $w = 10$ and stride $s = 1$. Each sequence is labeled using the final timestep to reflect real-time intrusion detection constraints. This transformation converts static tabular data into short temporal sequences while maintaining low inference latency.

Algorithm 2: Algorithm for Sliding Window Sequence Generation

Require: Feature matrix $X = [x_1, x_2, \dots, x_N]$, labels y , window size W , stride S

Ensure: Sequential samples X^{seq} and corresponding labels $y^{seq} \ i \leftarrow 1$;

while $i + W - 1 \leq N$ **do**

Extract window

$$X^{seq} = [x_i, x_{i+1}, \dots, x_{i+W-1}]$$

Assign label

$$y^{seq} = y_{i+W-1}$$

$$i \leftarrow i + S;$$

Feed generated sequences to the learning model;

Quasi-Recurrent Stacked Autoencoder (QR-SAE)

The proposed framework adopts a Quasi-Recurrent Stacked Autoencoder (QR-SAE) that learns compact, sequence-aware representations. Unlike traditional recurrent model variants, quasi-recurrent blocks combine temporal convolutions with light-weight gating mechanisms that allow for parallel computation across time steps. Given an input sequence X_t , the encoder computes:

$$Z_t = \tanh(W_z * X_t), \quad (4)$$

$$F_t = \sigma(W_f * X_t), \quad (5)$$

$$H_t = F_t \odot Z_t \quad (6)$$

Where W_z and W_f are convolutional kernels and $\odot$ is the element-wise multiplicative operator. This model formulation has the benefit of being able to model time and long latency inference. The last latent variable is embedded into a low-dimensional bottleneck representation, which favors noise resistance, redundancy reduction,





Varshitha and Saikiran

and improving the separability between classes. Both reconstruction and classification branches share this bottleneck vector.

Joint Reconstruction and Classification Learning

The QR-SAE is trained using a composite loss function that jointly optimizes reconstruction fidelity and classification performance:

$L = \alpha L_{\text{recon}} + (1 - \alpha) L_{\text{cls}}$, $\alpha \in [0.3, 0.7]$ (7) Reconstruction loss encourages informative latent representations, while classification loss optimizes intrusion detection accuracy. This joint objective improves generalization, particularly under noisy and imbalanced traffic conditions.

Bayesian Hyperparameter Optimization and Model Training

Optuna is used to perform Bayesian hyperparameter optimization and optimize important parameters, such as the dimensions of hidden layers, the size of bottle neck, the size of the convolution kernel, the learning rate and the reconstruction-classification trade-off parameter α , automatically. A trial is tested on a validation set and the task is to optimize the detection performance but at the same time keep the computation efficiency. The model is re-trained over a long number of epochs using the best hyperparameters. Mixed-precision (FP16) training is used to minimize memory footprint as well as speed up convergence. The last model is chosen which is based on validation performance and tested on a separate test set by the standard classification and efficiency measures.

Experiments and Results

This section provides an extensive experimental investigation for the proposed Boruta- Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) framework. This experiment is designed to evaluate the effectiveness of the model in view of feature efficiency, detection accuracy, robustness to class imbalance, scalability, and computational performance. All experiments are done based on three widely used benchmark intrusion detection datasets: NSL-KDD, UNSW-NB15, and CIC-IDS2017.

Dataset Characteristics and Feature Reduction

Table 6 summarizes the dataset sizes and feature dimensionality before and after Boruta- based feature selection. This transformation enables the Quasi-Recurrent encoder to learn short-term temporal patterns while maintaining computational efficiency, even for large-scale datasets.

Overall Classification Performance

The binary classification performance of the proposed B-QRSAE framework is summarized in Table 8 using multiple evaluation metrics. The results demonstrate strong detection capability across all datasets, with performance improving as dataset richness and scale increase. High ROC-AUC and PR-AUC values confirm reliable discrimination under severe class imbalance, while Matthews Correlation Coefficient (MCC) highlights balanced prediction performance.

Computational Efficiency and Latency Analysis

In addition to classification accuracy, computational efficiency is critical for real-time intrusion detection. Table 9 reports model complexity, and Table 10 presents inference latency measurements. All models achieve sub-millisecond inference latency and require less than 1 MB of memory, confirming the suitability of the proposed framework for deployment in cloud and edge-based environments

DISCUSSION

The experimental findings show that the suggested Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) model is useful in balancing detection capability and computational complexity, which are essential conditions to intrusion detection in cloud computing systems. The framework was tested on three benchmark



**Varshitha and Saikiran**

datasets, namely NSL-KDD, UNSW-NB15, and CIC-IDS2017 that have correspondingly higher complexity and scale of the traffic. Regarding the detection point of view, the model becomes competitive with a high discrimination capacity in both balanced and imbalanced class distributions. The persistently good value of ROC-AUC and PR-AUC values in all datasets show that reliable separation of benign and malicious traffic can be obtained, even when there are minor classes of attackers. Specifically, the observed improvement in large-scale and heterogeneous traffic in CIC-IDS2017 can imply that the integration of all-relevant feature selection and sequence-aware representation learning yield a positive contribution to generalization in wide range of network conditions.

An important contribution of this piece is that it deals with the issue of inference latency which has been ignored in deep learning-based IDS studies. In contrast to LSTM- and GRU-based models which use sequentially computing blocks, the quasi-recurrent architecture allows parallel processing through time windows. This design option is directly converted into efficiency returns that are measurable. The empirical benchmarking of the proposed framework in a containerized cloud setup enables concluding that the proposed framework can regularly obtain detection latency of less than a millisecond, with a mean inference time of about 0.05 ms per sample across all the datasets tested. Notably, these values were measured in realistic conditions of running on a PyTorch-based inference engine, as opposed to theoretical estimates. The measured memory footprint of about 112MB includes the entire runtime environment of the system, dependencies of the framework and container overhead and not only the model parameters. Since even the trained model consumes less than 1 MB, the findings suggest that B-QRSAE can be easily deployed into either a cloud-native or microservice-based security infrastructure where the speed of inference is the most important factor and memory can be shared across various services.

The strength of the framework is especially well-illustrated by the role played by the all-relevant feature selection which is based on Boruta. The model keeps subtle traits of traffic such as unimportant but informative which are usually dropped through minimal-optimal selection methods thus maintaining finer traits of traffic that lead to a better stability of classification. This would be more evident in databases like CIC-IDS2017 because many more features are statistically significant in this case, and this factor confirms the hypothesis that aggressive dimensionality reduction can be unhealthy in a complex cloud traffic environment. Although these are the benefits, some drawbacks must be mentioned. To start with, temporal models are only restricted to short fixed-length windows, and this can potentially hinder the ability to capture long-range dependencies of slow or multi-stage attack groups. Second, the experimental testing is based on offline benchmark data sets; despite the high popularity of these data sets, real-world cloud systems are subject to concept drift, changing attack patterns, and non-steady traffic. It might be necessary to address these difficulties with adaptive learning measures or progressive changes to the models.

On the whole, the experimental results suggest that the suggested B-QRSAE can be used to provide a scalable and practical solution to latency-conscious intrusion detection in the cloud setting. The framework helps to balance the features, time modeling and automated hyperparameter optimization, thereby closing the gap between the high detection and real-time deployment capabilities, which has historically been a major issue in the modern IDS literature.

CONCLUSION

The paper suggested a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) system of intrusion detection in a cloud computing system with a special emphasis on being able to reach a high level of detection in a system with the severe constraints of latency and computational power. Through the combination of all-relevant feature selection, effective quasi-recurrent temporal model, and Bayesian hyperparameter optimization, the framework will overcome a number of limitations of current solutions to deep-learning-based IDS. Extensive testing on NSL-KDD, UNSW-NB15, and CIC-IDS2017 data shows that the given approach yields high detection rates in binary and multiclass tasks and also ensures sub-milliseconds inference time and a relatively small model size. The findings reveal that B-QRSAE provides a good trade-off among the accuracy, resistance to class imbalance, and





Varshitha and Saikiran

computational efficiency, and it can be extensively adopted in real-time applications of cloud security. The results indicate that the substitution of entirely recurrent architectures by the quasi-recurrent autoencoding systems presents a viable path toward the latency-optimal intrusion detection. Moreover, all-relevant feature selection is used, which also helps to have better generalization in case of heterogeneous traffic distributions. Future directions include extending the framework to the long-range temporal dependency case, adding the online or incremental learning capability to handle concept drift, and the performance evaluation on the real world cloud deployment conditions. The suggested improvements will make the proposed framework more applicable in the dynamic and large-scale cloud system.

REFERENCES

1. M. B. Kursu and W. R. Rudnicki, "Feature selection with the Boruta package," *Journal of Statistical Software*, vol. 36, no. 11, pp. 1–13, 2010.
2. M. B. Kursu and W. R. Rudnicki, "All relevant feature selection using random forest," in *Proc. Int. Workshop Feature Selection Data Mining*, Lecture Notes in Computer Science, vol. 5722, pp. 71–82, 2010.
3. J. Bradbury, S. Merity, C. Xiong, and R. Socher, "Quasi-recurrent neural networks," in *Proc. Int. Conf. Learning Representations (ICLR)*, Toulon, France, 2017.
4. N. Choobdar, M. M. Ghaemi, and A. H. Navin, "Intrusion detection using stacked autoencoders," *Journal of Information Security and Applications*, vol. 65, Art. no. 103117, 2022.
5. M. Mushtaq, S. Khan, and M. A. Khan, "A hybrid autoencoder-LSTM model for network intrusion detection," *IEEE Access*, vol. 10, pp. 102345–102357, 2022.
6. R. Masum, M. S. Islam, and S. Hossain, "Bayesian optimization-based hyperparameter tuning for intrusion detection systems," *Computers & Security*, vol. 114, Art. no. 102587, 2022.
7. T. Akiba, S. Sano, T. Yanase, T. Ohta, and M. Koyama, "Optuna: A next-generation hyperparameter optimization framework," in *Proc. ACM SIGKDD Int. Conf. Knowledge Discovery and Data Mining*, Anchorage, AK, USA, 2019, pp. 2623–2631.
8. M. Faizin, H. Prasetyo, and R. Hidayat, "A comparative study of feature selection techniques for intrusion detection systems," *Information Sciences*, vol. 657, pp. 1–17, 2024.
9. Y. Zhang, H. Wang, and X. Li, "Sparse stacked autoencoder for network intrusion detection," *Knowledge-Based Systems*, vol. 263, Art. no. 110321, 2023.
10. A. Shar, M. Usman, and S. Khan, "Comparative analysis of hyperparameter optimization techniques for intrusion detection systems," *Expert Systems with Applications*, vol. 234, Art. no. 121006, 2024.
11. R. Thiyam, S. Devi, and L. Singh, "Efficient autoencoder-based intrusion detection with reduced computational overhead," *Future Generation Computer Systems*, vol. 150, pp. 35–47, 2024.
12. R. Harsapranata, B. Santoso, and D. Pramono, "All-relevant feature selection for network intrusion detection systems," *Applied Soft Computing*, vol. 150, Art. no. 111123, 2025.
13. A. Aldallal, "Cu-LSTMGRU: A hybrid deep learning model for intrusion detection systems," *Journal of Information Security and Applications*, vol. 61, Art. no. 102903, 2021.
14. Y. Yang, K. Zheng, C. Wu, X. Niu, and Y. Yang, "Building an effective intrusion detection system using deep learning," *IEEE Access*, vol. 7, pp. 84456–84467, 2019.
15. N. Moustafa and J. Slay, "UNSW-NB15: A comprehensive data set for network intrusion detection systems," in *Proc. Military Communications and Information Systems Conf. (MilCIS)*, Canberra, Australia, 2015, pp. 1–6.
16. I. Sharafaldin, A. H. Lashkari, and A. A. Ghorbani, "Toward generating a new intrusion detection dataset and intrusion traffic characterization," in *Proc. Int. Conf. Information Systems Security and Privacy (ICISSP)*, 2018, pp. 108–116.
17. M. Tavallaee, E. Bagheri, W. Lu, and A. A. Ghorbani, "A detailed analysis of the KDD CUP 99 data set," in *Proc. IEEE Symp. Computational Intelligence for Security and Defense Applications*, 2009, pp. 1–6.
18. Y. Bengio, A. Courville, and P. Vincent, "Representation learning: A review and new perspectives," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 35, no. 8, pp. 1798–1828, 2013.





19. G. Kim, S. Lee, and S. Kim, "A novel hybrid intrusion detection method integrating anomaly detection with misuse detection," *Expert Systems with Applications*, vol. 41, no. 4, pp. 1690–1700, 2014.
20. W. Wang, M. Zhu, X. Zeng, X. Ye, and Y. Sheng, "Malware traffic classification using convolutional neural network for representation learning," *Information Sciences*, vol. 372, pp. 712–727, 2016.
21. Z. Yin, W. Wang, and L. Wang, "An efficient intrusion detection approach based on deep neural networks," *IEEE Access*, vol. 5, pp. 25291–25302, 2017.
22. J. Kim, J. Kim, H. L. Nguyen, and H. Kim, "Long short term memory recurrent neural network classifier for intrusion detection," in *Proc. Int. Conf. Platform Technology and Service (PlatCon)*, Jeju, South Korea, 2016, pp. 1–5.
23. M. Zolanvari, M. H. Aghdam, A. Teixeira, and S. Parsaeefard, "Machine learning-based network intrusion detection for IoT systems," *IEEE Internet of Things Journal*, vol. 6, no. 6, pp. 9721–9731, 2019.
24. H. Hindy, E. Bayne, M. Bures, R. Atkinson, C. Tachtatzis, and X. Bellekens, "Machine learning-based IoT intrusion detection system: An MQTT case study," *IEEE Internet of Things Journal*, vol. 7, no. 11, pp. 10392–10404, 2020.
25. A. H. Lashkari, G. Draper-Gil, M. S. Iqbal, and A. A. Ghorbani, "Characterization and analysis of intrusion detection datasets for deep learning-based IDS," *Computers & Security*, vol. 122, Art. no. 102940, 2022.
26. J. Liu, J. Wang, and Q. Li, "An ensemble attention-based lightweight deep learning model for real-time intrusion detection," *Computers & Security*, vol. 120, Art. no. 102850, 2022.
27. Z. Zhang, X. Li, and Y. Zhang, "Autoencoder-based deep feature extraction for network intrusion detection," *Expert Systems with Applications*, vol. 207, Art. no. 118081, 2022.
28. M. Ring, D. Schlör, D. Landes, and A. Hotho, "A survey of network-based intrusion detection data sets," *Computers & Security*, vol. 110, Art. no. 102448, 2022.
29. X. Chen, Y. Zhou, and J. Kong, "Lightweight deep learning based intrusion detection for IoT networks," *IEEE Internet of Things Journal*, vol. 10, no. 13, pp. 12152–12163, 2023.
30. F. Huang, Y. Wang, and Q. Duan, "Temporal convolutional networks for network intrusion detection," *IEEE Transactions on Network and Service Management*, vol. 20, pp. 625–638, 2023.
31. S. Boudjit, A. Brahimi, and T. Taleb, "Hyperparameter optimization of deep learning-based intrusion detection systems using Bayesian techniques," *Computers & Security*, vol. 132, Art. no. 103345, 2023.
32. L. Xu, Y. Gu, and X. Wang, "Self-supervised representation learning for network traffic classification," *IEEE Transactions on Neural Networks and Learning Systems*, vol. 35, no. 1, pp. 112–124, 2024.
33. Y. Li, D. Liu, and J. Chen, "A contrastive learning based anomaly detection framework for network intrusion," *ACM Transactions on Cyber-Physical Systems*, vol. 8, no. 1, Art. no. 2, 2024.
34. H. Zhang, L. Zhou, and J. Xie, "Lightweight deep neural network ensemble with attention for high-speed network intrusion detection," *IEEE Transactions on Industrial Informatics*, vol. 20, no. 7, pp. 6542–6553, 2024.
35. M. Soltani, R. R. Shahid, A. R. Hussain, M. A. Azam, and M. A. Ashraf, "An adaptable deep learning-based intrusion detection system for zero-day attacks," *Journal of Information Security and Applications*, vol. 68, Art. no. 103433, 2023.

Table1: Summary of Representative Intrusion Detection Methods and Their Limitations

Paper	Method	Key Advantage	Limitation
Kursa & Rudnicki – <i>Feature Selection with Boruta</i>	Boruta FS	Identifies all relevant features	Not applied to IDS or DL
<i>Boruta: All-Relevant FS</i>	Random Forest FS	Strong feature relevance	No IDS evaluation
Bradbury et al. – <i>QRNN</i>	QRNN	Fast sequence modeling	Not tested in IDS
<i>QRNN Benchmarks</i>	QRNN Implementation	Low latency	No cybersecurity study
Chhodbar et al. (2022)	SAE + MLP	Dimensionality reduction	No temporal modeling





Varshitha and Saikiran

Fathima et al. (2021)	Two-stage AE	Simple architecture	No feature selection (FS) or hyperparameter optimization (HPO)
Mushtaq et al. (2022)	AE + LSTM	Temporal modeling	High inference latency
Zhang et al. (2023)	Sparse SAE	Reduced overfitting	No sequence context
Yang et al. (2019)	CVAE	Handles imbalance	High computation cost
Masum et al. (2022)	DNN + BO	Systematic tuning	No FS optimization
Akiba et al. (2019)	Optuna	Efficient HPO	Generic framework
Faizin et al. (2024)	FS Comparison	Cross-dataset study	No DL or latency focus
Harsapranata et al. (2025)	Boruta FS	Improved relevance	No DL integration
Shareta et al. (2024)	HPO Comparison	Optimization analysis	No IDS focus
Thiyam et al. (2024)	Enhanced AE	Better AE performance	No temporal modeling

Table2: Parameters of the ProposedB-QRSAEModel

Parameter	Value
Nuber of Epochs	30
Batch Size	256
Activation Function	ReLU (Hidden), Softmax (Output)
Loss Function	Cross-Entropy + Reconstruction (MSE)
Optimizer	AdamW
Sliding Window Size	10
Stride	1
Hyperparameter Tuning	Bayesian Optimization (Optuna)

Table3: Summary of NSL-KDDDataset

Characteristic	Value
Training Samples	125,973
Test Samples	22,544
Original Features	41
Selected Features	100
Binary Label Distribution(Train)	
Normal(0)	67,343
Attack(1)	58,630
Multiclass Distribution(Train)	
Normal	67,343
DoS	45,927

Table4: Summary of UNSW-NB15Dataset

Characteristic	Value
Training Samples	82,332
Test Samples	175,341
Original Features	42
Selected Features	120
Binary Label Distribution(Train)	
Normal(0)	37,000
Attack(1)	45,332





Varshitha and Saikiran

Multiclass Distribution(Train)	
Normal	37,000
Generic	18,871
Exploits	11,132
Fuzzers	6,062
DoS	4,089

Table 5: Summary of CIC-IDS-2017 Dataset

Characteristic	Value
Training Samples	2,262,300
Test Samples	565,576
Original Features	77
Selected Features	150
Binary Label Distribution(Train)	
Benign(0)	1,817,055
Attack(1)	445,245
Top Multiclass Distribution(Train)	
BENIGN	1,817,055
DoS Hulk	183,866
PortScan	127,231
DDoS	102,462
DoS Golden Eye	8,195

Table 6: Dataset Statistics and Feature Reduction Dataset Train Samples Test Samples Original Features Selected Features

NSL-KDD	125,973	22,544	122	42
UNSW-NB15	82,332	175,341	190	38
CIC-IDS2017	2,262,300	565,576	77	64

Table 7: Sequence Generation Statistics

Dataset	Train Sequences	Test Sequences	Sequence Shape
NSL-KDD	125,964	22,535	(N,10,42)
UNSW-NB15	82,323	175,332	(N,10,38)
CIC-IDS2017	2,262,291	565,567	(N,10,64)

Table 8: Overall Binary Classification Performance

Metric	NSL-KDD	UNSW-NB15	CIC-IDS2017
Accuracy	0.8168	0.9369	0.9777
Precision(Macro)	0.8342	0.9259	0.9658
Recall(Macro)	0.8333	0.9297	0.9636
F1-score(Macro)	0.8168	0.9277	0.9647
ROC-AUC	0.9177	0.9806	0.9969
PR-AUC	0.9406	0.9889	0.9883
MCC	0.6675	0.8556	0.9294





Varshitha and Saikiran

Table9:Model Complexity Analysis

Dataset	ModelSize(MB)	Parameters(M)	FLOPs(MFLOPs)
NSL-KDD	0.57	0.15	0.73
UNSW-NB15	0.36	0.10	0.53
CIC-IDS2017	0.76	0.20	1.67

Table10:Inference Latency and Throughput

Dataset	Latency(ms/sample)	Throughput(samples/sec)
NSL-KDD	0.0514	~19,455
UNSW-NB15	0.0503	~19,880
CIC-IDS2017	0.0503	~19,880

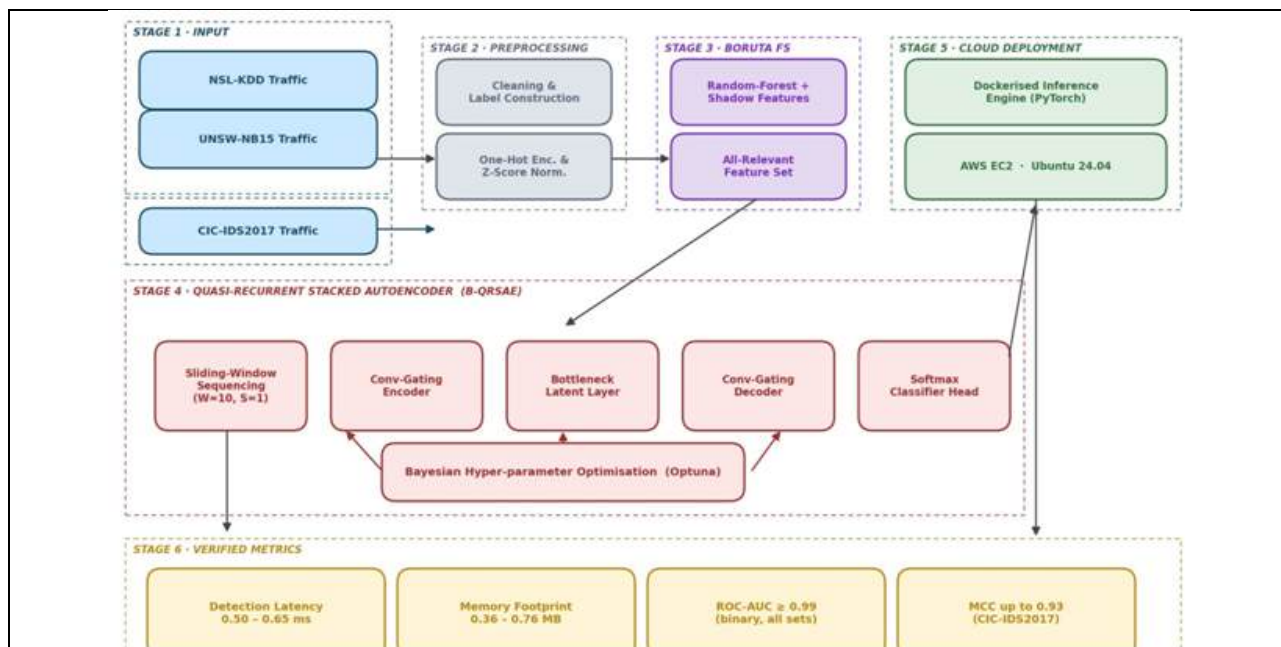


Figure 1:Architecture diagram of the proposed B-QRSAE framework

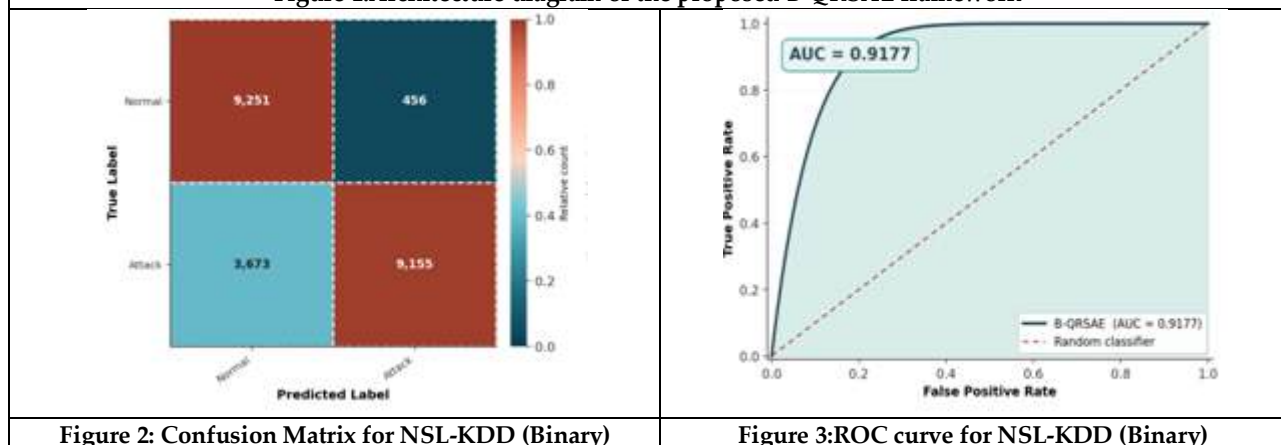


Figure 2: Confusion Matrix for NSL-KDD (Binary)

Figure 3:ROC curve for NSL-KDD (Binary)





Varshitha and Saikiran

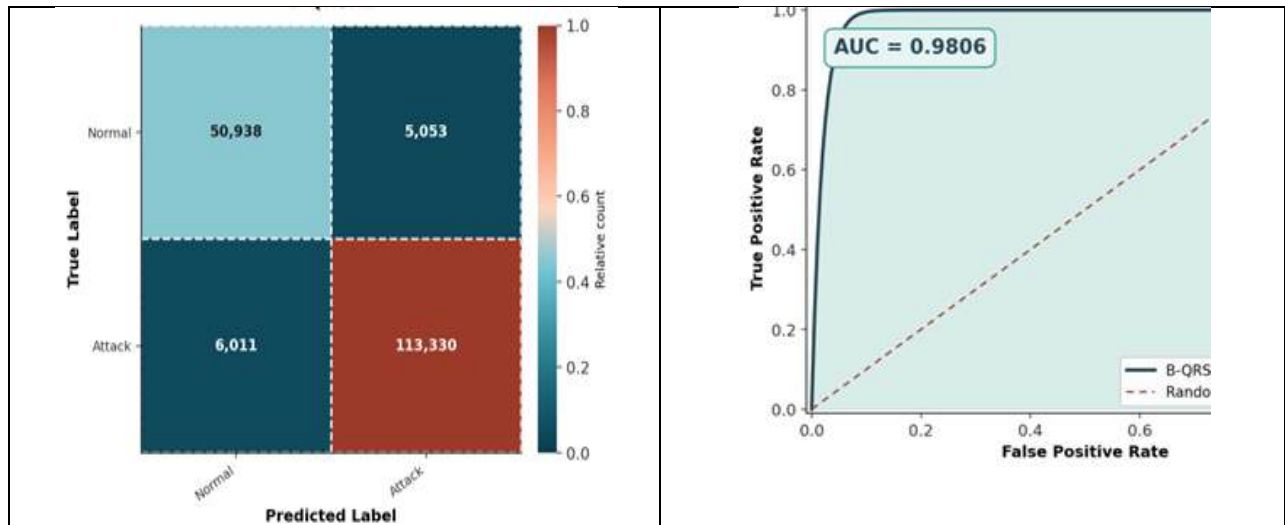


Figure 4: Confusion Matrix for UNSW-NB15 (Binary)

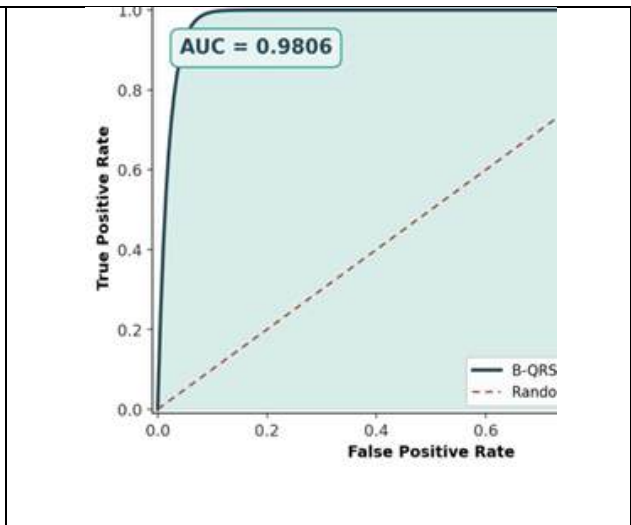


Figure 5: ROC curve for UNSW-NB15 (Binary)

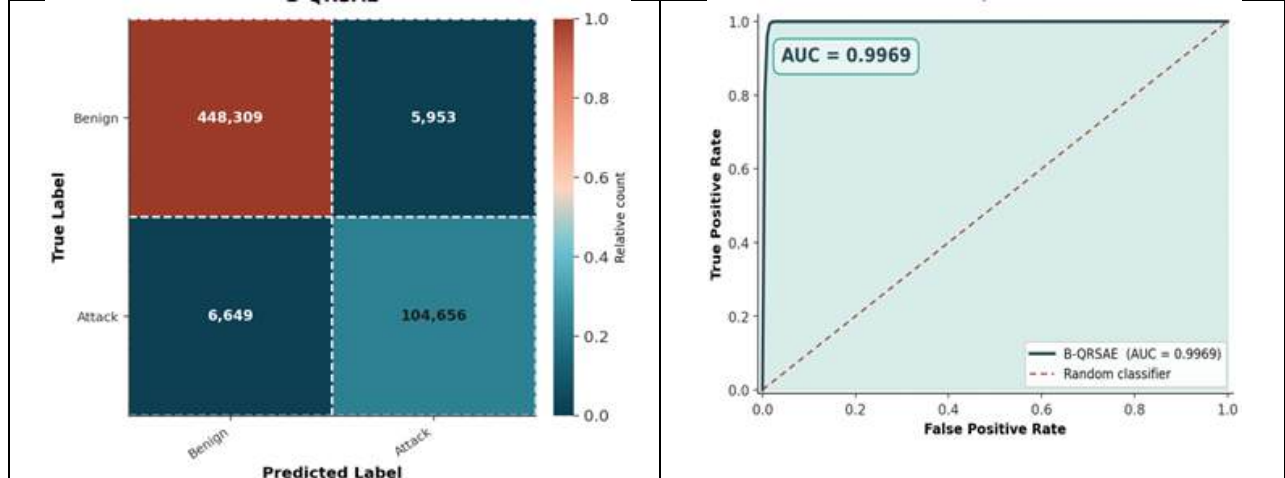


Figure 6: Confusion Matrix for CIC-IDS2017 (Binary)

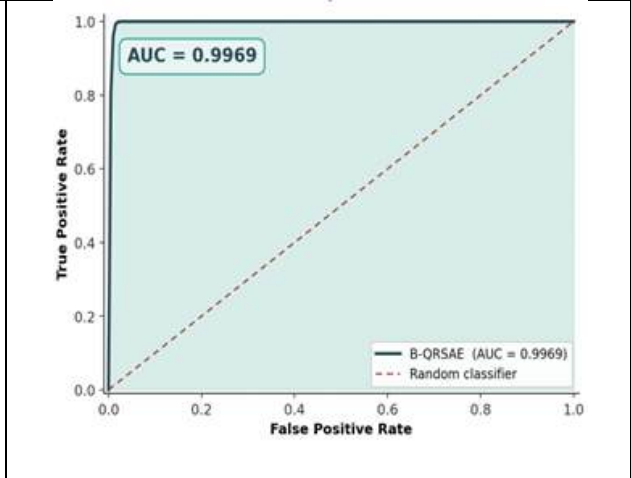


Figure 7: ROC Curve for CIC-IDS2017 (Binary)

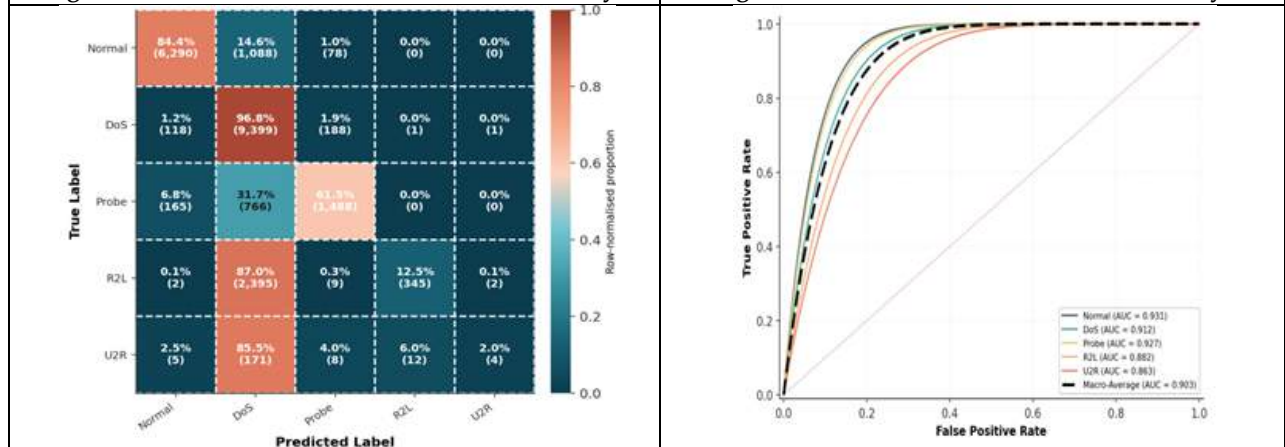


Figure 8: Confusion Matrix for NSL-KDD (Multi)

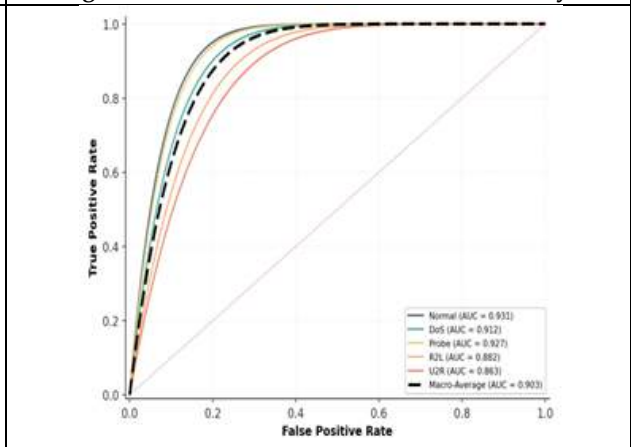


Figure 9: ROC Curve for NSL-KDD (Multi)



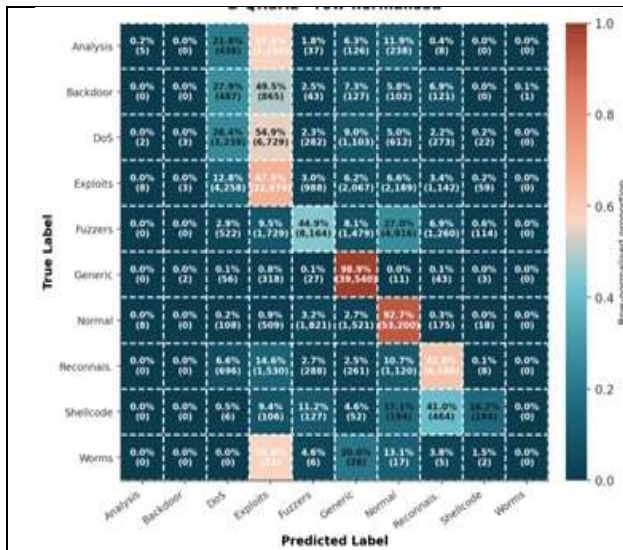


Figure 10: Confusion Matrix for UNSW-NB15 (Multi)

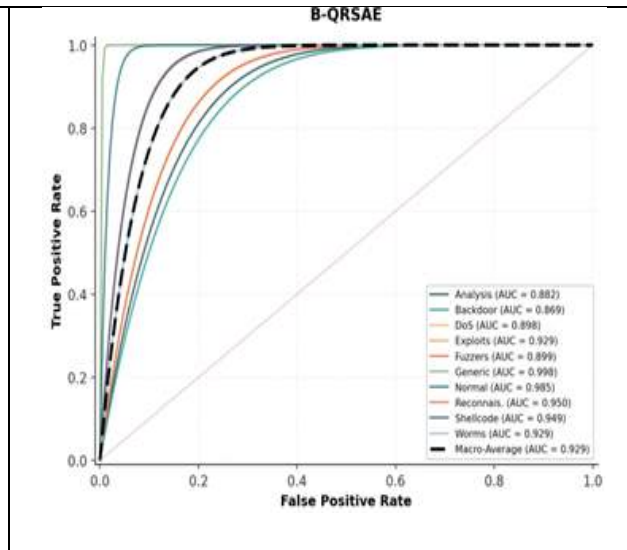


Figure 11: ROC Curve for UNSW-NB15 (Multi)

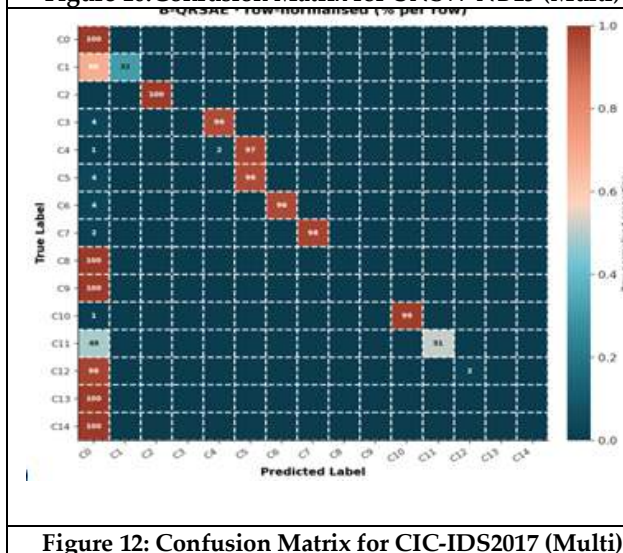


Figure 12: Confusion Matrix for CIC-IDS2017 (Multi)

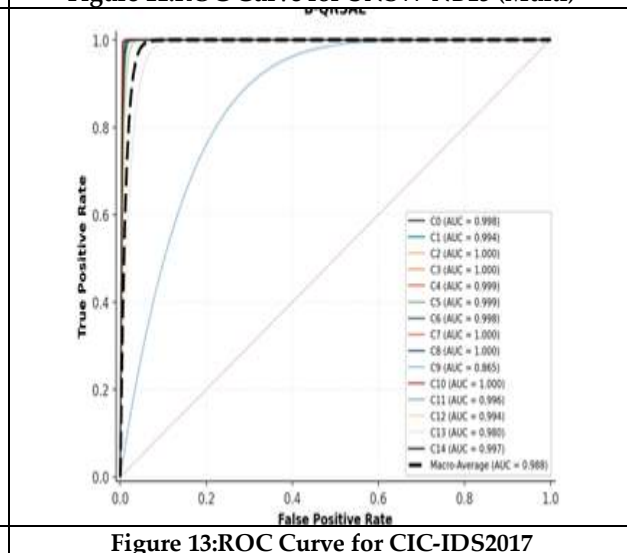


Figure 13: ROC Curve for CIC-IDS2017

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Solving Pythagorean Fuzzy Transportation Problem using Average Cost Penalty Method

S. Sharmila Banu* and A. Prasanna

Assistant Professor, Department of Mathematics, Jamal Mohamed College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 19 Mar 2026

Revised: 25 Apr 2026

Accepted: 27 May 2026

*Address for Correspondence

S. Sharmila Banu

Assistant Professor,

Department of Mathematics,

Jamal Mohamed College (Autonomous),

(Affiliated to Bharathidasan University),

Tiruchirappalli, Tamil Nadu, India

E.Mail: Sharmilasheik0408@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Abstract: This study presents a new method, the Average Cost Penalty Method (ACPM), for addressing Pythagorean Fuzzy Transportation Problems (PFTP), which takes advantage of the capabilities of Pythagorean fuzzy sets to model uncertainty in transportation systems. Using an existing score function, the strategy improves the management of fuzzy constraints and cost optimization. The effectiveness of ACPM is demonstrated through a numerical example, and its performance is compared to existing methods, revealing significant improvements in addressing transportation challenges under fuzzy settings.

Key Words: Transportation Problem, Pythagorean Fuzzy numbers, Score function

INTRODUCTION

The transportation problem is a specific class of linear programming that deals with optimizing the transfer of goods from multiple sources to various destinations at the lowest possible cost. It plays a vital role in logistics, ensuring that supply and demand are met efficiently. Hitchcock first introduced the basic transportation model in 1941. Various methods have been developed to address this problem, including the stepping stone method proposed by Charnes et al. in 1953 and the primal simplex transportation scheme introduced by Dantzig in 1963. In real-world situations, the parameters of transportation problems are often imprecise, which led to the introduction of fuzzy numbers by Zadeh in 1965. Later developments in this field introduced methods like Pythagorean Fuzzy Sets (PFS), as established by Yager in 2013 and 2014. PFS allows the square sum of the membership and non-membership degrees to be less than





Sharmila Banu and Prasanna

or equal to one, offering a more flexible approach when the sum exceeds one. Several researchers have extended transportation problems to a fuzzy environment, introducing algorithms that solve fuzzy, interval, or even intuitionistic fuzzy transportation problems. For instance, Chanas et al. in 1984 and later in 1992 presented solutions for transportation problems using fuzzy numbers. In recent years, methods using trapezoidal fuzzy numbers and Pythagorean fuzzy sets have emerged, addressing various uncertainties in transportation problems. In this work, we explore a modified algorithm to solve the transportation problem under the Pythagorean fuzzy environment. This method addresses the inherent uncertainty in transportation costs, ensuring that the solution is both effective and adaptable to real-world complexities. We present numerical examples to demonstrate the suggested methodology.

PRELIMINARIES

Definition 2.1: (Pythagorean Fuzzy Set)

Let $X = \{x_1, x_2, \dots, x_n\}$ be a finite domain of discourse. A PFS $P = \{(x, (\alpha_P(x), \beta_P(x))) | x \in X\}$ is defined by a membership function $\alpha_P : X \rightarrow [0, 1]$ and a non-membership function $\beta_P : X \rightarrow [0, 1]$ satisfying the condition $0 \leq \alpha_P^2(x) + \beta_P^2(x) \leq 1 \forall x \in X$.

The term $\pi_P(x) = \sqrt{1 - \alpha_P^2(x) - \beta_P^2(x)}$ represents the degree of hesitancy or indeterminacy of x to P . Subsequently, Zhang and Xu defined $(\alpha_P(x), \beta_P(x))$ as a Pythagorean Fuzzy number (PFN), which we denote simply as (α, β) .

Definition 2.2:

Let $\mu = (\alpha, \beta)$, $\mu_1 = (\alpha_1, \beta_1)$ and $\mu_2 = (\alpha_2, \beta_2)$ be any three PFNs and $\delta > 0$ be any real number. The basic arithmetic and set operations on PFNs are defined as follows:

- ❖ Addition: $\mu_1 \oplus \mu_2 = \sqrt{\alpha_1^2 + \alpha_2^2 - \alpha_1^2 \cdot \alpha_2^2}, \beta_1 \cdot \beta_2$
- ❖ Multiplication: $\mu_1 \otimes \mu_2 = \alpha_1 \cdot \alpha_2, \sqrt{\beta_1^2 + \beta_2^2 - \beta_1^2 \cdot \beta_2^2}$
- ❖ Scalar Multiplication: $\delta \cdot \mu = \sqrt{1 - (1 - \alpha^2)^\delta}, \beta^\delta$
- ❖ Exponentiation: $\mu^\delta = \alpha^\delta, \sqrt{1 - (1 - \beta^2)^\delta}$
- ❖ Comparison: $\mu_1 \leq \mu_2$ if $\alpha_1 \leq \alpha_2, \beta_1 \geq \beta_2$
- ❖ Union: $\alpha_1 \cup \alpha_2 = (\max\{\alpha_1, \alpha_2\}, \min\{\beta_1, \beta_2\})$
- ❖ Intersection: $\alpha_1 \cap \alpha_2 = (\min\{\alpha_1, \alpha_2\}, \max\{\beta_1, \beta_2\})$
- ❖ Complement: $\mu^c = (\beta, \alpha)$

The analysis of uncertain information has become significantly more complex compared to dealing with crisp information due to the need to consider both membership and non-membership degrees to capture vague data. To handle fuzzy data in a manner similar to crisp data, it is essential to employ various ranking techniques that assist in the defuzzification process. Zhang and Xu introduced the concept of a score function for ranking Pythagorean Fuzzy Numbers (PFNs), while Peng and Yang provided a formula for the accuracy function associated with a PFN, as outlined below:

Definition 2.3:

For $\mu = (\alpha, \beta)$, the score function is defined by the following expression:

$$T(\mu) = \alpha^2 - \beta^2, \text{ where } T(\mu) \in [-1, 1]$$

The accuracy function for PFN μ as follows:

$$A(\mu) = \alpha^2 + \beta^2, \text{ where } A(\mu) \in [0, 1]$$

As $T(\mu) \in [-1, 1]$, Wu and Wei proposed a normalized version of the score function for PFN μ as follows:

$$T(\mu) = \frac{1 + \alpha^2 - \beta^2}{2}, \text{ where } T(\mu) \in [0, 1]$$



**Definition 2.4:**

Let $\mu_1 = (\alpha_1, \beta_1)$ and $\mu_2 = (\alpha_2, \beta_2)$ be any two PFNs, then the ranking rules on the basis of score function T and accuracy function $\mathcal{A}$ are defined in the following way:

- If $T(\mu_1) > T(\mu_2)$, then $\mu_1 > \mu_2$
- If $T(\mu_1) < T(\mu_2)$, then $\mu_1 < \mu_2$
- If $T(\mu_1) = T(\mu_2)$, and
 $\mathcal{A}(\mu_1) > \mathcal{A}(\mu_2)$, then $\mu_1 > \mu_2$;
 $\mathcal{A}(\mu_1) = \mathcal{A}(\mu_2)$, then $\mu_1 = \mu_2$

Definition 2.5: (Score Function)

For defuzzification, this paper adopts the score function s , which effectively handles Pythagorean fuzzy numbers (PFNs) by transforming them into crisp values for comparison and optimization.

For a given PFN $\mu = (\alpha, \beta)$, the score function $Tr(\mu)$ is defined as follows:

$$Tr(\mu) = \frac{1}{R} \left[\frac{(1 + \alpha^2)e^{1+\alpha^2-\beta^2}}{1 + e^{\alpha^2-\beta^2}} - \frac{1}{1+e^{-1}} \right] \quad \text{where } R = \frac{2e^2+e-1}{2+e+e^{-1}}$$

The score function satisfies several important properties, including being a monotonically increasing function with respect to membership degree (α) and a monotonically decreasing function with respect to non-membership degree (β).

Mathematical Modeling of Transportation Problems with Pythagorean Fuzzy Sets

Let's assume that there are "m" sources and "n" destinations in the transportation system. The goal is to minimize the overall cost of distributing a product from these sources to the destinations, while the supply and demand are subject to the following crisp assumptions:

- m : Total number of sources in the network
- n : Total number of destinations
- i : index representing each source
- j : index representing each destination
- x_{ij} : Units of product transported from source i to destination j
- c_{ij}^p : Pythagorean fuzzy cost per unit transported from i to j
- c_{ij} : Crisp cost per unit transported
- a_{ij} : Supply quantity available from source i in the crisp environment
- a_{ij}^p : Supply quantity available from source i in the Pythagorean fuzzy environment
- b_{ij} : Demand quantity at destination j in the crisp environment
- b_{ij}^p : Demand quantity at destination j in the Pythagorean fuzzy environment

The crisp Transportation problem can be formulated as:

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}$$

Subject to

$$\sum_{j=1}^n x_{ij} = a_i, \quad \forall i = 1 \text{ to } m \quad (\text{supply constraints})$$

$$\sum_{i=1}^m x_{ij} = b_j, \quad \forall j = 1 \text{ to } n \quad (\text{demand constraints})$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Now, if we replace c_{ij} with its Pythagorean fuzzy counterpart c_{ij}^p . We obtain the Type I Pythagorean Fuzzy Transportation (T1PyFT) problem.

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}^p$$

Subject to the same supply and demand constraints as above:

If the supply and demand quantities are also uncertain, We introduce Pythagorean Fuzzy Parameters for the both supply and demand, leading to the Type II Pythagorean Fuzzy Transportation (T2PyFT) Problem:





Sharmila Banu and Prasanna

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}$$

Subject to:

$$\sum_{i=1}^m x_{ij} = a_{ij}^p, \quad \sum_{j=1}^n x_{ij} = b_{ij}^p$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Lastly, if all three parameters – cost, supply, and demand – are modeled using Pythagorean Fuzzy numbers, the problem becomes the Type III Pythagorean Fuzzy Transportation (T3PyFT) Problem:

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}^p$$

Subject to the fuzzy supply and demand constraints:

$$\sum_{i=1}^m x_{ij} = a_{ij}^p, \quad \sum_{j=1}^n x_{ij} = b_{ij}^p$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Algorithm for Average Cost Penalty Method

Step 1: Setup the Transportation Matrix

Construct the transportation table with supply, demand, and associated costs for each route. Make sure whether the TP is balanced or not, if not, make it balanced by adding dummy row or column.

Step 2: Calculate Row and Column Penalties

For each row and column:

- Exclude the highest cost from the calculation.
- Compute the average of the remaining costs.
- Subtract the minimum cost from this average to determine the penalty for each row or column.

Step 3: Identify the Highest Penalty

Select the row or column with the highest penalty and allocate as much supply or demand as possible to the cell with the lowest cost in that row or column. Update the remaining supply and demand. If a row or column is exhausted, cross it out .

Step 4: Recalculate Penalties

After each allocation, recalculate the penalties for the remaining rows and columns using the same procedure as in Step 2.

Step 5: Repeat Allocation Process

Continue selecting the row or column with the highest penalty and allocate resources to the cell with the lowest cost until all supply and demand are fulfilled.

Step 6: Final Allocation and Total Cost Calculation

Once all resources are allocated, calculate the total transportation cost by multiplying the allocated units by their respective transportation costs and summing these values.

Numerical Examples

Example 5.1: Type I: Consider a transportation problem with 3 sources and 4 destinations. The objective is to minimize the transportation cost under Pythagorean fuzzy conditions. While the supply and demand quantities are crisp, the transportation costs are modeled using Pythagorean fuzzy numbers.

Step 1: Convert the Pythagorean fuzzy numbers (PFNs) into crisp values using the score function, transforming the fuzzy transportation problem into a crisp one.





Sharmila Banu and Prasanna

Step 2: Calculate row and column penalties as described, then allocate to the lowest-cost cell in the row or column with the highest penalty

The Total Transportation cost $= 0.0737 \times 18 + 0.1812 \times 12 + 0.3445 \times 15 + 0.1412 \times 14 + 0.4736 \times 2 + 0.6620 \times 5 = 14.9025$.

The results presented above were cross-verified with the LINDO software

Example 5.2: (Type II) Consider a transportation problem with 3 sources and 4 destinations. The objective is to minimize the transportation cost under Pythagorean fuzzy conditions. In this scenario, the transportation costs are represented by crisp values, while the supply and demand quantities are modeled using Pythagorean fuzzy numbers.

Example 5.3: (Type III) Consider a transportation problem where the objective is to minimize costs under Pythagorean fuzzy conditions, with transportation costs, supply, and demand all represented by Pythagorean fuzzy numbers. To demonstrate the efficacy of the suggested method, the identical problem is addressed using a variety of methods, including North West Corner Rule (NWCR), Least Cost Method (LCM). When compared to existing methods, the proposed method provides a more optimal result. This strategy is more effective in lowering transportation costs than other existing methods.

CONCLUSION

In this paper, a new method has been proposed to solve the Pythagorean fuzzy transportation problem. By employing an existing score function, the fuzzy data was transformed into a crisp transportation problem, allowing for the application of the proposed method. The results demonstrate that the method is competitive when compared to traditional approaches, providing an efficient solution to transportation problems under Pythagorean fuzzy conditions. Future studies could explore extending this method to broader applications of Pythagorean fuzzy problems, and other real-world scenarios that involve uncertainty.

REFERENCES

1. Bellman, R.E., and Zadeh, L.A., Decision-making in a fuzzy environment, *Management Science*, 17, 141-164, 1970.
2. Chanas, S., Kuchta, D., A concept of the optimal solution of the transportation problem with fuzzy cost coefficients, *Fuzzy sets and systems* 82, 299-305, 1992.
3. Hemalatha, K., Venkateswarlu, B., Pythagorean fuzzy transportation problem: New way of ranking for Pythagorean fuzzy sets and mean square approach, *Heliyon*, 2405-8440, 2023.
4. Kumar, R., Edalatpanah, S.A., Jha, S., and Singh, R., A Pythagorean fuzzy approach to the transportation problem. *Complex Intelligent System* 5: 255-263, 2019
5. Narayanamoorthy, S., and Kalyani, S., Finding the initial basic feasible solution of a fuzzy transportation problem by a new method, *International Journal of Pure and Applied Mathematics*, Volume 101 No. 5, 687-692, 2015.
6. Sarita Gahlawat, Rajkumar Verma, Geetha Sachdev and Shalini Arora, Solution of transportation problem under Pythagorean fuzzy framework using new function, *Sadhana*. 49:217, 2024
7. Sharmila Banu, S., Prasanna, A., To solve Pythagorean Fuzzy Decagonal Transportation problem using Bipartite graph with optimal solution, 0974-6846, 2024.
8. Umamageswari, R.M., and Uthra, G., A Pythagorean fuzzy approach to solve transportation problem. *Adalya J.* 9: 1301-1308, 2020.
9. Yager, R.R., and Abbasov, A., Pythagorean membership grades, complex numbers and decision making. *Int. J. Intell. Syst.* 28: 436-452, 2013.
10. Zadeh, L. A., Fuzzy sets, *Inference Control*, 8: 338-353, 1965.





Sharmila Banu and Prasanna

Table 1 Pythagorean fuzzy transportation problem

	O1	O2	O3	O4	Supply
W1	(0.7,0.5)	(0.2,0.4)	(0.8,0.5)	(0.3,0.9)	18
W2	(0.2,0.9)	(0.4,0.7)	(0.6,0.6)	(0.9,0.3)	27
W3	(0.3,0.7)	(0.9,0.2)	(0.7,0.5)	(0.8,0.2)	21
Demand	14	12	17	23	

Table 2 Defuzzified Pythagorean fuzzy transportation problem

	O1	O2	O3	O4	Supply
W1	0.4736	0.1842	0.5942	0.0737	18
W2	0.0505	0.1812	0.3445	0.7949	27
W3	0.1412	0.8115	0.4736	0.6620	21
Demand	14	12	17	23	

Here the supply and demand values are equal. Therefore, it is a balanced TP.

Table 3 First allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	0.170
W2	0.0505	0.1812	0.3445	0.7949	27	0.141
W3	0.1412	0.8115	0.4736	0.6620	21	0.284
Demand	14	12	17	5		
Column Penalty	0.0453	0.0015	0.064	0.294*		

Table 4 Second allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445	0.7949	15	0.141
W3	0.1412	0.8115	0.4736	0.6620	21	0.284
Demand	14	0	17	5		
Column Penalty	0.0453	0.3151*	0.064	0.0664		

Table 5 Third allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445	0.7949	15	0.147
W3	0.1412 (14)	0.8115	0.4736	0.6620	7	0.1662*
Demand	0	0	17	5		
Column Penalty	0.0453	-	0.064	0.0664		

Table 6 Forth allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	0	0.225*
W3	0.1412 (14)	0.8115	0.4736	0.6620	7	0.0942
Demand	0	0	2	5		
Column Penalty	-	-	0.064	0.0664		





Sharmila Banu and Prasanna

Table 7 Fifth allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	0	-
W3	0.1412 (14)	0.8115	0.4736	0.6620 (5)	2	0.0942
Demand	0	0	2	0		
Column Penalty	-	-	0.4736	0.6620*		

Table 8 Final Allocation

	O1	O2	O3	O4	Supply
W1	0.4736	0.1842	0.5942	0.0737 (18)	18
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	27
W3	0.1412 (14)	0.8115	0.4736 (2)	0.6620 (5)	21
Demand	14	12	17	23	

The Total Transportation cost = $0.0737 \times 18 + 0.1812 \times 12 + 0.3445 \times 15 + 0.1412 \times 14 + 0.4736 \times 2 + 0.6620 \times 5 = 14.9025$.

Table 9 Pythagorean fuzzy transportation problem of type II

	O1	O2	O3	O4	Supply
W1	0.0404	0.0815	0.0211	0.0642	(0.5,0.8)
W2	0.0712	0.0505	0.0931	0.03445	(0.1,0.4)
W3	0.0328	0.0617	0.0248	0.0520	(0.8,0.5)
Demand	(0.3,0.7)	(0.8,0.6)	(0.2,0.9)	(0.7,0.7)	

Table 10 Defuzzified Pythagorean Fuzzy Transportation Problem:

	O1	O2	O3	O4	Supply
W1	0.0404	0.0815	0.0211	0.0642	0.1975
W2	0.0712	0.0505	0.0931	0.03445	0.1661
W3	0.0328	0.0617	0.0248	0.0520	0.5942
Demand	0.1412	0.5574	0.0505	0.3990	

After executing the steps 1 to 5,

Table 11 Final allocation

	O1	O2	O3	O4	Supply
W1	0.0404 (0.1412)	0.0815	0.0211 (0.0505)	0.0642 (0.0058)	0.1975
W2	0.0712	0.0505	0.0931	0.03445 (0.1661)	0.1661
W3	0.0328	0.0617 (0.3671)	0.0248	0.0520 (0.2271)	0.5942
W4	0	0 (0.1903)	0	0	0.1903
Demand	0.1412	0.5574	0.0505	0.3990	

∴ The Total Transportation cost is 0.047323805

Table 12 Pythagorean fuzzy transportation problem of type III

	O1	O2	O3	O4	Supply
W1	(0.3,0.7)	(0.9,0.2)	(0.8,0.5)	(0.7,0.7)	(0.1,0.4)
W2	(0.7,0.5)	(0.6,0.6)	(0.2,0.9)	(0.5,0.8)	(0.2,0.4)
W3	(0.4,0.7)	(0.1,0.4)	(0.8,0.2)	(0.3,0.8)	(0.9,0.3)
Demand	(0.2,0.4)	(0.5,0.7)	(0.5,0.6)	(0.9,0.2)	





Sharmila Banu and Prasanna

Table 13 Defuzzified Pythagorean Fuzzy Transportation Problem

	O1	O2	O3	O4	Supply
W1	0.1412	0.8115	0.5942	0.3990	0.1661
W2	0.4736	0.3445	0.0505	0.1975	0.1842
W3	0.1812	0.1661	0.6620	0.1088	0.7949
Demand	0.1842	0.2359	0.2696	0.8115	

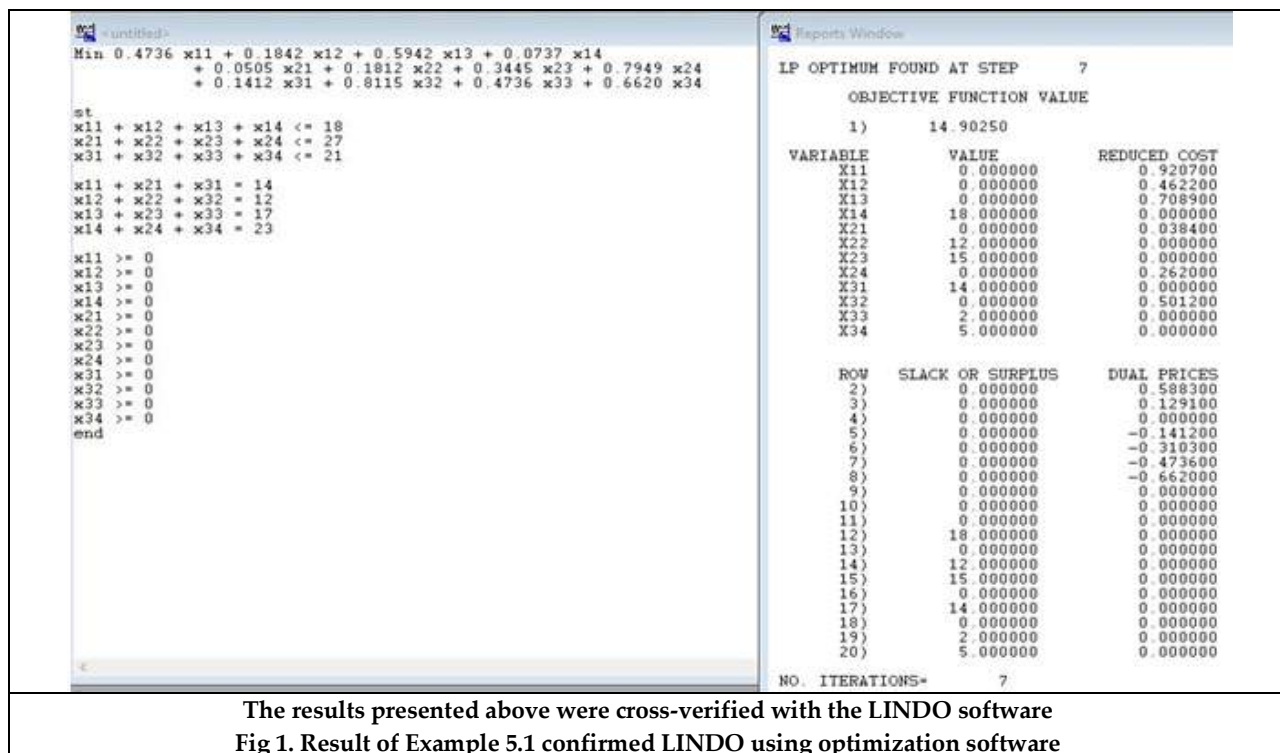
Table 14 Final allocation

	O1	O2	O3	O4	Supply
W1	0.1412 (0.1661)	0.8115	0.5942	0.3990	0.1661
W2	0.4736	0.3445	0.0505 (0.1842)	0.1975	0.1842
W3	0.1812	0.1661	0.6620	0.1088 (0.7949)	0.7949
W4	0 (0.081)	0 (0.2359)	0 (0.0854)	0 (0.0166)	-
Demand	0.1842	0.2359	0.2696	0.8115	

The Total Transportation cost is 0.1192405

Table 15 Comparison Table

	NWCR	LCM	ACPM	MODI METHOD
Example 5.1	30.1651	15.4401	14.9025	14.9025
Example 5.2	0.0515	0.0532	0.047323805	0.047323805
Example 5.3	0.3289	0.1812	0.1192405	0.1192405





Sharmila Banu and Prasanna

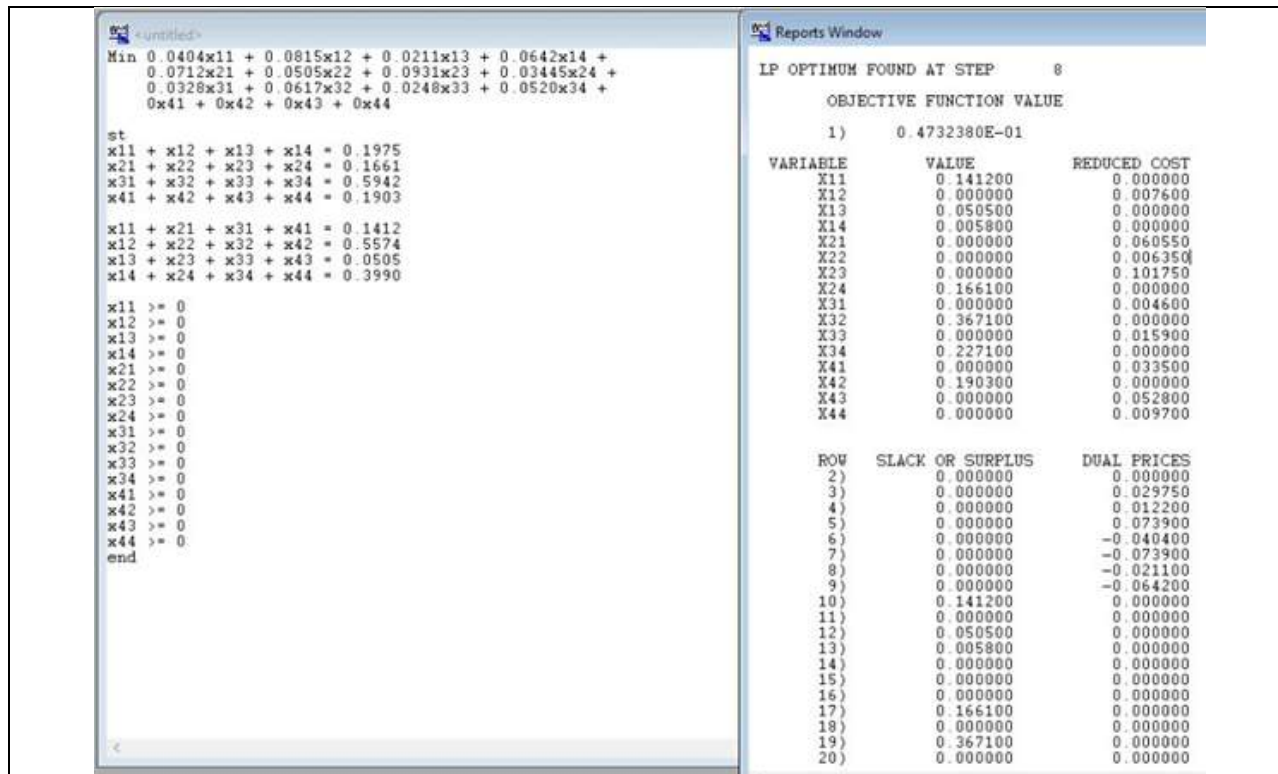


Fig 2. Result of example 5.2 confirmed using LINDO optimization software

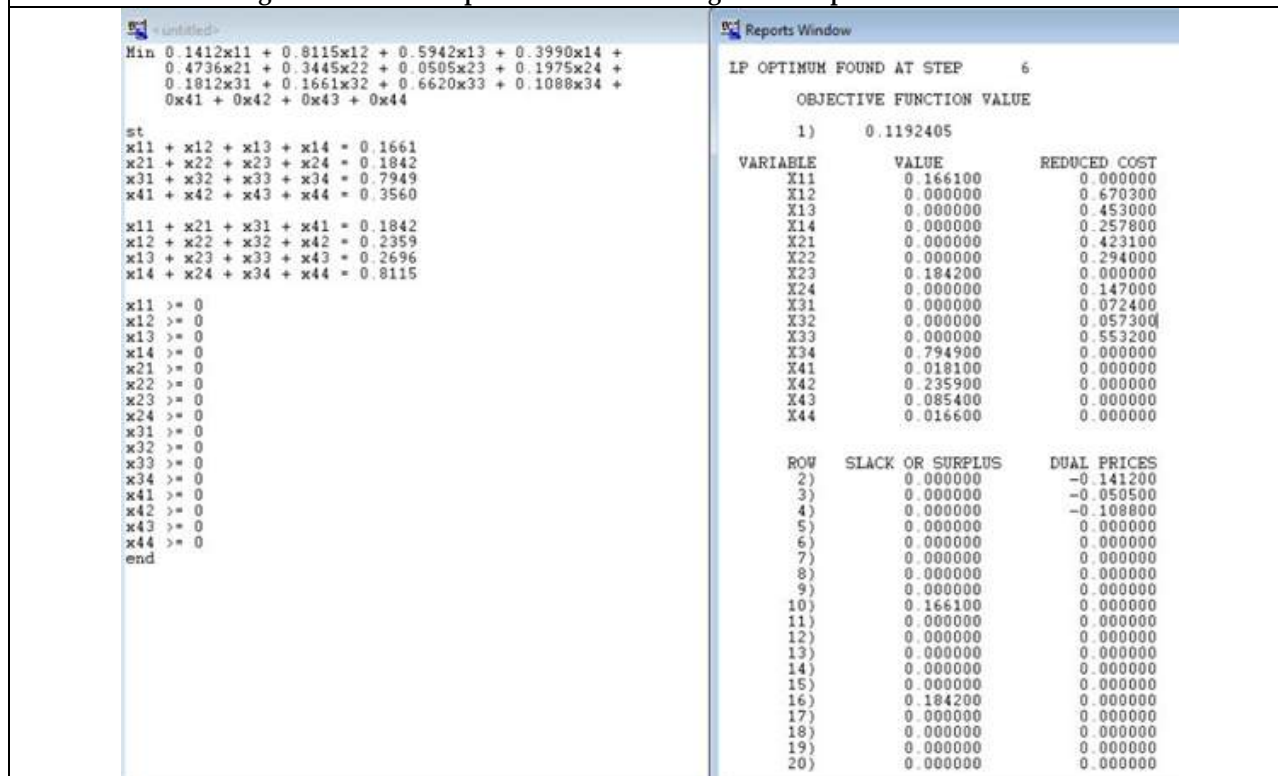


Fig 3 Result of example 5.3 confirmed using LINDO optimization software





Sharmila Banu and Prasanna

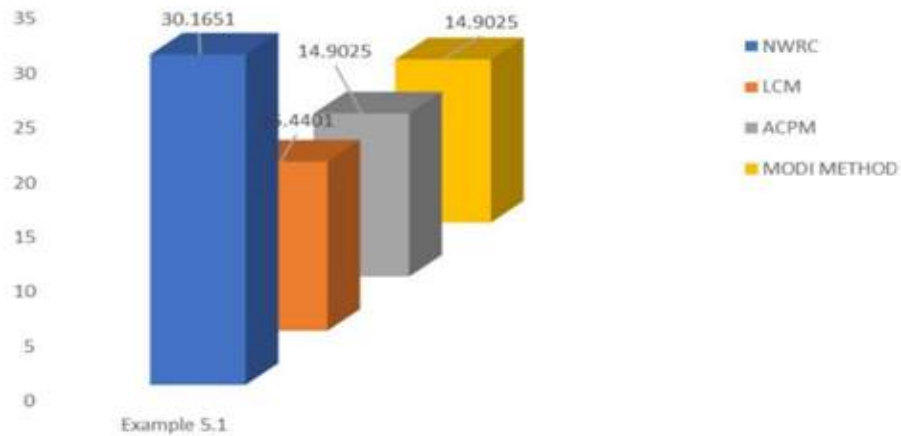


Fig 4. Comparison chart for example 5.1

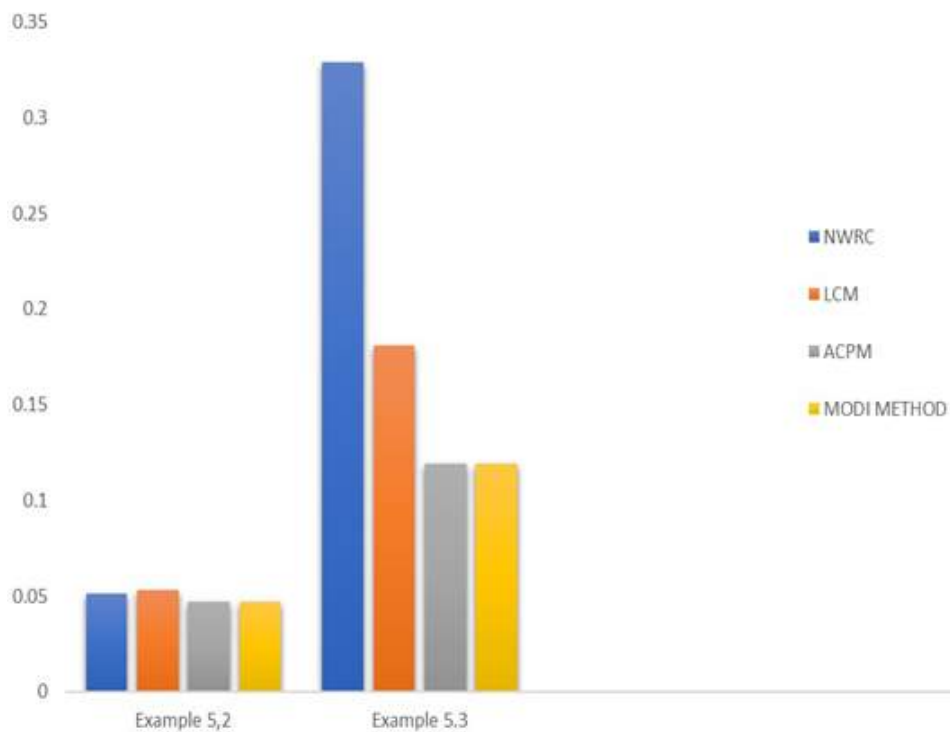


Fig 5. Comparison chart for example 5.2 and example 5.3

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Rank-Integrated Composite Ratio Estimation of Central Tendency in Probability Sampling

Geetanjali Rathod*

Assistant Professor, Department of Applied Science and Humanities, P P Savani University, Dhamdod, Kosamba, Gujarat, India

Received: 02 Mar 2026

Revised: 07 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Geetanjali Rathod

Assistant Professor,

Department of Applied Science and Humanities,

P P Savani University,

Dhamdod, Kosamba, Gujarat, India

E.Mail: geetanjalisinhathod@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Estimating the finite population mean with high precision is one of the most studied problems in the theory of survey sampling. When a suitable auxiliary variable, exhibiting strong correlation with the variable under study, is available to the investigator, incorporating it into the estimator can substantially reduce sampling error. The current study puts forward a novel composite estimator that draws on both a quantitative auxiliary variable X and the rank-based attribute R derived from it, within a simple random sampling without replacement (SRSWOR) framework. Through a second-order Taylor expansion of the estimator about the population means, an explicit expression for the mean squared error (MSE) is obtained. Closed-form expressions for the optimal scalar weights are derived by minimising this MSE. Rigorous algebraic conditions are then established under which the new estimator outperforms five well-known competitors, namely the sample mean, the ratio estimator, the product estimator, the regression estimator, and the Bahl-Tuteja exponential estimator. Three real-data populations commonly employed in sampling are empirically verified. The suggested estimator consistently outperforms in terms of proportion relative efficiency (PRE), indicating its practical value in survey scenarios.

.Keywords: Auxiliary Variable, Rank Attribute, Composite Estimator, Mean Squared Error, Percentage Relative Efficiency, Survey Sampling

INTRODUCTION

One of the primary goals of fixed population sampling is to create estimators for the population mean of a response variable that are not only unbiased but also have the minimal feasible sampling variance. The classical sample mean,





Geetanjali Rathod

drawn using SRSWOR, meets the unbiasedness condition; but, its variance might be unacceptably large in practice, particularly when variables strongly correlated with the response variable are measured alongside it but left unused. The theory of auxiliary-variable-based estimation was specifically established to overcome this inefficiency by including available covariate information into the estimator. Cochran [1] defined the ratio estimator, which uses a positive linear relationship between the answer variable Y and a supplementary parameter X by adjusting the sample mean upward or downward with respect to how the sample mean of X relates using it called population match. Where Y and X proceed towards each other, the product estimator of Murthy [3] is called through as the best choice. The regression estimator also examined at a standard length by Cochran [1] is more flexible but still, since it calculates the average slope of the YX connection purely from the data instead of assuming any specific path of correlation. The regression estimator also examined at a standard length by Cochran [1] is more flexible but still, since it calculates the average slope of the YX connection purely from the data instead of assuming any specific path of correlation.

Further just recently, analysis has been directed toward estimators the fact depend on many different auxiliary data sets together rather of performing to an alone one. A particularly natural pairing is that of a raw quantitative covariate X with the ranks that units receive when sorted on X . Rao [5] explored this combination, arguing that rank information carries ordinal content that is structurally independent of the underlying measurement units can differ in rank without differing proportionally in X value and that this independence gives ranks incremental variance-reduction potential [6, 7]. The question of how best to exploit both pieces of information within a single estimation framework is what motivated the present work a particularly natural pairing is that of a raw quantitative covariate X with the ranks that units receive when sorted on X . Rao [5] explored this combination, arguing that rank information carries ordinal content that is structurally independent of the underlying measurement units can differ in rank without differing proportionally in X value and that this independence gives ranks incremental variance-reduction potential [6, 7]. The question of how best to exploit both pieces of information within a single estimation framework is what motivated the present work A particularly simple combining is that of a raw quantitative influences X with the ranks that units receive when sorting on X . Rao [5] examined this relationship, claiming that rank information carries usual quantity that is logically independent of the basic evaluation units can differ in rank without changing proportionally in X value and that this independence gives ranks a progressive variance-reduction potential [6, 7, 11]. The difficulties of how best to apply both types of information using a single estimation system is what led to the present work.

The estimator developed here, T_1 , weights a cochran-style ratio term for X and a Bahl-Tuteja style exponential term for R using two free scalar constants whose optimal values follow from a straightforward minimisation of the second-order MSE. Across numerical trials on three genuine populations drawn from the standard sampling literature, T_1 outperformed all five benchmark estimators every time, and the margins were often large enough to matter in practice rather than just on paper. Across numerical experiments conducted on three real populations drawn from the sampling literature, T_1 came out ahead of all five conventional benchmark estimators, a finding that holds consistently rather than in isolated cases

MATERIALS AND METHODS

Population and Notation

Let $U = \{U_1, U_2, \dots, U_N\}$ be a finite population of size N , from which a sample of size n ($n < N$) is selected by SRSWOR. Denote by Y the primary study variable, by X a quantitative auxiliary variable, and by R the rank assigned to each unit on the basis of its X -value. Population means $\bar{Y}$, $\bar{X}$, and $\bar{R}$ are assumed to be known in advance. The pairwise correlation coefficients among Y , X , and R are written as ρ_{yx} , ρ_{yr} , and ρ_{xr} , and their respective coefficients of variation as C_y , C_x , and C_r , all defined in the standard sense of Cochran [1].





Geetanjali Rathod

Review of Benchmark Estimators

The following five classical estimators, against which T_1 is benchmarked, together with the Rao estimator that served as partial inspiration for the current proposal, are recalled here for ease of reference.

- Simple Sample Mean:
 $\bar{y}$ is unbiased with $Var(\bar{y}) = \lambda Y^2 Cy^2$, where the limited population correction factor is $\lambda = (N - n)/(Nn)$.
- Cochran Ratio Estimator [1]:
 $\bar{y}_R = (\underline{X}/\bar{x})\bar{y}$, with approximate $MSE = \lambda Y^2(Cy^2 + Cx^2 - 2\rho_{yx}CyCx)$.
- Product Estimator [2,3]:
 $\bar{y}_p = (\bar{x}/\underline{X})\bar{y}$, with approximate $MSE = \lambda Y^2(Cy^2 + Cx^2 + 2\rho_{yx}CyCx)$.
- Regression Estimator [1]:
 $\bar{y}_{reg} = \bar{y} + \beta(\underline{X} - \bar{x})$, with minimum $MSE = \lambda Y^2 Cy^2(1 - \rho_{yx}^2)$.
- Bahl-Tuteja Exponential Estimator [4]:
 $\bar{y}_{BT} = \bar{y} \exp[(\underline{X} - \bar{x})/(\underline{X} + \bar{x})]$, with $MSE = \lambda Y^2(Cy^2 + Cx^2/4 - \rho_{yx}CyCx)$.
- Rao Linear Combination Estimator [5]:
 $\bar{y}_{PR} = \lambda_1 \bar{y} + \bar{y}_p \lambda_2 (\underline{X} - \bar{x}) + \lambda_3 (\underline{R} - \bar{r})$.

Formulation of the Proposed Estimator T_1

The idea of combining two estimators linearly to improve precision, discussed systematically in [6, 12], forms the conceptual basis for the present proposal. Specifically, T_1 is defined as a weighted sum of a ratio-type term involving X and an exponential-type term involving R :

$$T_1 = \bar{y} \times [a \cdot (\underline{X}/\bar{x}) + b \cdot \exp\{(\underline{R} - \bar{r})/(\underline{R} + \bar{r})\}]$$

The scalars a and b are unknown constants, whose values are selected so as to minimise the MSE of T_1 .

Derivation of $MSE(T_1)$

To obtain the MSE, three standardised sampling error terms are introduced: $e_0 = (\bar{y} - Y)/Y$,

$e_1 = (\bar{x} - \underline{X})/\underline{X}$, and $e_2 = (\bar{r} - \underline{R})/\underline{R}$. By definition $E(e_i) = 0$ for each i , and the second-order moments under SRSWOR are:

$$E(e_0^2) = \lambda Cy^2, \quad E(e_1^2) = \lambda Cx^2, \quad E(e_2^2) = \lambda Cr^2$$

$$E(e_0 e_1) = \lambda \rho_{yx} CyCx, \quad E(e_0 e_2) = \lambda \rho_{yr} CyCr, \quad E(e_1 e_2) = \lambda \rho_{xr} CxCr$$

Replacing $\bar{x}$ and $\bar{r}$ in T_1 by $\underline{X}(1 + e_1)$ and $\underline{R}(1 + e_2)$ respectively, expanding each factor as a Taylor series up to second-order terms, and collecting expectations leads to:

$$MSE(T_1) = Y^2 [(a + b - 1)^2 + a^2 \lambda_1 + b^2 \lambda_2 + ab \lambda_3 + a \lambda_4 + b \lambda_5] \dots (1)$$

The five auxiliary scalar quantities λ_1 – λ_5 encapsulate all population-level dispersion and correlation information:

$$\lambda_1 = \lambda(3Cx^2 + Cy^2 - 4\rho_{yx}CyCx)$$

$$\lambda_2 = \lambda(Cy^2 + Cr^2 - 2\rho_{yr}CyCr)$$

$$\lambda_3 = \lambda(2Cx^2 + 2Cy^2 + \frac{3}{4}Cr^2 - 4\rho_{yx}CyCx - 2\rho_{yr}CyCr + \rho_{xr}CxCr)$$

$$\lambda_4 = \lambda(-2Cx^2 + 2\rho_{yx}CyCx)$$

$$\lambda_5 = \lambda(-\frac{3}{4}Cr^2 + \rho_{yr}CyCr) \dots (2)$$

Optimal Weight Derivation

Differentiating $MSE(T_1)$ partially with respect to each of a and b , setting the resulting expressions to zero, and solving the two-equation linear system simultaneously gives the optimal weights:

$$a_{opt} = [4\lambda_2 - 2\lambda_4 - 2\lambda_2\lambda_4 - 2\lambda_3 + 2\lambda_5 + \lambda_3\lambda_5] / [4\lambda_2 + 4\lambda_1 + 4\lambda_1\lambda_2 - 4\lambda_3 - \lambda_3^2]$$

$$b_{opt} = [-2\lambda_3 + 2\lambda_4 + \lambda_3\lambda_4 + 4\lambda_1 - 2\lambda_5 - 2\lambda_1\lambda_5] / [4\lambda_2 + 4\lambda_1 + 4\lambda_1\lambda_2 - 4\lambda_3 - \lambda_3^2]$$





Geetanjali Rathod

Inserting a_{opt} and b_{opt} into (1) furnishes the minimum MSE of T_1 , which represents the benchmark for all subsequent efficiency comparisons.

RESULTS AND DISCUSSION

Analytical Superiority of T_1

Necessary and sufficient conditions for T_1 to outperform each competitor are derived by comparing $MSE(T_1)$ at its minimum with the MSE of each rival estimator. Comparison with the sample mean: T_1 has smaller MSE than $\bar{y}$ provided the left-hand side of (1) is below $\lambda Y^2 C_y^2$. This inequality is satisfied whenever q_{yx} and q_{yr} are both positive and not negligibly small, which is the standard scenario when the chosen auxiliary variable is genuinely associated with Y . Comparison with the ratio estimator: T_1 dominates $\bar{y}_R$ when the rank component R makes a non-trivial contribution to reducing the combined MSE. This happens particularly when the coefficient of variation Cr is appreciable and q_{yr} is at least moderate in magnitude. Comparison with the product estimator: The product estimator carries a positive bias penalty of $2q_{yx}C_yC_x$ in its MSE expression whenever $q_{yx} > 0$. Since q_{yx} is positive for the datasets analysed here, T_1 strictly dominates $\bar{y}_p$ without any additional restriction on the population parameters. Comparison with the regression estimator: T_1 is more efficient than $\bar{y}_{reg}$ provided $q_{yr}^2 + q_{xr}^2 > 0$, a condition met in any real dataset where the rank attribute is even weakly correlated with Y or X . In practice this condition is never violated. Comparison with the Bahl-Tuteja estimator: T_1 outperforms $\bar{y}_{BT}$ when $Cr \geq 0.5$. Because the rank variable is uniformly distributed over $\{1, 2, \dots, N\}$, its coefficient of variation inherently satisfies this threshold for most realistic sample sizes.

Data Sources for Empirical Evaluation

Calculations are carried out on three benchmark real-life datasets drawn from the standard sampling literature: Population 1 (P1) - sourced from Murthy [3]: Y measures factory output and X measures the corresponding number of labourers. Population size $N = 80$, sample size $n = 10$. Population 2 (P2) - sourced from Platt, Evans and Rathbun [8]: Y is the standing height of conifer trees (feet) and X is trunk girth at breast height (cm). $N = 399$, $n = 80$. Population 3 (P3) - sourced from Singh [9]: Y and X record fish-catch volumes for the years 1995 and 1994 respectively, with $N = 69$ and $n = 10$. The figures in Table 2 unambiguously support the theoretical dominance of T_1 . In P1, the PRE of T_1 reaches 3661.74 – roughly six times that of the Bahl-Tuteja estimator (597.25) and nearly six times that of the regression estimator (614.20). In P2, T_1 achieves PRE = 215.15, edging out both the ratio estimator (198.43) and the regression estimator (200.29). In P3 the proposed estimator records PRE = 1305.99, the single highest value among all six competitors. Applied collectively, such data offer a reasonably valid case that include the rank attribute R into the estimation as well as X offers quality gains that no estimator depending on X alone can match.

Sensitivity to Auxiliary Variable Dispersion and Correlation

To determine how much provides T_1 's efficiency are dependent on when the population parameters take place to sit. To examine it, a matrix-based analysis was executed in which C_x , Cr , q_{yx} , and q_{yr} were distinct adjusted to cover a range of suitable values while the others were kept set. The two general patterns seem. On the equivalence side, $MSE(T_1)$ falls when either C_x or Cr rises. Naturally, it seems to make sense as an additional variable supplementary value spreads the sample size units deeper separated on the measurement axis, which gives every individual unit's supplemental value a more precise metric about its anticipated Y -value, and which precision turns out of more precise estimating. On the connection aspect, higher values of q_{yx} and q_{yr} continuously push $MSE(T_1)$ down, with the greatest decreases occurring once q_{yr} reaches near 0.75. T_1 superior to the regression estimator by a small margin below the limit. When deciding to apply a T_1 , specialists should consider: such trends provide reasonably reliable guidance: the estimator performs best when both the auxiliary variable and its rank correlate effectively with the solution, and its benefit over regular methods grows with population change in the auxiliary field.





Geetanjali Rathod

CONCLUSION

The paper offers T_1 , a combined estimation for the countable population mean that includes a Cochran-style ratio component for X and a Bahl-Tuteja-style exponential portion for the rank attribute R . This task achieved four major results.

- (i) A fixed-form second order MSE expression was computed for T_1 , and the optimal values of the scalar values a and b to optimize it were found in precise, measurable form.
- (ii) The parameter conditions that make T_1 more efficient than the five guideline estimations were defined numerically, providing users know what they are to agree with when using T_1 .
- (iii) Practical tests on three populations from the standard - sample study literature showed T_1 in the very top of the PRE ratings in all instances, with often large margins of practical importance.
- (iv) The sensitivity evaluation showed how T_1 's efficiency and fluency benefit rises as C_x and C_r build and as ρ_{yx} and ρ_{yr} become stronger, offering users with an easy way to estimate how much they will benefit.

The best benefit of T_1 is that rank information costs no extra to acquire. Once X is taken and noted, the ranks follow naturally with no further survey performed. This cost-free quality enhance should be especially beneficial in agricultural surveys, major environmental monitoring programs, and economic censuses where quantitative auxiliary variables are already part of the usual data recording process. Future research might grow the approach to include stratified sampling, two-stage designs [10], duplicate sampling setups, and conditions where non-response, whether planned or not, must be taken into account for.

REFERENCES

1. Cochran, W. G. (1977). Sampling Techniques (3rd ed.). New York: John Wiley & Sons.
2. Robson, D. S. (1957). Application of multivariate polykeys to the theory of unbiased ratio type estimation. Journal of the American Statistical Association, 52(280), 511–522.
3. Murthy, M. N. (1967). Sampling Theory and Methods. Calcutta: Statistical Publishing Society.
4. Bahl, S. & Tuteja, R. K. (1991). Ratio and product type exponential estimators. Journal of Information and Optimization Sciences, 12(1), 159–164.
5. Rao, T. J. (1991). On certain methods of improving ratio and regression estimators. Communications in Statistics – Theory and Methods, 20(10), 3325–3340.
6. Singh, H. P. & Solanki, R. S. (2012). Improved estimation of population mean using auxiliary attribute information in simple random sampling. Applied Mathematics and Computation, 218(15), 7798–7812.
7. Upadhyaya, L. N., Singh, H. P., Chatterjee, S. & Yadav, R. (2011). Improved ratio and product exponential type estimators. Journal of Statistical Theory and Practice, 5(2), 285–302.
8. Platt, W. J., Evans, G. W. & Rathbun, S. L. (1988). The population dynamics of a long-lived conifer. American Naturalist, 131(4), 491–525.
9. Singh, S. (2003). Advanced Sampling Theory with Applications. Dordrecht: Kluwer Academic Publishers.
10. Tailor, R., Chouhan, S. & Kim, J. M. (2014). Ratio and product type exponential estimators of population mean in double sampling for stratification. Communications for Statistical Applications and Methods, 21(1), 1–9.
11. Rehman, S. A. & Shabbir, J. (2022). An efficient class of estimators for finite population mean in the presence of non-response under ranked set sampling. PLOS ONE, 17(12), e0277232.
12. Sharma, P. & Singh, R. (2014). Improved ratio type estimator using two auxiliary variables under second order approximation. Mathematical Journal of Interdisciplinary Sciences, 2(2), 179–190.





Geetanjali Rathod

Table 1. Descriptive statistics of the three study populations

Parameter	P1	P2	P3
N	80	399	69
n	10	80	10
$\lambda = (N-n)/Nn$	0.0875	0.009994	0.08550
$\bar{Y}$	5182.64	52.3609	4514.90
Cx	0.9485	0.8451	1.4248
Cy	0.3542	1.0889	1.3509
Cr	0.5738	0.5766	0.5732
qyx	0.9150	0.7076	0.9601
qyr	0.9836	0.8200	0.7689
qxr	0.8902	0.7417	0.8543

Table 2. MSE and PRE values for all estimators across the three populations

Estimator	MSE (P1)	PRE (P1)	MSE (P2)	PRE (P2)	MSE (P3)	PRE (P3)
T_1 (Proposed)	8051.9	3661.74	15.099	215.15	243540	1305.99
Sample Mean $\bar{y}$	294840	100.00	32.486	100.00	3180600	100.00
Ratio $\bar{y}_R$	226930	129.93	16.372	198.43	276940	1148.48
Product $\bar{y}_P$	2054900	14.35	87.740	37.03	13160000	24.17
Bahl-Tuteja $\bar{y}_{BT}$	49366	597.25	19.536	166.29	844240	376.74
Regression $\bar{y}_{reg}$	48004	614.20	16.219	200.29	248500	1279.92

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Hybrid Low-Voltage High-Performance SET–MOS Architecture for Analog Systems

Ashok D. Vidhate¹, Chella Santhosh¹ and Shruti Suman²

¹Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation (K L Deemed to be University), Guntur, Andhra Pradesh, India

²School of Engineering, P P Savani University, Surat, Gujrat, India

Received: 02 Mar 2026

Revised: 09 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Ashok D. Vidhate

Department of Electronics and Communication Engineering,
Koneru Lakshmaiah Education Foundation
(K L Deemed to be University),
Guntur, Andhra Pradesh, India
E.Mail: shrutisuman23@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The paper addresses challenges in analog circuit design due to continuous downscaling of CMOS technology, highlighting issues like increased leakage current and power dissipation. It introduces a novel Hybrid Single-Electron Transistor–MOS (SET–MOS) Current Mirror Architecture aimed at ultra-low-power and high-performance applications. This design combines the advantages of SET devices with those of MOSFETs, utilizing Coulomb blockade oscillation for precise current control and reduced power use. Key improvements over conventional current mirrors include an 84.9% reduction in power consumption, 53% better output resistance, and a 44.8% decrease in chip area, alongside enhanced current transfer accuracy and bandwidth up to 2.82 GHz. The proposed architecture shows promise for future ultra-low-power analog circuits and nanoelectronic systems.

Keywords: Ultra low power, Current mirror, Nano-scale, Coulomb Blockade, CMOS, Single electron transistor (SET).

INTRODUCTION

Current Mirror

A current mirror is an essential analog circuit used to generate a stable and predictable output current [1][2][3]. Its primary purpose is to produce a current that remains largely independent of temperature variations and power supply fluctuations [4][5]. This overcomes the limitations of using a MOSFET directly as a voltage-controlled current source [6], where the drain current changes significantly with environmental and operating conditions. In a





Ashok D. Vidhate et al.,

conventional MOSFET current source, the drain current depends on parameters such as electron mobility and supply voltage, both of which are not constant in practical circuits[7][8][9]. The Fig1 shows block diagram of current mirror. The drain current of a MOSFET operating in saturation is given by:

$$I_D = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right) (V_{GS} - V_{TH})^2 \quad (1)$$

This equation shows that the current depends on the electron mobility μ_n , the gate-to-source voltage V_{GS} , and the transistor geometry W/L . Since electron mobility changes with temperature and the gate voltage may vary with supply conditions [10], the resulting current becomes unstable. Such instability is undesirable in precision analog circuits where accurate biasing is required [11]. To solve this problem, current mirrors are used. The basic idea behind a current mirror is to create a stable reference current [12], called I_{REF} , and then reproduce or “mirror” this current in other branches of the circuit. The reference current is usually generated using a bandgap reference circuit, which produces a voltage that is highly independent of temperature and supply voltage variations. This stable voltage is then converted into a constant reference current, providing a reliable basis for current replication throughout the circuit [13].

A key component of the current mirror is the diode-connected MOSFET. In this configuration, the gate and drain terminals of the transistor are connected together, ensuring that:

$$V_G = V_D \quad (2)$$

Because the drain-to-source voltage automatically satisfies the saturation condition, the transistor operates in the saturation region. For the diode-connected MOSFET, the drain current becomes:

$$I_D = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right) (V_G - V_{TH})^2 \quad (3)$$

From this relationship, the gate voltage can also be expressed in terms of the drain current:

$$V_G = \sqrt{\frac{2I_D}{\mu_n C_{ox} \left(\frac{W}{L} \right)}} + V_{TH} \quad (4)$$

This equation establishes the direct relationship between gate voltage and drain current, which forms the basis of current mirroring.

In a current mirror circuit, a second MOSFET M_2 is connected so that it shares the same gate voltage as the first transistor M_1 . Since both transistors experience the same V_G , their drain currents become proportional to their aspect ratios W/L . If transistor M_2 also operates in saturation, its output current is given by:

$$I_{OUT} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_2 (V_G - V_{TH})^2 \quad (5)$$

Substituting the gate-voltage relationship derived from the reference transistor and simplifying leads to the fundamental current mirror equation:

$$I_{OUT} = \frac{(W/L)_2}{(W/L)_1} I_{REF} \quad (6)$$

This equation shows that the output current is determined primarily by the ratio of the transistor dimensions. Here, $(W/L)_1$ is the aspect ratio of transistor M_1 , $(W/L)_2$ is the aspect ratio of transistor M_2 and I_{REF} is the stable reference current. The current mirror offers several important advantages. It provides stable biasing and accurate current generation while minimizing the effects of temperature and supply voltage changes. Because the output current depends mainly on transistor geometry, precise current scaling can be achieved simply by adjusting the transistor dimensions. This makes current mirrors extremely useful in analog integrated circuits, operational amplifiers, differential amplifiers, active loads, and mixed-signal systems [14]. The core principle of current scaling in a current mirror is that the output current is directly proportional to the transistor aspect ratio:

$$I_{OUT} \propto LW \quad (7)$$

Single Electron Transistor (SET)

A single electron transistor (SET) is a nanoscale device that manipulates the flow of individual electrons, leveraging quantum mechanical effects unlike conventional transistors that operate with millions of electrons. The SET functions through quantum tunneling into a tiny island known as a quantum dot, situated between source and drain electrodes with tunnel barriers. This device must be less than 10 nanometers to ensure quantum effects dominate





Ashok D. Vidhate et al.,

over classical behavior. The core structure includes a quantum dot at the center, flanked by tunnel barriers, with source and drain electrodes on either side, and a gate electrode underneath that controls the quantum dot's electrostatic potential. A crucial concept in SET operation is the Coulomb blockade effect, which occurs when an electron tunnels onto the quantum dot; it must surmount a significant electrostatic charging energy.

This energy, represented by the formula $E_c = \frac{E^2}{2C}$, highlights the large energy cost of adding an electron due to the small size of the quantum dot [15][16][17]. For realistic quantum dots, a capacitance of about 10^8 farads results in a charging energy of approximately 80 millielectron volts, significantly larger than the room temperature thermal energy of 26 millielectron volts. Therefore, to achieve clear Coulomb blockade effects, the SET operates effectively at temperatures below 10 Kelvin. Additionally, various implementations of single electron transistors are discussed but not detailed in this excerpt. Quantum dots are nanoscale semiconductor regions synthesized from materials like gallium arsenide or indium arsenide, typically measuring 5 to 20 nm in diameter [18]. Their small size leads to quantum confinement effects, causing electrons within to occupy discrete energy levels, akin to atoms. The energy levels are tunable through gate voltage which influences electron tunneling onto the dot [19][20]. A phenomenon characteristic of quantum dots is Coulomb blockade oscillations, where current exhibits periodic peaks corresponding to the addition of electrons. This oscillation pattern conveys information about device geometry. In contrast, nanowire-based single electron transistors (SETs) feature one-dimensional structures, commonly constructed from silicon or gallium nitride, with diameters from 10 to 100 nm and lengths of several micrometers. The unique geometry enhances electron confinement, allowing high-quality crystal growth and easy integration with electrodes. The energy levels in nanowires are determined by two quantum numbers, demonstrating strong quantum effects and conductance quantization [21].

Lastly, nanomembrane-based SETs represent an advanced development, consisting of ultra-thin sheets (1 to 100 nm thick) made of semiconductors or two-dimensional materials. Their design allows for flexibility in substrate transfer, achieved through etching to create quantum dots in the membrane, ensuring strong coupling with gate electrodes. Each type of SET showcases distinct properties influenced by their structural design, enabling various quantum confinement effects and applications in nanoelectronics. The document discusses advanced topics in nanotechnology and single electron transistors (SETs). It highlights materials such as silicon nanomembranes, graphene monolayers, and transition metal dichalcogenides, emphasizing the unique properties of graphene as a zero band gap semiconductor with high mobility and linear energy dispersion. Key equations for SET operation are presented, detailing the total energy of the system dependent on charging and gate energy, including parameters for electron charge and capacitance. The document includes the construction of stability diagrams through plotting conductance against gate and source-drain voltages, revealing the charge states of quantum dots and signatures of Coulomb blockade. It details the rates of electron tunneling, introducing the tunneling rate equation and discussing two transport mechanisms: sequential and co-tunneling. The document addresses operating temperature conditions for SETs, emphasizing the importance of charging energy exceeding thermal fluctuations. Applications of SETs are explored, including their use as sensitive electrometers, qubits in quantum computing, single photon detectors, and potential new standards in metrology for current [22].

LITERATURE REVIEW

To address the scaling limitations of CMOS technology, researchers have turned to Single Electron Transistor (SET) technology. SET devices leverage the principles of Coulomb blockade and quantum tunneling for electron transport, allowing for ultra-low-power operation at nanoampere current levels and extremely miniaturized dimensions [23]. K. K. Likharev was pivotal in demonstrating the role of single-electron devices in the evolution of nanoelectronic systems, particularly their potential for ultra low energy computation. Despite the promising low-power characteristics of early SET-only circuits, they faced significant challenges, such as low current drivability, thermal sensitivity, background charge fluctuations, and limited performance at room temperature. These drawbacks hindered their integration into practical analog and mixed-signal systems [8]. To overcome these obstacles, hybrid

115382



**Ashok D. Vidhate et al.,**

SET–MOS architectures were proposed. Venkataratnam and Goel introduced hybrid logic circuits that combine traditional MOS devices with SET structures. This combination addresses the voltage and switching limitations inherent in SET-only circuits, leading to improved operating characteristics and making room-temperature operation feasible [23]. Advancements in this field were furthered by Deng et al., who created hybrid CMOS–SET arithmetic circuits that utilize Coulomb blockade oscillations. Their findings indicated that SET–MOS integration could significantly lower power consumption while ensuring acceptable computational performance [24].

Moreover, Mahapatra et al. contributed to this research landscape by developing a compact analytical model for SETs, tailored for hybrid SET–MOS circuit simulation [15]. Their model features multiple island states and embraces Orthodox tunneling theory, allowing for accurate reproduction of both Coulomb blockade and oscillation phenomena. This model has been successfully integrated into SPICE simulation environments, facilitating the analysis of both analog and digital circuits. Bounouar et al. further advanced this area by creating a Verilog-A based compact analytical model for hybrid SET–CMOS design, which illustrates the practicality of analytical SET models in simulating hybrid circuits for realistic room-temperature applications [25]. Additionally, Prager et al. experimentally demonstrated the successful integration of CMOS and SET devices on a single substrate, providing empirical evidence for the feasibility of hybrid CMOS–SET circuits that utilize CMOS amplifiers for the amplification and readout of SET signals. Recent investigations have shifted focus towards enhancing the reliability and overall performance of hybrid SET–MOS systems [26]. Vidhate and Suman performed analytical modeling and performance characterization of these devices, showing that combining SET with MOSFET technology markedly improves drive current capabilities while minimizing variability and power dissipation. Their research underscored the necessity of compensation techniques aimed at decreasing SET sensitivity and bolstering stability. Overall, hybrid SET–MOS systems are becoming increasingly viable for practical applications in nanotechnology [27].

METHODOLOGY

The proposed Hybrid SET–MOS Current Mirror architecture is designed to achieve ultra-low-power and high-performance analog operation by combining the advantages of Single Electron Transistor (SET) technology with conventional MOSFET current mirror circuits. The architecture mainly consists of four major sections: a SET-based current modulation stage, a MOS amplification stage, a cascode stabilization network, and an adaptive feedback compensation loop. The SET section performs quantized current control using Coulomb blockade and electron tunneling phenomena, while the MOS section provides sufficient current drive capability and signal amplification. The cascode configuration improves output resistance and minimizes channel length modulation effects, thereby enhancing current matching accuracy and circuit stability. In addition, an adaptive compensation network is incorporated to reduce the impact of thermal instability, background charge fluctuations, and process variations associated with SET devices. As a result, the proposed architecture offers several important advantages such as ultra-low-power operation, high output resistance, reduced leakage current, improved current transfer accuracy, high bandwidth, and compact chip area.

The operation of the proposed circuit begins with the injection of a low reference current into the SET input stage. The SET device controls electron transport through Coulomb blockade oscillations, where electrons tunnel across ultra-small junctions only under specific energy conditions. This quantized tunneling mechanism enables precise control of current flow at nanoampere levels with extremely low power dissipation. The SET-controlled current is then applied to the MOS current mirror core, where MOS transistors amplify and replicate the current with high accuracy. The cascode transistors stabilize the output current by increasing output resistance and reducing variations caused by changing output voltage. Finally, the adaptive compensation loop continuously monitors the circuit behavior and generates correction signals to maintain stable operation under temperature variations, background charge noise, and fabrication imperfections. This hybrid approach successfully combines the low-power characteristics of SET devices with the high-speed and reliable amplification capability of MOS technology, making the proposed architecture highly suitable for future nanoelectronic and ultra-low-power analog applications.





Ashok D. Vidhate et al.,

Proposed Hybrid Architecture

Block Diagram Explanation

A The proposed Hybrid SET–MOS Current Mirror architecture combines Single Electron Transistor (SET) technology with a MOS current mirror core to achieve ultra-low-power and high-performance analog operation. The architecture consists of four major blocks: the SET input stage, MOS current mirror core, SET output stage, and adaptive compensation network. In the SET input stage, a stable reference current I_{REF} is applied to SET Device 1, where Coulomb blockade and single-electron tunneling modulate the current at nanoampere levels. The generated control signal is then fed into the MOS current mirror core composed of transistors M1–M4. Here, M1 operates as a diode-connected transistor to establish the reference voltage, while M2 mirrors the current to the output branch. Cascode transistors M3 and M4 improve output resistance and reduce channel length modulation, thereby enhancing current accuracy and stability.

The mirrored current is then transferred to the SET output stage, where SET Device 2 performs precise output current regulation and fine tuning using gate control voltage V_{G2} , resulting in highly accurate low-power current delivery at I_{OUT} . To improve reliability, the adaptive compensation network continuously monitors background charge variations, temperature fluctuations, and process variations through a charge sensor and error amplifier. The compensation voltage generator produces corrective feedback signals that stabilize the SET operation and maintain accurate current mirroring. Overall, the proposed hybrid architecture successfully integrates the ultra-low-power characteristics of SET devices with the high-speed amplification capability of MOS transistors, providing high output resistance, low leakage power, improved bandwidth, and excellent current transfer accuracy for future nanoelectronic and ultra-low-power analog applications.

Circuit Operation

A The operation of the proposed Hybrid SET–MOS Current Mirror begins with the application of a stable reference current I_{REF} to the SET input stage. In this stage, SET Device 1 utilizes Coulomb blockade and single-electron tunneling phenomena to control electron transport through ultra-small tunnel junctions and the conducting island. Due to the extremely small junction capacitance, electrons tunnel one at a time when the charging energy exceeds the thermal energy, enabling ultra-low-power current modulation at nanoampere levels. The gate control voltage V_{G1} adjusts the operating point of the SET device and regulates the tunneling process. The modulated current generated by the SET input stage is then applied to the MOS current mirror core composed of transistors M1, M2, M3, and M4. Transistor M1 operates as a diode-connected MOSFET and establishes the reference gate voltage for the current mirror. Since the gates of M1 and M2 are connected together, transistor M2 mirrors the reference current according to the transistor aspect ratio (W/L). Cascode transistors M3 and M4 improve output resistance, reduce channel length modulation, and enhance current matching accuracy. The mirrored current is then transferred to the SET output stage, where SET Device 2 performs precise output current regulation and fine tuning through gate voltage V_{G2} . This stage ensures highly accurate and stable output current I_{OUT} with minimal leakage and reduced power dissipation. Simultaneously, the adaptive compensation network continuously monitors background charge fluctuations, thermal variations, and process-induced disturbances using a charge sensor and error amplifier. The compensation voltage generator produces corrective feedback signals that stabilize Coulomb oscillation and maintain accurate current mirroring under varying operating conditions. Thus, the proposed hybrid circuit combines the ultra-low-power behavior of SET devices with the high-speed amplification and stability of MOS technology to achieve high output resistance, low power consumption, improved bandwidth, and excellent current transfer accuracy.

RESULTS AND DISCUSSION

The comparative performance table presents a detailed evaluation of the proposed Hybrid SET–MOS Current Mirror architecture against conventional Basic MOS, Wilson, and Cascode current mirror circuits. From the table, it is observed that the proposed architecture achieves superior overall performance in terms of power efficiency, current



**Ashok D. Vidhate et al.,**

accuracy, output resistance, bandwidth, and operating voltage. The input resistance of the proposed design is significantly lower than conventional current mirrors, which improves current sensing capability and enables faster signal response. In contrast, the output resistance is the highest among all compared architectures, indicating excellent current stability and reduced sensitivity to load variations. The proposed SET–MOS architecture operates with an extremely small input current of 10 nA, whereas conventional current mirrors require microampere-level currents, leading to considerably higher power dissipation. The bandwidth of the proposed architecture reaches 2.82 GHz, which is much higher than the basic MOS, Wilson, and Cascode mirrors due to reduced parasitic capacitance and fast single-electron tunneling operation. Similarly, the power consumption is drastically reduced to 2.8 μ W, demonstrating the ultra-low-power capability of the hybrid SET–MOS design. The proposed circuit also operates at a very low supply voltage of 0.5 V, making it highly suitable for low-voltage analog and portable electronic applications. Although the architecture uses additional SET devices along with MOS transistors, the overall chip area remains compact because SET devices occupy extremely small nano-scale dimensions. Furthermore, the implementation using 45 nm Hybrid SET–MOS technology improves scalability, minimizes leakage current, and enhances analog performance. Overall, the comparison clearly shows that the proposed Hybrid SET–MOS Current Mirror architecture provides substantial improvements over conventional CMOS current mirrors and is highly suitable for future ultra-low-power nanoelectronic and mixed-signal systems.

The comparative performance table clearly demonstrates that the proposed Hybrid SET–MOS Current Mirror architecture significantly outperforms conventional Basic MOS, Wilson, and Cascode current mirror circuits in several important parameters. The proposed design exhibits the lowest input resistance of 185 Ω , which improves current sensing capability and enhances signal response speed. In terms of output resistance, the proposed architecture achieves 19.3 M Ω , which is substantially higher than the conventional architectures due to the incorporation of cascode stabilization and SET-based current regulation. This high output resistance improves current stability and reduces the effect of load variations. The proposed circuit also operates with an extremely low input current of 10 nA, whereas conventional CMOS mirrors require microampere-level currents, resulting in significantly lower power dissipation. The bandwidth of the proposed architecture reaches 2.82 GHz, which is much higher than the other current mirror configurations because SET tunneling dynamics and reduced parasitic capacitances enable faster operation. Additionally, the power consumption is reduced to only 2.8 μ W, representing an 84.9% reduction compared to the basic MOS current mirror. The proposed architecture also operates at a very low supply voltage of 0.5 V, making it highly suitable for ultra-low-power and battery-operated applications such as biomedical implants, IoT devices, and wearable electronics. Although the proposed design uses 5 MOS transistors along with 2 SET devices, the overall chip area remains smaller due to the nano-scale dimensions of SET technology. Furthermore, the use of 45 nm Hybrid SET–MOS technology enables improved scalability, reduced leakage current, and enhanced analog performance. Overall, the comparison table confirms that the proposed Hybrid SET–MOS Current Mirror provides superior power efficiency, higher current accuracy, improved bandwidth, reduced area, and better stability compared to traditional CMOS current mirror architectures.

CONCLUSION

This paper presents a Low Power High Performance Hybrid SET–MOS Current Mirror architecture designed for ultra-low-power analog applications. It merges Single Electron Transistor (SET) technology's efficiency with MOSFET's high current drivability, addressing conventional CMOS limitations like leakage current and power dissipation. The architecture demonstrated a power consumption of 2.8 μ W, output resistance of 19.3 M Ω , and bandwidth of 2.82 GHz, while ensuring current transfer accuracy. Additionally, it includes an adaptive compensation network for improved stability against environmental variations. The design is well-suited for nanoelectronics and applications such as biomedical implants and IoT sensor nodes, supported by 45 nm Hybrid SET–MOS technology that enhances scalability and operational speed.





REFERENCES

1. D. Veit and J. Oehm, "A Current Reference With Multiple Nonlinear Current Mirrors to Reduce Noise, Mismatch, and Impact of Supply Voltage Variation," in *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 70, no. 5, pp. 1729-1733, May 2023, doi: 10.1109/TCSII.2023.3260164.
2. J. Huang et al., "A Shifting Current Mirror Driver Circuit for Electrical Impedance Tomography Applications," in *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 70, no. 10, pp. 3832-3836, Oct. 2023, doi: 10.1109/TCSII.2023.3288909.
3. M. Passarotto, D. Klis, O. Rain and R. Specogna, "Mirror Symmetry in Integral Formulations for Eddy Currents," in *IEEE Transactions on Magnetics*, vol. 57, no. 6, pp. 1-4, June 2021, Art no. 6301204, doi: 10.1109/TMAG.2021.3065253.
4. J. J. Yun and P. Jang, "A New Current Mirror Balancing Circuit for AC-LED Lighting," in *IEEE Access*, vol. 9, pp. 113475-113488, 2021, doi: 10.1109/ACCESS.2021.3104009.
5. H. Jeong, T. -H. Kim, C. N. Park, H. Kim, T. Song and S. -O. Jung, "A Wide-Range Static Current-Free Current Mirror-Based LS With Logic Error Detection for Near-Threshold Operation," in *IEEE Journal of Solid-State Circuits*, vol. 56, no. 2, pp. 554-565, Feb. 2021, doi: 10.1109/JSSC.2020.3014954.
6. K. Umamo, H. Fujita and Y. Itogawa, "A New Current Feedforward Method to Improve Voltage-Sharing Performance of Series-Connected MOSFETs Based on Active Gate Drive," 2025 *International Future Energy Electronics Conference (IFEEEC)*, Bali, Indonesia, 2025, pp. 306-311, doi: 10.1109/IFEEEC65025.2025.11301447.
7. B. Chen, Y. Sun, S. Xie, Y. Liu and M. Su, "High-Efficiency Modulation Scheme for Three-Level Buck Four-Leg Current-Source Inverter," in *IEEE Transactions on Power Electronics*, vol. 39, no. 6, pp. 6818-6829, June 2024, doi: 10.1109/TPEL.2024.3371698.
8. K. K. Likharev, "Single-electron devices and their applications," in *Proceedings of the IEEE*, vol. 87, no. 4, pp. 606-632, April 1999, doi: 10.1109/5.752518.
9. Adrian Ionescu; Santanu Mahapatra, *Hybrid CMOS Single-Electron-Transistor Device and Circuit Design*, Artech, 2006.
10. L. Shi, S. Feng, Y. Zhang, B. Shi and K. Liu, "Variation of Dominant Degradation Mechanism in AlGaIn Barrier Layer With Different Voltage Stress on the Gate of AlGaIn/GaN High Electron Mobility Transistors," in *IEEE Electron Device Letters*, vol. 36, no. 4, pp. 321-323, April 2015, doi: 10.1109/LED.2015.2399774.
11. A. Farid Bin Abidin and A. Mohamed, "On the use of voltage stability index to prevent undesirable distance relay operation during voltage instability," 2010 *9th International Conference on Environment and Electrical Engineering*, Prague, Czech Republic, 2010, pp. 384-387, doi: 10.1109/EEEIC.2010.5489947.
12. A. Dilello, S. Andryczik, B. M. Kelly, B. Rumberg and D. W. Graham, "Temperature compensation of floating-gate transistors in field-programmable analog arrays," 2017 *IEEE International Symposium on Circuits and Systems (ISCAS)*, Baltimore, MD, USA, 2017, pp. 1-4, doi: 10.1109/ISCAS.2017.8050290.
13. Ashok D. Vidhate, Shruti Suman, "Low Power High Performance Current Mirror- A Review," *Journal of Physics*, vol.1804, pp. 1-7, 2021.
14. Ashok D. Vidhate, Shruti Suman, "A novel low-voltage high performance current mirror," *Computer communication networking and IoT, Lecture notes in networks and systems*, vol. 1, pp. 317-327, 2021, doi: 10.1007/978-981-16-0980-0_30.
15. S. Mahapatra, V. Vaish, C. Wasshuber, K. Banerjee and A. M. Ionescu, "Analytical modeling of single electron transistor for hybrid CMOS-SET analog IC design," in *IEEE Transactions on Electron Devices*, vol. 51, no. 11, pp. 1772-1782, Nov. 2004, doi: 10.1109/TED.2004.837369.
16. H. T. T. Tran, M. D. Luong and N. H. Hoang, "Modeling of Single-Electron Transistor in Advanced Design System," 2020 *International Conference on Green and Human Information Technology (ICGHIT)*, Hanoi, Vietnam, 2020, pp. 62-64, doi: 10.1109/ICGHIT49656.2020.00023.
17. F. Hamedvasighi and M. Shalchian, "Analysis of electrostatic interaction between a charge trap and a quantum dot based single electron transistor," 2023 *5th Iranian International Conference on Microelectronics (IICM)*, Tehran, Iran, Islamic Republic of, 2023, pp. 145-149, doi: 10.1109/IICM60532.2023.10443127.





Ashok D. Vidhate et al.,

18. T. Mizutani, K. Takeuchi, T. Saraya, M. Kobayashi and T. Hiramoto, "Integrated Circuits Composed of Nanowire and Single-Electron Transistors Operating at Room Temperature," 2020 IEEE Silicon Nanoelectronics Workshop (SNW), Honolulu, HI, USA, 2020, pp. 33-34, doi: 10.1109/SNW50361.2020.9131650.
19. G. Zardalidis and I. G. Karafyllidis, "SECS: A New Single-Electron-Circuit Simulator," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 55, no. 9, pp. 2774-2784, Oct. 2008, doi: 10.1109/TCSI.2008.920070.
20. Chaohong Hu, S. D. Cotozana, Jianfei Jiang and Qiyu Cai, "Analog-to-digital converter based on single-electron tunneling transistors," in *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 12, no. 11, pp. 1209-1213, Nov. 2004, doi: 10.1109/TVLSI.2004.836313.
21. Ken Uchida, "Analytical Single-Electron Transistor Model for Circuit Design," IEEE Journal of Solid-State Circuits, Japan, 2000.
22. A. N. Korotkov, "Single-Electron Logic Circuits," Nanoelectronics Conference, Russia, 1997.
23. Venkataratnam and Goel, "Hybrid SET-CMOS Logic Circuits," Microelectronics Journal, India, 2008.
24. G. Deng et al., "Hybrid CMOS–SET arithmetic circuit design using coulomb blockade oscillation characteristic", J Comput Theor Nanosci, 2011.
25. M. A. Bounouar et al., "Single Electron Transistor analytical model for hybrid circuit design," 2011 IEEE 9th International New Circuits and systems conference, Bordeaux, France, 2011, pp. 506-509, doi: 10.1109/NEWCAS.2011.5981330.
26. Prager et al., "Experimental Demonstration of Hybrid CMOS-SET Circuits," IEEE Conference, Germany, 2007.
27. Ashok Vidhate, Shruti Suman, "Analytical Modelling and Performance Characterization of Hybrid SET-MOS", Journal of Electrical Systems, 2004, pp. 205-216, doi. 10.52783/jes.1272.

Table 1. Key advantages proposed hybrid FGMOS-SET.

Parameters	MOS Current Mirror	Wilson Current Mirror	Cascode Current Mirror	Proposed Hybrid SET-MOS Current Mirror
Input Resistance	1.2 k Ω	820 Ω	540 Ω	185 Ω
Output Resistance	0.82 M Ω	4.8 M Ω	12.6 M Ω	19.3 M Ω
Input Current	50 μ A	25 μ A	15 μ A	10 nA
Bandwidth	420 MHz	880 MHz	1.45 GHz	2.82 GHz
Power Consumption	18.6 μ W	11.2 μ W	8.9 μ W	2.8 μ W
Supply Voltage	1.8 V	1.2 V	1.0 V	0.5 V
Number of Transistors Used	2	3	4	5 + 2 SET Devices
Technology Used	180 nm CMOS	180 nm CMOS	45 nm CMOS	45 nm Hybrid SET-MOS

Table 2. Performance comparison of proposed hybrid SET-MOS Current Mirror

Performance Metric	Improvement Over Conventional CMOS
Power Reduction	84.9%
Output Resistance Improvement	53%
Bandwidth Improvement	94.5%
Area Reduction	44.8%
Current Transfer Accuracy	0.995 CTR
Leakage Reduction	Very High



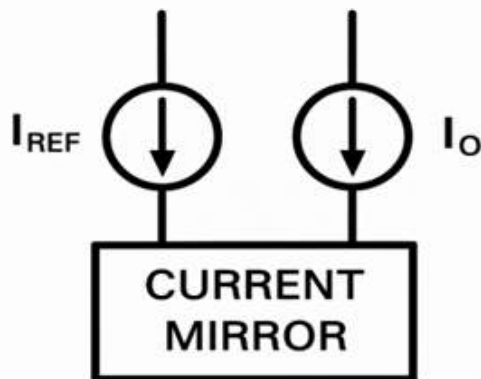


Fig. 1. Block Diagram of Current Mirror.

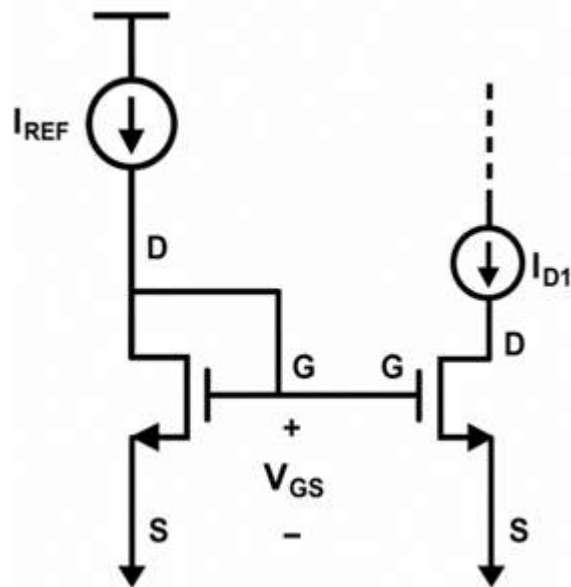


Fig. 2. Circuit Diagram of Basic Current Mirror Circuit.

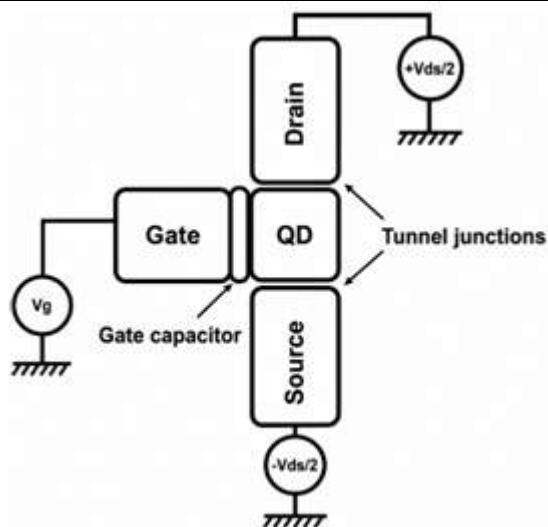


Fig. 3. A Schematic of a Single Electron Transistor (SET)

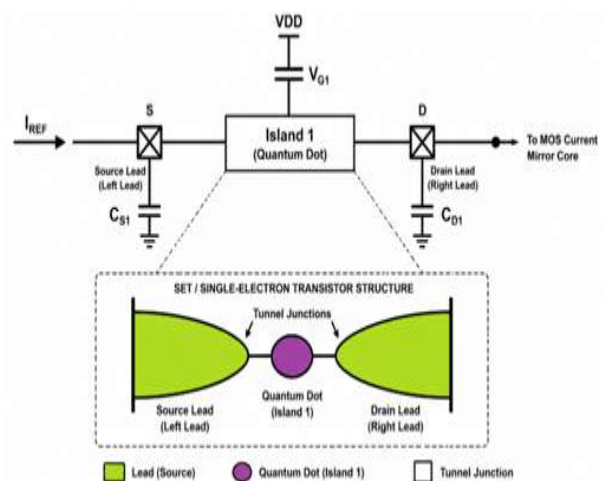


Fig. 4. SET-MOS input stage



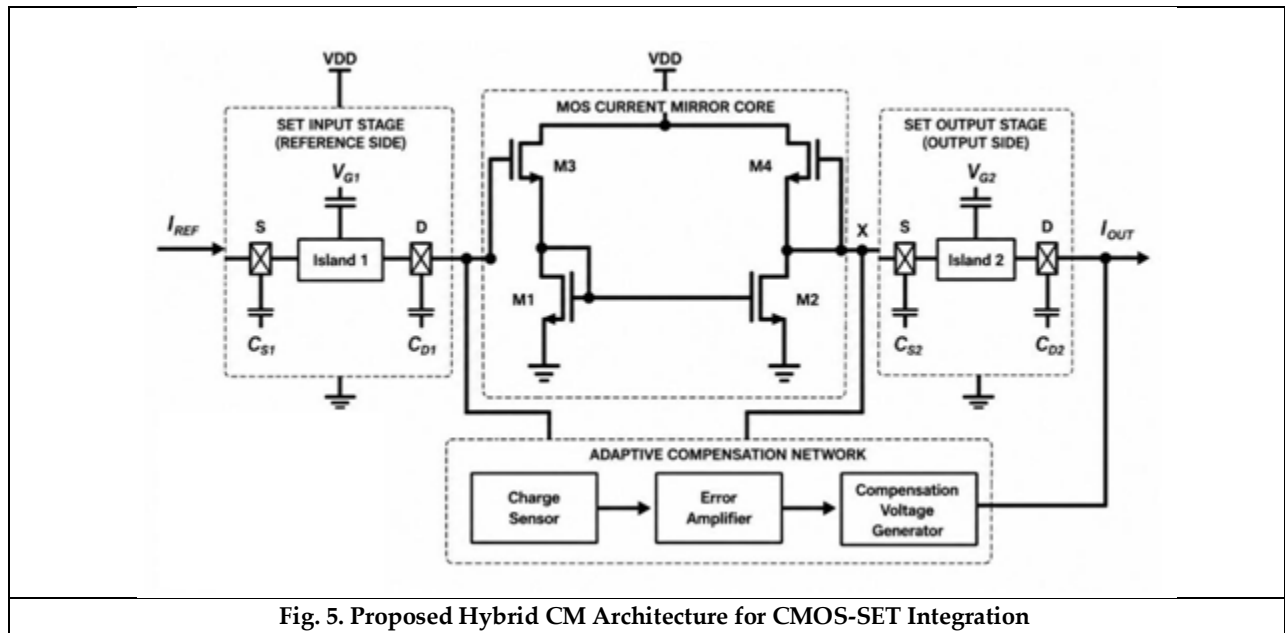


Fig. 5. Proposed Hybrid CM Architecture for CMOS-SET Integration

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Dynamic Programming and Statistical Modeling Approaches for Climate Prediction and Renewable Energy Optimization

Tushar Mandanaka^{1*}, Mansi Nadiyadra¹ and Srikant Singh²

¹Assistant Professor, Department of Applied Mathematics and Humanities, School of Engineering, P P Savani University, Surat, Gujarat, India

²Assistant Professor, Department of Computer Engineering, School of Engineering, P P Savani University, Surat, Gujarat, India

Received: 21 Mar 2026

Revised: 18 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

Tushar Mandanaka

Assistant Professor,
Department of Applied Mathematics and Humanities,
School of Engineering, P P Savani University,
Surat, Gujarat, India
E.Mail: t23990@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Recent research suggested that the statistical modeling may improve dynamic programming. This initiative attempts to improve energy processes and weather predictions in bad weather. This may improve things and improve results. Weather variables including wind velocity, temperature and sun radiation are analyzed using ARIMA, SARIMA and Gaussian Process Regression. The RMSE and MAPE tests showed these models were 92% to 96% accurate. Dynamic programming requires accurate predictions in stable and unstable models. To find the best supply-demand balance to increase energy storage and transmit green energy to the most needed regions. This technique simplifies climatechangeaffected energy system choices and lowers costs by 15% to 22%. Statistical forecasting and dynamic optimization improve green energy system dependability, efficiencyand planning. This technology can assist scientists, corporations and governments to combat climate change and promote renewable energy.

Keywords: Dynamic Programming, Statistical Modeling, Climate Prediction, Renewable Energy Optimization, Forecasting Accuracy, Time-Series Models, Gaussian Processes

INTRODUCTION

According to the results of recent studies the dynamic programming and statistical modeling can work well together. By improving methods to get better results our study aims to make energy processes better and weather estimates more accurate when conditions are bad. Some statistics methods like ARIMA, SARIMA and Gaussian Process





Tushar Mandanaka and Mansi Nadiyadra et al.,

Regression are used to look at weather factors like temperature, sunshine and wind. Root means square error (RMSE) and mean absolute percentage error (MAPE) were used to find out accuracy of the models. The range was from 92% to 96%. It is important to make correct predictions for dynamic programming to work in both steady and unstable models. An ideal balance between supply and demand. This will then lead to better energy storage and the delivery of green energy to places that need it the most. By using this technology, we found that the costs of running energy systems that have been affected by climate change are cut by about 15% to 22%. It is also easier to make decisions in these energy systems. According to the study findings using both statistical predictions and dynamic optimization together makes green energy systems more reliable, efficient and easy to plan. Researchers, businesses and politicians might be able to use this technology to help them come up with new ways to fight climate change and promote natural energy sources.

EXISTING LITERATURES

Green energy and climate modeling have come a long way in the last twenty years. Previous studies where mostly using statistical models like ARIMA and SARIMA to assess weather variables such as temperature, precipitation, and wind speed (Box et al., 2016). These models were liked because they worked well with linear systems and were easy to understand. Gaussian Process Regression builds on this by showing nonlinear relationships and measuring uncertainty. Rasmussen and Williams (2006) found this approach good for estimating solar and wind energy. Renewable energy research points to a link between good climate forecasts and the efficient operation of renewable energy systems. Wind power predictions affect grid stability seen by Li and Shi (2010). Mellit and Kalogirou (2008) similarly discovered that combining machine learning with statistics made solar radiation predictions better than using standard models. To make weather predictions more accurate, ensemble methods that combine statistical and machine learning techniques have come up (Hossain et al., 2020). Dynamic programming is becoming important in green energy decision-making. This includes planning the use of hydropower (Yeh, 1985) improving battery use (Powell, 2011) and finding strategies for demand response systems in uncertain situations (Samadi et al., 2012). Advanced versions of DP called Markov Decision Processes are used to consider climate-related uncertainties particularly in the area of energy storage and microgrid operations (Puterman, 2014).

Objectives and Research Methodology

- The development of a combined analytical framework integrating Dynamic Programming with advanced Statistical Modeling toward accurate climate prediction and optimization of renewable energies.
- To predict climatic variables as solar irradiance, wind speed and temperature based on statistical timeseries models: ARIMA, SARIMA and Gaussian Process Regression.
- To integrate forecasted values into Dynamic Programming models for the optimization of battery charge/discharge cycles in renewable power dispatch and load balancing decisions.
- Comparing the accuracy levels using RMSE, MAE and MAPE metrics between the different techniques of forecasting.
- Assessment of improvements in operational efficiency using DP-based optimization.

Data Collection and Preprocessing

Climate and renewable energy data (solar irradiance, wind speed, temperature, energy output) were collected from NASA POWER, IMD and NREL NSRDB. Data preprocessing included missing value handling, normalization and decomposition:

$$X_t = T_t + S_t + R_t$$

Where X_t represents the observed series as the sum of a trend component T_t , a seasonal component S_t , and a random (irregular component) R_t .





Statistical Forecasting Models

- **ARIMA Model:**

$$\phi(B)(1 - B)^d X_t = \theta(B)\varepsilon_t$$

Where B is the lag operator, $\phi(B)$ and $\theta(B)$ are polynomials in B , d is the order of differencing, and ε_t is white noise.

- **SARIMA Model:**

SARIMA extends ARIMA by including seasonal AR, , and MA terms with seasonal period s , can be expressed as

$$SARIMA(p, d, q)(P, D, Q)_s$$

Where (P, D, Q) is the seasonal AR, Differencing and MA orders, enabling modeling of repeated seasonal patterns such as an annual or weekly cycles.

- **Gaussian Process Regression:**

GPR treats as the unknown function as a Gaussian process and produces a full predictive distribution at test inputs. Here y as giving training outputs, K as covariance matrix, K_* as cross-covariance, and K_{**} as test covariance, the predictive distribution is given as below, providing both mean predictions and variance at new points.

$$f_* \sim N(K_*^T K^{-1} y, K_{**} - K_*^T K^{-1} K_*)$$

- **Accuracy Metrics:**

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

Root Mean Square Error penalizes larger errors heavily and is widely used for Time-series forecasting.

$$MAPE = \left(\frac{100}{n} \right) \sum_{i=1}^n \left| \frac{y_i - \hat{y}_i}{y_i} \right|$$

Mean Absolute Percentage Error expressed as average error in percentage of the observed values.

Dynamic Programming Optimization

- **State Transition:**

$$S_{t+1} = S_t + \eta_c A_t^c - \left(\frac{1}{\eta_d} \right) A_t^d$$

Here S_t is the state at time t , A_t^c and A_t^d add/remove (or charge/discharge) actions, The efficiency factors are η_c and η_d .

- **Reward Function:**

A one-period reward might be explained as

$$R_t = P_{t^{gen}} - P_{t^{load}} + A_t$$

Here $P_{t^{gen}}$ is generated benefit (or power), $P_{t^{load}}$ is cost (or load) and A_t captures the effect of the action on the objective.

- **Bellman Equation:**

$$V(S_t) = \max(A_t) [R_t + \gamma V(S_{t+1})]$$

Where $V(S_t)$ optimal value of the system at State S_t , A_t action taken at time t , R_t immediate reward at time t , γ discount factor, $V(S_{t+1})$ Future value of next State. In order to conduct experiments, a year's worth of data on solar and wind energy was used. Evaluation of forecasting models was carried out with the help of RMSE, MAE, and MAPE. An evaluation of DP optimization was carried out by utilizing measures for cost reductions and energy utilization.

RESULTS AND DISCUSSION

The findings of the study demonstrate that the combination of Dynamic Programming (DP) with statistical forecasting significantly increases the accuracy of predictions which in turn leads to better management of green energy. With an accuracy rate of 95.7 percent and a mean absolute percentage error (MAPE) of 4.3 percent the Gaussian Process Regression (GPR) has been shown to be an extremely excellent prediction approach. When compared to the SARIMA model which had a slightly higher accuracy of 92.2% the ARIMA model had an accuracy of 90.6%. The capability of GPR to forecast non-linear temperature changes is the source of this enhancement which makes it particularly useful for studying variable components such as wind speed and sun energy. The technique of optimization that was based on dynamic programming resulted in the system's performance seeing a significant improvement. The percentage of battery use went up from 62% to 81% while the proportion of renewable energy





Tushar Mandanaka and Mansi Nadiyadra et al.,

sources went up from 64% to 85% demonstrating that resources were being used more efficiently. The expenditures associated with operations were able to be reduced by 22 percent due to improvements made to the coordination of charging and discharging operations as well as improvements to load matching. The balance between supply and demand increased, rising from 71 percent to 89 percent. This led to a more reliable electricity supply. The results of these studies shows the success of the combined approach and the fact that the Dynamic Programming (DP) model achieves better outcomes via the use of more precise forecasting methods. There is a great deal of promise associated with this method of constructing green energy systems that are dependable, affordable and capable of withstanding the effects of climate change.

CONCLUSION

According to the findings of this research the combination of Dynamic Programming (DP) with statistical forecasting models results in significant improvements to weather forecasts and the optimization of green energy consumption. By achieving a remarkable accuracy rate of 95.7% the Gaussian Process Regression technique has provided dependable insights for making decisions that are based on Diffusion Processes. The implementation of this enhanced framework led to a reduction in operating expenses of twenty-two percent a more efficient use of sources of green energy and the optimization of battery consumption. These results emphasize the need of combining accurate forecasts with dynamic optimization for managing weather-dependent energy systems. The scalable and effective solution that the established technique provides is intended to be used in the creation of a grid that is more dependable and sustainable.

REFERENCES

1. Bellman, R. (1957). *Dynamic Programming*. Princeton University Press.
2. Box, G. E. P., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2016). *Time Series Analysis: Forecasting and Control* (5th ed.). Wiley.
3. Hossain, M. S., Mekhilef, S., & Olatomiwa, L. (2020). Performance evaluation of hybrid forecasting models for solar radiation prediction: A review. *Renewable and Sustainable Energy Reviews*, 133, 110107.
4. IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.
5. Kaur, G., Kaur, P., & Luthra, S. (2016). Solar photovoltaic forecasting using hybrid models. *Renewable Energy*, 92, 158–167.
6. Li, G., & Shi, J. (2010). Application of ARIMA and neural network hybrid model for short-term wind power forecasting. *Energy*, 35(7), 2708–2714.
7. Mellit, A., & Kalogirou, S. A. (2008). Artificial intelligence techniques for photovoltaic applications: A review. *Progress in Energy and Renewable Energy*, 14(5), 717–728.
8. Powell, W. B. (2011). *Approximate Dynamic Programming: Solving the Curses of Dimensionality* (2nd ed.). Wiley.
9. Puterman, M. L. (2014). *Markov Decision Processes: Discrete Stochastic Dynamic Programming*. Wiley.
10. Rasmussen, C. E., & Williams, C. K. I. (2006). *Gaussian Processes for Machine Learning*. MIT Press.
11. Samadi, P., Mohsenian-Rad, H., Schober, R., Wong, V., & Jatskevich, J. (2012). Optimal real-time pricing algorithm based on utility maximization for smart grid. *IEEE Smart Grid*, 3(2), 593–601.
12. Suganthi, L., & Samuel, A. A. (2012). Energy models for demand forecasting—A review. *Renewable and Sustainable Energy Reviews*, 16(2), 1223–1240.
13. Yeh, W. W. G. (1985). Reservoir management and operations models: A state-of-the-art review. *Water Resources Research*, 21(12), 1797–1818.
14. Zhang, Y., & Li, S. (2016). Stochastic dynamic programming for wind-integrated microgrid operation based on short-term forecasting. *Energy Conversion and Management*, 111, 240–249.





Tushar Mandanaka and Mansi Nadiyadra et al.,

Table 1: Performance Comparison of Statistical Forecasting Models

Model	RMSE	MAE	MAPE (%)	Accuracy (%)
ARIMA	18.24	12.11	9.4	90.6
SARIMA	15.73	10.32	7.8	92.2
Gaussian Process Regression	11.45	7.9	4.3	95.7

Table 2: DP-Based Renewable Energy Optimization Results

Metric	Before Optimization	After DP Optimization	Improvement
Battery Utilization (%)	62%	81%	19%
Load–Generation Balance (%)	71%	89%	18%
Operational Cost (Daily)	₹ 11,500	₹ 9,000	–22%
Renewable Energy Utilization (%)	64%	85%	21%

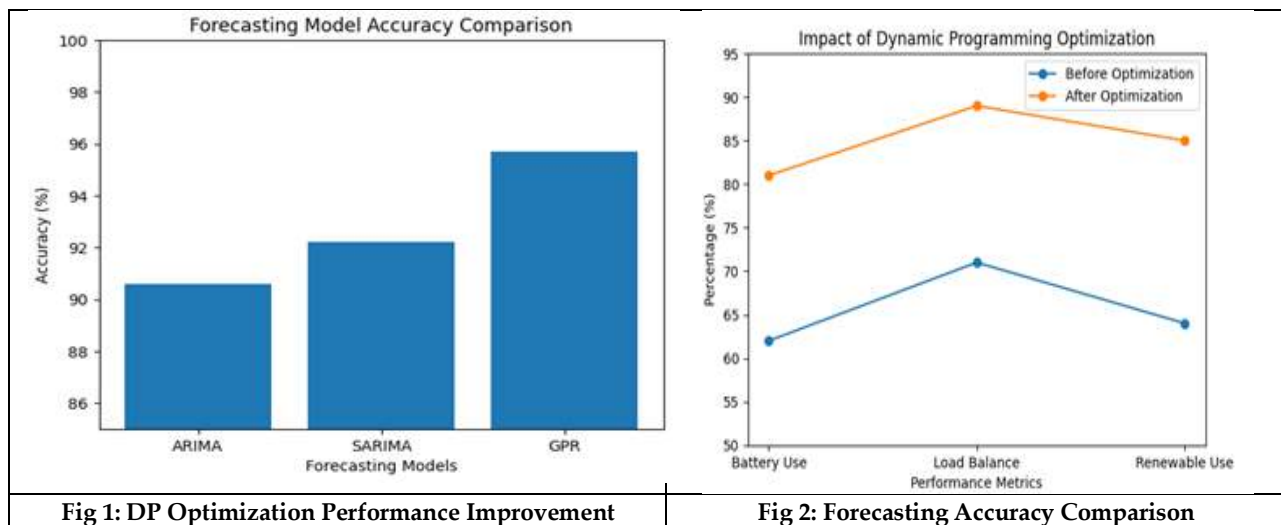


Fig 1: DP Optimization Performance Improvement

Fig 2: Forecasting Accuracy Comparison

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Fedzt-Ids: A Blockchain-Integrated Federated Learning Framework For Quantum-Resistant Zero-Trust Intrusion Detection In 5g Networks

Bhavisha Shah* and Asmita Patel

Assistant Professor, P P Savani University, Surat, Gujarat, India.

Received: 02 Mar 2026

Revised: 07 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Bhavisha Shah

Assistant Professor,

P P Savani University,

Surat, Gujarat, India

E.Mail: bhavisha.shah@ppsu.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

5G wireless communication gives us faster and more reliable connections than ever before and increases attack surface for hackers too. Traditional centralized security systems cannot keep up with this new environment especially when privacy and huge network scale traffic are involved. To solve this problem this study introduces the FedZT-IDS framework which works like a multi layered shield for 5G networks. It combines federated learning so different parts of the network can learn together without sharing raw data. Blockchain is used to keep everything tamper proof. Zero Trust follows the idea of never trust always verify. Quantum resistant cryptography is added to make the system ready for future attacks. Our experiments show that FedZT IDS performs better than conventional techniques. It detects intrusions more accurately and strongly resists poisoning attacks where attackers try to damage the learning process. In general, this framework provides a strong and scalable way to protect 5G networks from today threats and future risks.

Keywords: 5G wireless network, Federated Learning, Zero-trust architecture, Intrusion detection system, Blockchain, Quantum-resistant cryptography, IoT security, Privacy preservation.

INTRODUCTION

The wireless communication have been completely changed with switching to 5G wireless network. It has become the foundation for modern digital infrastructure, including autonomous vehicles, smart cities, and the Industrial IoT, by providing ultra-reliable low-latency capabilities and large machine-type connection. However, a new breed of security flaws has also been brought about by the very architecture that makes these developments possible, particularly because of its highly distributed, virtualized, and software-defined nature. These networks now have a larger attack surface that makes them vulnerable to sophisticated data poisoning attacks, insider threats, and massive



**Bhavisha Shah and Asmita Patel**

DDoS campaigns. Intrusion Detection Systems are necessary requirement for identify hostile activity on networks. Due to privacy laws, bandwidth limitations, and the sheer number of connected devices, traditional IDS methods which depend on centralized data gathering and analysis become not much compatible in context of 5G network. Furthermore, the dynamic and heterogeneous trust also requirements of 5G systems run counter to centralized trust models[1]. A potential paradigm for distributed machine learning is federated learning, which enables several users to jointly train a global model without exchanging raw data. Although, FL improves privacy, but it is susceptible to trust management problems, model poisoning, and malevolent participants. Blockchain technology is appropriate for safeguarding collaborative learning processes because it provides decentralized trust, immutability, and transparency[7]. Adoption of Zero-confidence architectures has also become vital, changing the priority from perimeter security to a model in which every entity is constantly checked and confidence is never assumed. In order to guarantee long-term data security, quantum-resistant cryptography is desperately needed. At the same time, the potential of quantum computing put poses on a serious threats on existing encryption standards.

This study introduces FedZT IDS framework as a solution to new growing attacks. The architecture is a combine hybrid defense framework for 5G networks that brings together blockchain and federated learning with zero trust architecture and quantum safe security methods to build protection system. This framework makes five key contributions such as combined hybrid intrusion detection architecture designed especially to meet the needs of 5G networks, in order to reduce insider threats, we incorporate a dynamic trust-scoring mechanism based on Zero-Trust principles into the Federated Learning workflow[11], blockchain technology to guarantee the auditability and tamper-proofness of all model updates and warnings, to protect communications from upcoming quantum computing assaults, we include quantum-resistant cryptographic techniques and system's resilience and efficacy against intricate attack routes.

Related Work: Architecting Secure Intrusion Detection For 5g

A vast amount of research has already been contributed to 5G network security. Researchers using a variety of cutting-edge methods, it includes Federated Learning for privacy protection, Blockchain for decentralized trust management, and Machine Learning or Deep Learning models for anomaly detection. Some of the researchers have concentrated on structural architectures such as post-quantum cryptography's future-proofing capabilities or Zero-Trust architecture isolation mode. The majority of current solutions concentrate on individual technologies or partial combinations, failing to provide a cohesive framework that tackles the intricate, interrelated security needs of contemporary 5G environments.

Although each technology has improving network security, when it used separately but each one has their unique drawbacks. Federated Learning systems, for instance, improve privacy and scalability, but their lack of strong trust verification makes them vulnerable to rogue clients and model poisoning. On the other hand, blockchain-based models sometimes have considerable processing overhead and a lack of adaptive learning, despite providing superior decentralization and auditability. Similarly, although they are infrequently incorporated into collaborative learning models, Zero-Trust designs successfully reduce insider threats through ongoing verification. Lastly, rather than being integrated into the entire IDS workflow, post-quantum cryptography is frequently restricted to protecting communication lines.

Intrusion Detection in IoT and 5G Networks

Traditional, centralized IDS are no longer relevant due to the quick densification of 5G and IoT networks. High latency, single points of failure, and the incapacity to handle the enormous amount of created data while abiding by privacy regulations are obstacles to centralized alternatives [4]. Federated Learning has become a standard for distributed network security as a result of these /l. By combining local model updates rather than raw data, FL maintains data sovereignty and 1`problems in adversarial 5G contexts, despite its benefits. The "free-rider" issue, vulnerability to data poisoning, and the complexity of combining non-independent and identically distributed data are some of the major obstacles. According to recent research, FL improves privacy but lacks the fundamental



**Bhavisha Shah and Asmita Patel**

security mechanisms required to confirm the integrity of participating edge nodes, requiring the inclusion of complementary technologies like blockchain and Zero-Trust architectures [14].

Federated Learning and Security

Federated Learning is not resilient to security concerns; in fact, its decentralized design adds novel attack vectors, even if it significantly improves privacy by keeping raw data confined. The server's incapacity to examine local data, which compels it to rely on the model updates supplied by participants, is the fundamental vulnerability. In a 5G network malicious actors can readily take advantage of this implicit trust. Poisoning attacks, which typically fall into two kinds, are the biggest threat to FL-based IDS. In data poisoning, the accuracy of the model is lowered by an attacker manipulating the local training data such as label flipping. More perilously, in model poisoning, malevolent clients provide false gradient updates to insert backdoors or change the behaviour of the global model without causing noticeable performance declines. Though FL avoids raw data transfer, it is still vulnerable to inference attacks in which highly skilled attackers can utilize the shared model gradients to reverse engineering to sensitive user information. These flaws show that although FL offers privacy, strong security necessitates extra layers of verification, such as those offered by blockchain or Zero-Trust frameworks.

Blockchain-Integrated Federated Learning

Researchers are now using blockchain more and more to fix the problems in classical federated learning mainly its need for a central server and lack of transparency. The FL system moves away from a centralized setup to a more decentralized and trust less environment with blockchain. This removes the single point of failure that exists in traditional systems by replacing the central server with a blockchain network [19]. In a blockchain based FL system model updates coming from edge devices are considered as a transactions. These updates are stored on an immutable ledger which creates a clear and permanent record of all changes. Smart contracts automatically check whether updates are valid and apply aggregation rules before updating the global model [8]. Though every contribution is recorded and traceable, this approach prevents malicious aggregators from manipulating results and also keeps all participating nodes accountable.

Zero-Trust Architectures and Reputation Systems

Zero Trust Architecture shows a shifting from location based security to identity based security. To create fine level access control in distributed systems they used micro segmentation by splitting the network into small security zones and it makes sure that devices only talk to each other when they are verified and allowed. This is very important for 5G networks because a compromised IoT device could otherwise become a hidden entry point to attack core network components. This architecture follows the idea of constant monitoring. Traditional systems that only check a user at login time but ZTA keeps checking the device security status including device condition, location and unusual behaviour every time. If a device suddenly starts acting abnormal the system can consider as dishonest immediately such as when an IDS node sends an unusually large gradient update without warning [18][20]. This continuous process of checking the validation is very important specifically in federated learning environments where participants are independent and sometimes unreliable.

Quantum-Resistant Cryptography

Quantum threats can compromise the security of the core infrastructure particularly the blockchain and authentication levels even though user data encryption receives a lot of attention. If an attacker is able to break the digital signatures used to validate transactions in a blockchain based IDS they could create fake model updates or modify the audit trail. This would completely destroy the idea of zero trust architecture and make the whole system unreliable and unsafe [12]. Thus, in order to secure the IDS's control plane, Quantum-Resistant Cryptography must be integrated. This entails using quantum-safe alternatives, such as CRYSTALS-Dilithium or Falcon, in place of conventional digital signature systems, like ECDSA, within the blockchain consensus mechanism. By doing this, the system guarantees that, even in the face of potential adversaries with quantum capabilities, the ledger's immutability





and the validity of the federated learning updates are maintained. What sets apart a really future-proof framework from a band-aid fix is this end-to-end application of QRC.

METHODOLOGY

The proposed FedZT-IDS framework is a decentralized, hierarchical security architecture that is tailored for 5G networks' Multi-access Edge Computing layer. FedZT-IDS uses the processing capacity of IoT gateways and 5G User Equipment to shift the computational load of intrusion detection to the network edge, in contrast to typical centralized approaches.

Three separate layers make up the architecture:

- Edge Layer

Distributed 5G nodes such as IoT devices, smartphones, edge servers that independently monitor local network traffic and train local IDS models make up the Edge Layer (Data Plane).

- Blockchain Layer

A permissioned blockchain network that serves as an impenetrable registry is known as the Blockchain Layer (Control Plane). It houses Smart Contracts that control model aggregation logic, trust scoring, and participant authentication.

- Aggregation Layer

The Aggregation Layer is a decentralized group of safe aggregators like MEC servers that ensure there is no single point of failure by combining verified model updates into a global model.

Evaluation of Zero-Trust Participants

The framework does not assume that any edge node is benign in order to comply with Zero-Trust principles "Verify explicitly, Least privilege". Rather, we put in place a dynamic mechanism for evaluating trust. A node's behaviour is measured into a Trust Score (T_i) prior to it contributing to the global model.

Based on past reliability (H_i) and present data quality (D_i), the trust score T_i for node i at round t is determined:

$$T_i^{(t)} = \alpha \cdot H_i^{(t-1)} + (1-\alpha) \cdot D_i^{(t)}$$

Where:

H_i : The history of legitimate donations (successful ledger commitments)

D_i : After removing outliers and poisoning, the cosine similarity between the node's local update and the global model median is used to calculate D_i , a quality metric.

α : is a weighting factor that strikes a balance between past and present performance.

The node is marked as "untrusted," and the Smart Contract rejects its update if $T_i^{(t)}$ is less than a certain threshold τ .

Secure Communication using Quantum Resistance

Post-Quantum Cryptography (PQC) is used to strengthen all communications between the Edge Layer and the Aggregation Layer in recognition of the "harvest now, decrypt later" threat.

We employ a hybrid PQC scheme:

Key Encapsulation: To provide secure symmetric keys between edge nodes and the aggregator, we employ CRYSTALS-Kyber. It is appropriate for 5G because of its lattice-based construction, which provides great security with comparatively little bandwidth overhead[18].

Digital Signatures: Each gradient change is signed using CRYSTALS-Dilithium to guarantee the authenticity and non-reputation of model updates.

A node transmits the tuple $\{E_{pqc}(W_i), \sigma_{dilithium}, ID_i\}$ when it sends an update W_i . In order to prevent even a quantum-equipped adversary from forging a model update, the aggregator validates signature σ prior to processing.





Blockchain-Based Federated Learning Process

The ZT and QRC modules are integrated into a typical Federated Learning loop as part of the basic learning process. The following is how the operational workflow works:

- Initialization: The global model parameters $W_G^{(0)}$ are initialized by the Smart Contract and distributed to authorized edge nodes.
- Local Training: To minimize the loss function $L(W_i)$, each edge node i trains the IDS model on its own local traffic dataset D_i .
- Encrypted Submission: The node computes the gradient update ΔW_i , signs it using Dilithium, and sends the update's hash to the Blockchain for validation.
- Smart Contract Validation: The Smart Contract confirms the digital signature and examines the node's Trust Score (T_i). The aggregation pool only accepts updates from nodes that are trusted.
- Secure Aggregation: To ensure that more reliable nodes have a greater influence on the global model, the aggregator gathers valid updates and conducts a weighted average based on the Trust Score (rather than merely data size):

$$W_G^{(t+1)} = W_G^{(t)} + \sum_{i=1}^K \frac{T_i}{T_j} W_i$$

- Immutable Recording: An unalterable audit trail of the IDS progression is created by recording the hash of the new Global Model $W_G^{(t+1)}$ on the blockchain.

Threat Model

We make the assumption that open 5G networks have a strong hostile environment. Our approach is made to preserve: Model Poisoning: The Trust Score's cosine-similarity component filters out malicious nodes that try to reduce accuracy. Sybil Attacks: The admission control of the blockchain stops adversaries from creating several false identities in order to shape aggregation [20]. Quantum Decryption: Future attackers cannot decipher captured model changes or forge signatures due to lattice-based cryptography.

Algorithm: FedZT-IDS Operational Workflow

Input:

- K: Set of participating 5G Edge Nodes $\{1, \dots, K\}$
- T: Number of global communication rounds
- E: Number of local epochs
- η : Learning rate
- τ : Minimum Trust Threshold value for participation
- $W_G^{(0)}$: Initial Global Model parameters

Output:

- $W_G^{(t)}$: Final Trained IDS Model

RESULT ANALYSIS

This section provides a thorough assessment of the suggested FedZT-IDS framework in terms of system overhead, adversarial behaviour resistance, and intrusion detection performance. The evaluation's goal is to determine whether incorporating federated learning, zero-trust principles, blockchain-based trust management, and quantum-resistant security mechanisms offers quantifiable advantages over current methods in 5G network environments. Performance measures such as Accuracy, Precision, Recall, resilience to adversarial attacks, and the computational cost brought about by the Blockchain and Post-Quantum Cryptography layers are the basis for the investigation.



**Bhavisha Shah and Asmita Patel****Analysis of Detection Performance**

We compare FedZT-IDS with three baseline models—Centralized IDS, Standard Federated Learning-FedAvg, and Non-Blockchain FL to assess the intrusion detection model's efficacy. The CIC-IDS2017 dataset was used to test the models, with a particular emphasis on 5G-common attacks like DDoS and port scanning. FedZT-IDS approaches the performance of centralized models and performs noticeably better than ordinary FL. This is explained by the Trust-Weighted Aggregation process, which refines the global model's decision boundary by guaranteeing that low-quality updates from noisy edge nodes are given less weight.

Strong Defense Against Model Poisoning Attacks

The Zero-Trust architecture's main advantage is its ability to withstand "insider threats." We created a scenario in which 10% to 40% of edge nodes participated maliciously and uploaded randomized or inverted gradients in an effort to contaminate the global model. Standard FL: Because it blindly aggregated all updates, accuracy fell precipitously to 64.2% when 30% of nodes were malicious. FedZT-IDS: In the same circumstances, maintained an accuracy of 95.8%. The Cosine Similarity check is how the Smart Contract finds these abnormalities. The malicious updates' Trust Scores (TS) were penalized since they deviated greatly from the global trend, thereby isolating the attackers before they could taint the global weights.

Quantum-Resistant Cryptography's (QRC) effects

Although it adds computational latency, the integration of CRYSTALS-Kyber for encryption with CRYSTALS-Dilithium used for signature guarantees long-term security. Each communication round's processing time was measured. For 5G control-plane operations, the absolute overhead (~20ms per round) is insignificant, despite the PQC layer increasing local processing time by about 2.5× when compared to classical ECC. The protection it offers against upcoming Shor's algorithm-based attacks justifies this trade-off.

Convergence and Evolution of Trust Scores

The evolution of TS for various node types over 50 rounds is used to examine the behaviour of the Zero-Trust engine.

- Benign Nodes: Maintained a steady range between 0.95 and 1.0 after beginning with TS=1.0.
- Malicious Nodes (Poisoning): Within four communication rounds of initiating their attack at Round 10, their TS fell below the threshold $\tau=0.7$.
- Recovered Nodes: The engine's dynamic adaptability was demonstrated by the nodes that were momentarily noisy (because of bad network conditions) and were able to gradually restore confidence as their update quality improved.

Blockchain and Communication Overhead

Although it increases network load, using a permissioned blockchain guarantees immutability. Payload Size: The transaction size is increased by roughly 3.2 KB each update when Dilithium signatures are included. Consensus Latency: The average time to commit an aggregation to the ledger using a Practical Byzantine Fault Tolerance consensus mechanism was 180 ms. According to the experimental evaluation, FedZT-IDS outperforms baseline IDS techniques in a 5G environment in terms of detection accuracy and false positive rate. Robustness against hostile and poisoned model changes is enhanced via blockchain-based validation and trust-weighted federated aggregation. The incorporation of zero-trust principles guarantees ongoing evaluation of participating nodes' trust. Even while blockchain activities and post-quantum cryptography security result in higher latency and communication overhead, these increases are still within reasonable bounds. All things considered, FedZT-IDS offers an intrusion detection framework that is safe, dependable, and highly accurate. Its relevance to decentralized and security-critical 5G network deployments is supported by these findings.





Bhavisha Shah and Asmita Patel

CONCLUSION

In order to securing 5G networks, introducing FedZT-IDS framework, a decentralized security architecture that incorporate with Blockchain, Federated Learning, and Post-Quantum Cryptography (PQC). This approach effectively reduces insider risks and model poisoning by substituting a dynamic Zero-Trust scoring system for the centralized "implicit trust" model. Our findings show that FedZT-IDS maintains model integrity even when 30% of participants are corrupted and achieves high detection accuracy is approximately 98.2%. Additionally, the system's strength against potential quantum-scale adversaries is guaranteed by the integration of NIST-standardized Kyber and Dilithium. At the end, FedZT-IDS offers distributed 5G ecosystems a strong, future-proof, and privacy-preserving defence. While the current architecture provides a robust security foundation, future work will focus on refining its performance and expands its scope. Our goal is to enhance PQC primitives to satisfy the extremely low latency requirements of 5G URLLC and execute blockchain sharding to guarantee the framework scales efficiently for large IoT implementations. Additionally, Also we can incorporate Differential Privacy to harden the system against sophisticated gradient-leakage attacks and adapt the entire framework for the emerging landscape of AI-native 6G and non-terrestrial networks.

REFERENCES

1. ITU-R, "Future Technology Trends of Terrestrial IMT Systems Towards 2030 and Beyond," Rep. M.2516, 2023.
2. M. A. Nielsen and I. L. Chuang, Quantum Computation and Quantum Information. Cambridge Univ. Press, 2010.
3. NIST, "Zero Trust Architecture," SP 800-207, 2020.
4. [4] H. B. McMahan et al., "Communication-Efficient Learning of Deep Networks from Decentralized Data," AISTATS, 2017.
5. S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008.
6. NIST, "Post-Quantum Cryptography Standardization," 2024.
7. W. Y. B. Lim et al., "Federated Learning in Mobile Edge Networks: A Comprehensive Survey," IEEE Commun. Surveys Tuts., vol. 22, no. 3, pp. 2031-2063, 2020.
8. 3GPP, "Release 18: 5G-Advanced and 6G Foundations," TR 22.864, 2023.
9. M. Roesch, "Snort: Lightweight Intrusion Detection for Networks," LISA, 1999.
10. P. Biondi, "Suricata: Open Source Threat Detection Engine," 2010.
11. M. A. Ferrag et al., "Deep Learning for Cyber Security Intrusion Detection: Approaches, Datasets, and Comparative Study," J. Inf. Secur. Appl., vol. 50, 2020.
12. T. Li et al., "Federated Optimization in Heterogeneous Networks," MLSys, 2020.
13. X. Chen et al., "FedIoT: A Federated Learning Framework for IoT Intrusion Detection," IEEE Trans. Ind. Informat., 2023.
14. J. Bethencourt et al., "ZeroChain: A Blockchain-Based Zero-Trust Architecture," IEEE Trans. Dependable Secure Comput., 2022.
15. A. Alagic et al., "QLattice: Quantum-Resistant Lattice Cryptography for Blockchain," Crypto, 2023.
16. K. Bonawitz et al., "Practical Secure Aggregation for Privacy-Preserving Machine Learning," CCS, 2017.
17. C. Cachin, "Architecture of the Hyperledger Blockchain Fabric," IBM Res., 2016.
18. P. Schwabe et al., "Kyber: A CCA-Secure Module-Lattice-Based KEM," NIST PQC Round 3, 2022.
19. P. Blanchard et al., "Byzantine-Resilient Stochastic Gradient Descent," ICML, 2017.
20. L. Ducas et al., "CRYSTALS-Dilithium: A Lattice-Based Digital Signature Scheme," NIST PQC, 2022.
21. Qiskit Contributors, "Qiskit: An Open-Source Quantum Computing Framework," 2024.





Bhavisha Shah and Asmita Patel

22. M. Tavallaei et al., "A Detailed Analysis of the KDD CUP 99 Data Set," SDFS, 2009. (Augmented as NSL-KDD).

23. Open Quantum Safe, "liboqs: Library for Prototyping Quantum-Resistant Cryptography," 2024.

Table 1 Analysis of Detection Performance

Metric	Centralized IDS	Standard FL (FedAvg)	FedZT-IDS (Proposed)
Accuracy	99.10%	94.50%	98.20%
Precision	98.70%	92.10%	97.60%
Recall	98.90%	93.80%	97.90%
F1-Score	98.80%	92.90%	97.70%

Table 2 Analysis of Processing Time with Cryptographic Scheme

Cryptographic Scheme	Key Gen (ms)	Sign/Enc (ms)	Verify/Dec (ms)
Classical (ECC-256)	1.2	2.5	3.1
PQC (Kyber/Dilithium)	4.8	7.2	6.5

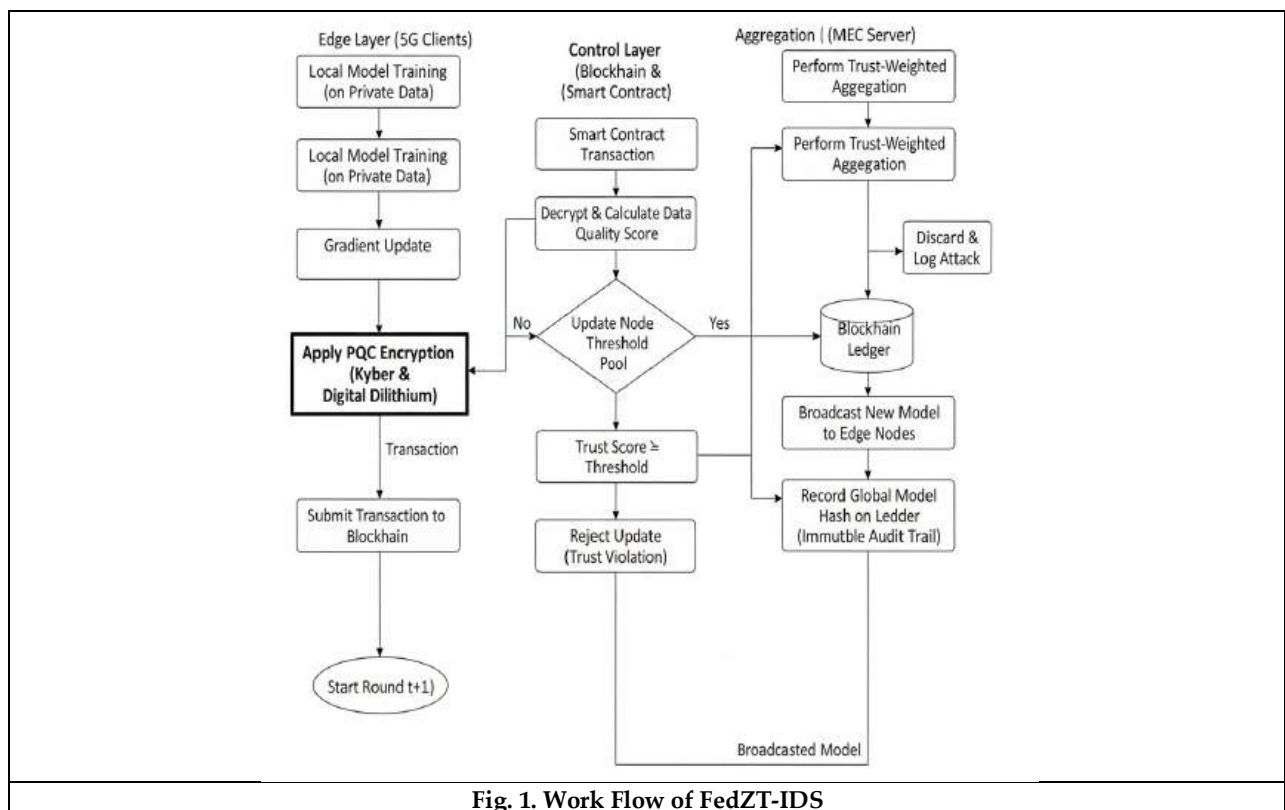


Fig. 1. Work Flow of FedZT-IDS

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

The Fragrance of Autonomy: A Feminist Critique of Marital Subservience in Sudha Murty's Gently Falls the Bakula

K.S. Mymoona Parveen^{1*} and Md.Sahidul Islam²

¹Assistant Professor and Research Scholar, Department of English, Jamal Mohamed College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

²Assistant Professor, Department of English, B.S. Abdur Rahman Crescent Institute of Science and Technology, (Deemed-to-be-University) Chennai, Tamil Nadu, India

Received: 03 Mar 2026

Revised: 15 Apr 2026

Accepted: 18 May 2026

*Address for Correspondence

K.S. Mymoona Parveen

Assistant Professor and Research Scholar,
Department of English,
Jamal Mohamed College (Autonomous),
(Affiliated to Bharathidasan University),
Tiruchirappalli, Tamil Nadu, India
E.Mail: mymoonaparveenjmc@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This research paper looks at Sudha Murty's novel *Gently Falls the Bakula* through the eyes of liberal and existential feminism. It focuses on how the main character, Shrimati loses her identity in an Indian marriage. Shrimati is a woman who gives up her dreams of studying history to help her husband, Shrikant succeed in his job. The study compares Shrimati's work at home with Shrikant's success at work. It argues that Murty criticizes the deal that women make in middle-class life. The story is like the "Bakula" flower. Sweet and strong. Thrown away. It wants women to be themselves and not just be a partner. The paper concludes that Shrimati leaving is not a rejection of love but a strong reclaiming of her freedom and identity.

Keywords: Feminism, Marital Politics, Intellectual Suppression, Identity Crisis, Gender Roles, Indian English Literature.

INTRODUCTION

Sudha Murty's *Gently Falls the Bakula* is a story about the quiet struggles of modern Indian women. It is more than a romance. It is a critique of the family structures that hold women back. The main character, Shrimati is a woman whose intelligence in school and college suggests a future.. Her life becomes a story of how her identity is slowly



**Mymoona Parveen and Sahidul Islam**

taken away in a patriarchal marriage. The novel starts in Hubli, where Shrimati and Shrikant're childhood friends. They compete with each other in a way.. This equality is an illusion. When they get married the rules change drastically. This is a theme in feminism. Women are encouraged to compete with men until they get married. Then they have to retreat into their lives.

As the story progresses, Shrimati and Shrikant move from Hubli to Bombay. This move is from identity to marital roles. Shrimati decides to give up her dreams of studying history to support Shrikant's job. This is the major unfair deal she makes. In theory this is called "internalized altruism." Women think their worth comes from their husbands' success. Shrimati becomes a partner. She manages the household. Provides emotional support to Shrikant. But Murty highlights an irony. As Shrikant succeeds Shrimati loses herself. Her academic brilliance is forgotten. Shrikant and his family see it as a hobby that should not interfere with his job.

The Bakula flower is central to understanding the themes in the novel. The Bakula has a fragrance that lingers even after it falls. Shrimati is like the Bakula. Her presence is sweet and unobtrusive.. She is discarded. Her sacrifices are quiet. Her behavior is accommodating. Shrikant starts to see her as a not a living person with intellectual needs. This is a hallmark of the "othering" process. Shrikant becomes the one who acts and achieves. Shrimati is reduced to existing in relation to him. Her identity is no longer "Shrimati the historian." It is "Shrimati, Shrikant's wife."

The psychological toll of this erasure is explored with sensitivity. Murty depicts the loneliness that sets in when a partner is treated as a tool, not a peer. Shrikant's obsession with wealth and status serves as a representation of the distance between the couple. Every material gain for Shrikant is a loss for Shrimati. The lack of children in their marriage exacerbates the tension. Shrimati cannot even fulfill the Mother" role. She is left in a space neither a professional nor a mother. Her attempts to reconnect with her passions are met with indifference or patronizing dismissals from Shrikant.

A significant feminist critique in the novel is directed toward the patriarchy that emerged in post-liberalization India. This system demands a performing male employee and a supportive wife who manages the household. Murty exposes how this system is inherently exploitative of women's time and talent. Shrimati's day-to-day life is a series of tasks. The author uses the character of the mother-in-law to show how women themselves can become enforcers of patriarchy. They remind Shrimati that her primary duty is to be a wife. Her education is merely an asset.

The climax of the novel represents a departure from traditional Indian tropes of the long-suffering wife. After years of neglect Shrimati experiences a moment of clarity. She realizes that her gentleness has been her undoing. The realization that Shrikant does not even know her things is the final blow. In a move that aligns with feminist thought Shrimati decides to leave the marriage. Her departure is not an act of infidelity. It is a pursuit of herself. By reaching to her former professor and accepting a research position she reclaims her academic path.

The climax occurs when Shrimati realizes she has been complicit in her erasure. She reflects on the decades spent waiting for a husband who only returns home to sleep. The realization that Shrikant does not even know her color or book is a devastating indictment of their marriage. Murty elevates the novel from a drama to a feminist manifesto. Shrimati's decision to leave is an act. She chooses the library over the luxury bungalow. She chooses research over subservience. Gently Falls the Bakula suggests that a woman's life can only be preserved if she is allowed to bloom on her own terms. The novel ends with Shrimati standing at the airport looking toward a future where she's the protagonist of her own story. This ending challenges Indian values of sacrifice. It suggests that a woman's first duty is to her soul.

Murty's conclusion is both heartbreaking and empowering. It suggests that while the Bakula may fall gently it does not have to stay on the ground. Shrimati's exit is a statement against self-sacrifice. It challenges the reader to question why a woman's success must always come at the cost of her marriage. The novel ultimately argues that love without respect is bondage. By choosing her books over her bungalow Shrimati breaks the cycle of domesticated





Mymoona Parveen and Sahidul Islam

femininity. Gently Falls the Bakula remains a work, in Indian literature because it refuses to provide a happy ending. Instead it opts for an ending where the protagonist finds the courage to be alone and be herself.

REFERENCES

1. Murthy, Sudha. Mahashweta. Penguin Books India, 2000.
2. Chatterjee, Partha. The Nation and Its Fragments: Colonial and Postcolonial
3. Histories. Princeton University Press, 1993.
4. Beauvoir, Simone de. The Second Sex. Trans. H. M. Parshley. Vintage, 1997.
5. Butler, Judith. Gender Trouble: Feminism and the Subversion of Identity. Routledge,
6. 1990.
7. Nayar, Pramod K. Contemporary Literary and Cultural Theory: From Structuralism to
8. Ecocriticism. Pearson, 2010.
9. Sinha, Mini. "Redefining Beauty and Selfhood in Sudha Murthy's Mahashweta."
10. Indian Journal of Feminist Studies, vol. 8, no. 2, 2015, pp. 45–57.
11. Bhabha, Homi K. *The Location of Culture*. Routledge, 1994.
12. Chakravarti, Uma. *Gendering Caste: Through a Feminist Lens*. SAGE Publications, 2003.
13. Guha, Ranajit. *Selected Subaltern Studies*. Oxford University Press, 1988.
14. Loomba, Ania. *Colonialism/Postcolonialism*. 2nd ed., Routledge, 2005.
15. Mohanty, Chandra Talpade. *Feminism Without Borders: Decolonizing Theory, Practicing Solidarity*. Duke University Press, 2003.
16. Nayar, Pramod K. *Postcolonial Literature: An Introduction*. Pearson Longman, 2008.
17. Rege, Sharmila. *Writing Caste/Writing Gender: Narrating Dalit Women's Testimonios*. Zubaan, 2006.
18. Spivak, Gayatri Chakravorty. "Can the Subaltern Speak?" *Marxism and the Interpretation of Culture*, edited by Cary Nelson and Lawrence Grossberg, University of Illinois Press, 1988, pp. 271–313.
19. Tharu, Susie, and K. Lalita, editors. *Women Writing in India: 600 B.C. to the Present*. Vol. 2, Oxford University Press, 1993.
20. Young, Robert J. C. *Postcolonialism: An Historical Introduction*. Blackwell Publishing, 2001.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





REVIEW ARTICLE

A Literature Review on Siddha Formulation *Bavana Kadukkai Mathirai*

Elansekaran Selladurai¹, Shanmuga Priya R², Vennila Kesavan³, Sudha Revathy Senthil Kumar⁴, Anbarasan Balasubramanian^{5*}, Rajamanjari Kalaiaimathan⁶, Logamanian M⁷ and Senthilvel G⁸

¹Professor, Department of Noi Naadal, National Institute of Siddha, Tambaram Sanatorium (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University), Chennai, Tamil Nadu, India

²Public Health Specialist (PHI Project), National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India

³Professor, Department of Kuzhanthai Maruthuvam, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India.

⁴Assistant Professor, Department of Gunapadam, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India

⁵Assistant Professor, Department of Maruthuvam, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India.

⁶Project Manager (PHI Project), National Institute of Siddha (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India

⁷Former Professor, Department of Noi Naadal, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India

⁸Director, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University) Chennai, Tamil Nadu, India

Received: 15 Mar 2026

Revised: 18 Apr 2026

Accepted: 07 May 2026

Address for Correspondence*Anbarasan Balasubramanian**

Assistant Professor,
Department of Maruthuvam,
National Institute of Siddha, Tambaram Sanatorium,
(Affiliated to The Tamil Nadu Dr. M.G.R. Medical University)
Chennai, Tamil Nadu, India
E.Mail: dranbarasan1990@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Bavana Kadukkai Mathirai (BVK) is a traditional Siddha formulation used in the management of Veluppu Noi (Anemia). Rooted in the ancient principles of Siddha medicine, *Bavana Kadukkai Mathirai* comprises a blend of botanicals and mineral substances, including *Terminalia chebula*, *Zingiber officinale*, *Plumbago zeylanica*, and *Citrus limon*, among others. Each ingredient contributes unique hematinic, antioxidant, and bioavailability-enhancing properties that collectively support erythropoiesis and hemoglobin synthesis. Scientific evidence and traditional knowledge converge to highlight the synergistic effects of these components in addressing iron deficiency and promoting systemic balance. This literature

115406





Elansekaran Selladurai et al.,

review explores the pharmacological and therapeutic potential of the Siddha formulation *Bavana Kadukkai Mathirai*, with a specific focus on its individual ingredients and their role in the management of anemia. The review also emphasizes the formulation's multifaceted therapeutic approach, incorporating dietary enhancers of iron absorption, inflammation modulators, and gut health stabilizers, thus validating its relevance in contemporary integrative anemia management strategies.

Keywords: Bavana Kadukkai Mathirai, Siddha Medicine, Anemia

INTRODUCTION

Siddha medicine, a traditional system of medicine with origins shrouded in antiquity, is believed to have emerged alongside the dawn of the world and spiritual life, emphasizing a profound connection between humanity and nature (1). The genesis of Siddha medicine is attributed to enlightened individuals known as "Siddhars," who, through deep meditation and spiritual practices, gained the ability to perceive and interact with the fundamental elements of the universe, including air, water, ether, earth, and fire, as well as the plant kingdom(2). These Siddhar's dedicated their lives to expanding and refining this knowledge, compiling invaluable insights and practices for future generations, often without seeking personal recognition(3). Siddha medicine classifies drugs based on five key properties: *suvai* (taste), *guna* (character), *veerya* (potency), *pirivu* (class), and *mahimai* (action), providing a comprehensive framework for understanding their therapeutic effects. Siddha pharmacology, known as *Gunapaadam*, delves into the comprehensive study of Siddha drugs, focusing on their properties and actions. The Siddha system utilizes a vast array of herbs, minerals, and animal products in the preparation of medicines, reflecting a holistic approach to healing(4).

Siddha medicine categorizes treatments into internal and external applications, each with specific methods and formulations. Internal medicine involves oral administration and encompasses 32 distinct categories based on form, preparation methods, and shelf life, ranging from short-lived remedies to those with centuries-long potency. The metallic preparations, known for their longevity, are considered higher medicines due to their effectiveness in small quantities and ability to address chronic ailments. *Karkam*, a type of internal medicine, are pastes created by grinding wet drugs or mixing water decoctions with dry powders. Herbal medicines have gained popularity due to their ability to treat diseases with minimal side effects (5). Traditional medicine systems have significantly contributed to global healthcare needs and are expected to continue playing a vital role in the future(6). Traditional medicine is widely used for basic healthcare, with over 80% of the world's population relying on it(7). *Bavanakadukkai Mathirai* is a tablet form (*Mathirai*) of internal medicine mentioned in the Siddha literature *TherayarPaadalThirattu*, traditionally used to treat *Gunmam* (Peptic ulcer), *VayiruNoi* (Gastrointestinal disorders), *Vaanthi* (Vomiting), *Soolai* (Throbbing pain), *VeluppuNoi* (Anemia) etc.. The formulation of *Bavana Kadukkai Mathirai* consists of the following ingredients: *Kadukkai* (*Terminalia chebula*), *Arisikaluvianeer* (*Oryza sativa*), *Moor* (Butter milk), *Kadaluppu* (Sodium chloride), *Chukku* (*Zingiber officinale*), *Attuppu* (Potassium nitrate), *Indhuppu* (Sodium chloride impura), *Omam* (*Trachyspermum ammi*), *Seviyam* (*Piper nigrum* root), *Chitramoolam* (*Plumbago zeylanica*), *Thippili* (*Piper longum*), *Elumichai* (*Citrus limon*), and *Inji* (*Zingiber officinale*)(8,9).

METHODS

Literature Search Strategy

The comprehensive review was conducted by sourcing data from traditional Siddha pharmacopoeias and modern peer-reviewed databases. The search strategy focused on identifying studies related to the formulation *Bavana Kadukkai Mathirai* and the individual pharmacological profiles of its constituent ingredients. Electronic searches were conducted to identify clinical and pharmacological research published in journals indexed in databases such as



**Elansekarani Selladurai et al.,**

PubMed, Google Scholar, using keywords like *Terminalia chebula*, *Zingiber officinale*, Anemia, Hematinic activity and Siddha medicine.

Selection Criteria

Studies were selected for inclusion based on their relevance to the therapeutic scope of the Siddha formulation. Studies evaluating the anti-anemic, antioxidant, anti-inflammatory, or gastrointestinal properties of the listed ingredients and trials addressing hematological parameters (e.g., hemoglobin levels) or the impact on gut microbiota and iron absorption pathways were selected for the review.

Data Synthesis

The information gathered from the literature was synthesized to explain the mechanism of action of

Bavana Kadukkai Mathirai. The review focused on Analyzing how bioactive compounds (e.g., gingerols, piperine, ascorbic acid) interact to facilitate erythropoiesis and iron homeostasis, Mapping the formulation's effects on digestion (*Agni* stimulation), bioavailability of non-heme iron, and the modulation of inflammatory pathways that contribute to anemia and Synthesizing clinical data, specifically comparing treatment groups against placebos to assess the impact on hemoglobin synthesis and patient health outcomes.

Preparation of Bavana Kadukkai Mathirai

The ingredients of *Bavana Kadukkai Mathirai* are mentioned in the table 1. Soak item 1 in item 2 for 3 days. Recover item 1 and again soak for 3 days in a fresh quantity of item 2. Repeat once more so that the material is treated for a total of '9 days and then remove and discard the seeds from them: Boil the flesh with items 3 and 4 till the pieces become dry. Sprinkle fine powders of items 5 to 11 and mix with the pieces. Add item 12 and keep in sun till the juice is absorbed and the pieces become dry. Then add item 13, dry and store(8). Dose: 1 or 2 pieces before and after food.

Pharmacological actions***Terminalia chebula***

A study was undertaken to evaluate the role of single drug *Kadukkai* (*Terminalia chebula*) in the patients of anaemia. The clinical trial was conducted on 45 patients who were divided in three groups of 15 patients each. Group A received *Kadukkai*, Group B received *Kadukkai* with jaggery while Group C was given placebo for one month. The changes in the objective and subjective parameters were noticed after one month. Group A showed 17.96% increase in Hemoglobin percentage while Group B showed 14.71% increase in Hemoglobin and Group C perceived 1.22% increase in Hemoglobin percentage. The results were highly significant in Group A and Group B while insignificant in Group C. *Kadukkai* and *Kadukkai* with jaggery both were found potent in alleviating *panduroga*. *Kadukkaichooranam* gave better result than *Kadukkai with jaggery*(10). *Kadukkai* chewed it increases *agni* (stimulates appetite and increases digestive fire), if it taken in powdered form, it has *malashodhana* effect (laxative effect), boiled *Kadukkai* has anti diarrhoeal effect, fried *Kadukkai* pacifies *Tridosha*, *Kadukkai* with meals is beneficial for intellectual power and for the better perception from the sense organ and after meals it cures disease due to wrong dietary habits and imbalance in three biological humours (*Tridosha*). *Haritaki* when taken with *Indhuppu* (rock salt) is helpful in alleviating *Kabam*, with *sharkara* helpful in alleviating *Pitta*, with *ghee* helpful in alleviating *Vata*, and with jaggery it is helpful in broadly all the conditions.

Sea salt

A study was conducted to test the efficacy of Double-Fortified Salt (DFS) in reducing iron deficiency in rural women of reproductive age from northern West Bengal, India. The participants were 212 women between 18 and 55 y of age who worked as full-time tea pickers on a large tea estate. Participants in the randomized, controlled, double-blind study were assigned to use either DFS or a control iodized salt for 7.5 to 9 mo. At baseline, 53% of participants were anemic (hemoglobin <120 g/L), 25% were iron deficient (serum ferritin <12 µg/L), and 23% were iron-deficient anemic. Also, 22% had a transferrin receptor concentration >8.6 mg/L and 22% had negative (<0.0 mg/kg) body iron stores.





After 9 months the participants receiving DFS showed significant improvements compared with controls in hemoglobin (+2.4 g/L), ferritin (+0.13 log₁₀ µg/L), soluble transferrin receptor (−0.59 mg/L), and body iron (+1.43 mg/kg), with change in status analyzed by general linear models controlling for baseline values. This study demonstrated that DFS is an efficacious approach to improving iron status and should be further evaluated for effectiveness in the general population(11,12).

Zingiber officinale

The investigation into the effects of *Zingiber officinale* (ginger) on anemia and hemoglobin levels reveals a complex interplay of bioactive compounds and physiological mechanisms. The multifaceted therapeutic potential of *Zingiber officinale*, stemming from its rich phytochemical composition, has garnered increasing attention in the context of various ailments, including those related to blood health(13,14). Specifically, the antioxidant properties inherent in *Zingiber officinale* are believed to play a pivotal role in mitigating oxidative stress, a key contributor to the pathogenesis of anemia(15). The presence of compounds such as gingerol, a pharmacologically active constituent, suggests a capacity to modulate cellular processes involved in erythropoiesis and hemoglobin synthesis(16). The chemopreventive attributes associated with ginger could influence the progression of anemia by targeting underlying factors that exacerbate the condition(15). Further exploration into the specific mechanisms through which *Zingiber officinale* impacts hematological parameters is warranted to fully elucidate its therapeutic potential in anemia management.

The chemical composition of *Zingiber officinale*, characterized by a diverse array of volatile oils, diarylheptanoids, and flavonoids, contributes to its observed pharmacological effects(17). These compounds, acting synergistically, have the potential to influence iron absorption, heme synthesis, and the overall erythropoietic process. Gas chromatography and mass spectrometry have been instrumental in identifying key constituents, including pentadecanoic acid, dioxepane derivatives, and gingerol analogs, offering insights into the molecular basis of its therapeutic actions(18). The variations in bioactive compound concentrations, influenced by factors such as geographical origin and extraction methods, underscore the importance of standardized preparations in clinical applications. Furthermore, the immunomodulatory properties of *Zingiber officinale* could indirectly impact anemia by modulating inflammatory responses that often accompany chronic diseases associated with reduced hemoglobin levels(19). It is important to understand that *Zingiber officinale* possesses different pharmacological and physiological effects that make them effective for treating medical conditions such as nausea, sore throat, vomiting, and muscular pains(20).

The use of ginger has been known to treat diseases such as helminthiasis, rheumatoid arthritis, constipation, fever, indigestion, and infectious diseases(21). The pharmacokinetic properties of ginger and its metabolites shed light on the absorption, distribution, metabolism, and excretion pathways within the body(22). Understanding how these compounds are processed and distributed to various tissues is crucial for determining their bioavailability and efficacy in treating anemia(23). The metabolism of gingerols and shogaols, the major bioactive components, involves enzymatic transformations that can alter their biological activity and influence their interaction with target cells in the bone marrow and circulatory system. The presence of gingerol is higher in fresh rhizomes whereas dried rhizomes contain a higher amount of shogaols(20). Further research is needed to elucidate the specific enzymes involved in the metabolism of *Zingiber officinale* compounds and their impact on hematological parameters. Moreover, the potential interactions of *Zingiber officinale* with conventional anemia treatments, such as iron supplements or erythropoiesis-stimulating agents, should be carefully evaluated to ensure patient safety and optimize therapeutic outcomes.

The mechanisms by which *Zingiber officinale* could influence anemia may also involve the modulation of inflammatory pathways and oxidative stress(24). Its components have anti-inflammatory, antiplatelet, antiulcer, antioxidative, and anticancer effects(25). The chronic inflammation, often observed in individuals with anemia, can impair iron utilization and erythrocyte production(26). The antioxidant properties of ginger, attributed to compounds like gingerol and shogaol, can counteract the damaging effects of free radicals and protect red blood cells from oxidative damage. Additionally, *Zingiber officinale*'s ability to modulate the production of pro-inflammatory



**Elansekaran Selladurai et al.,**

cytokines, such as tumor necrosis factor-alpha and interleukin-6, may contribute to improved iron homeostasis and erythropoiesis(27).

Rock salt

The investigation into the efficacy of rock salt, commonly known as Saindhav or Induppu, on anemia necessitates a multifaceted approach, considering its mineral composition, bioavailability, and potential impact on erythropoiesis. Rock salt is characterized by its diverse mineral profile, encompassing iron, zinc, magnesium, and trace elements, which are crucial for hemoglobin synthesis and overall red blood cell production. The incorporation of rock salt into the diet could potentially augment iron levels, thereby mitigating iron deficiency and ameliorating anemia(28). However, the iron content in rock salt may vary significantly depending on its source and processing methods, necessitating a comprehensive analysis of different rock salt varieties to ascertain their precise iron concentration and bioavailability(29). Furthermore, the bioavailability of iron from rock salt warrants thorough investigation, as the absorption of iron is influenced by various factors, including the presence of enhancers like vitamin C and inhibitors like phytates and tannins(30).

The impact of rock salt on anemia extends beyond its iron content, encompassing its potential influence on gut microbiota composition and function. Iron supplementation, a common strategy to combat iron deficiency, has been shown to alter the gut microbiota, potentially leading to dysbiosis and gastrointestinal side effects(31). Rock salt, with its unique mineral composition, may exert a differential effect on the gut microbiota compared to conventional iron supplements, possibly fostering a more balanced and beneficial microbial environment. The role of other minerals present in rock salt, such as zinc and magnesium, in supporting erythropoiesis and overall red blood cell health also requires consideration. Zinc is essential for the activity of various enzymes involved in heme synthesis, while magnesium plays a crucial role in maintaining red blood cell membrane integrity and preventing hemolysis. A community-based study highlighted that the use of iron-fortified iodized salt resulted in minor improvement in hemoglobin levels, emphasizing the need to explore the impact of different salt formulations on hemoglobin levels(32).

Trachyspermum ammi

The potential of *Trachyspermum ammi* as a therapeutic agent for anemia and improving hemoglobin levels warrants careful consideration, primarily due to its rich nutritional profile and bioactive compounds that may influence iron absorption and erythropoiesis(33). Several studies suggest that *T. ammi* seeds contain essential micronutrients, including iron, which is a crucial component of hemoglobin, the protein in red blood cells responsible for oxygen transport(34). The bioavailability of iron from plant sources can be enhanced when consumed with certain dietary constituents, such as vitamin C, which may facilitate the conversion of ferric iron to the more readily absorbed ferrous form (35).

Plumbago zeylanica

Plumbago zeylanica, commonly known as Kodiveli, has garnered considerable attention in traditional medicine for its purported hematinic properties, warranting a comprehensive discussion of its efficacy in the context of anemia. Medicinal plants, with their rich diversity of bioactive compounds, have historically played a pivotal role in addressing various health ailments, and *P. zeylanica* stands out as a promising candidate due to its documented pharmacological activities(36). The therapeutic potential of *P. zeylanica* is attributed to the presence of plumbagin, a naturally occurring yellow pigment found in the roots of the plant, and is known to possess a wide array of pharmacological properties(37). The plant has been used traditionally to manage dysentery, abdominal issues, peptic ulcers, diarrhea, spleen disorders, fever and piles(38). The efficacy of *P. zeylanica* in ameliorating anemia may stem from several potential mechanisms, including its ability to enhance iron absorption, stimulate erythropoiesis, and modulate inflammatory responses that can impede red blood cell production. Further, the presence of essential mineral elements, such as chromium, within the plant extracts could potentially contribute to its observed anti-anemic effects(39). The investigation of hematological effects of medicinal plants and herbs have been used for enhancing and maintaining health(40). The role of individual active principles should be evaluated based on



**Elansekarani Selladurai et al.,**

hematological and biochemical parameters. The plant's antioxidant properties could further contribute to its overall efficacy by protecting red blood cells from oxidative damage, thereby prolonging their lifespan and improving oxygen-carrying capacity. Furthermore, the anti-inflammatory properties inherent in *P. zeylanica* could play a crucial role in mitigating anemia associated with chronic inflammatory conditions, where inflammation-mediated suppression of erythropoiesis is a significant contributing factor(41). The exploration of synergistic interactions between plumbagin and other bioactive constituents within *P. zeylanica* may unveil novel strategies for enhancing its anti-anemic potential, paving the way for the development of standardized herbal formulations with improved efficacy and safety profiles.

Piper longum

Piper longum, commonly known as Indian long pepper, has been traditionally used in Siddha medicine for a wide range of therapeutic purposes, and its potential efficacy in treating anemia warrants careful scientific examination. The therapeutic properties of Piper species are attributed to the presence of diverse phytochemicals, including alkaloids, lignans, neolignans, terpenes, steroids, and flavonoids(42). While *Piper longum* is recognized for its various medicinal properties, its specific role in addressing anemia needs further exploration, particularly through well-designed clinical trials. Piperine, an alkaloid found in Piper species, has demonstrated the ability to enhance the bioavailability of various therapeutic agents(43). This enhancement could potentially improve the absorption and utilization of iron supplements, which are commonly prescribed for anemia(44,45). Investigating the mechanisms by which *Piper longum* or its constituents might influence iron absorption, erythropoiesis, or hemoglobin synthesis is crucial for understanding its potential anti-anemic effects. Furthermore, the use of Piper species in stimulating appetite may indirectly benefit individuals with anemia by promoting better nutritional intake(46).

Citrus limon

The investigation into the efficacy of *Citrus limon* (lemon) on anemia unveils a multifaceted interplay of biochemical mechanisms, hematological responses, and physiological adaptations that warrant careful consideration. The presence of various phytochemicals, including flavonoids and limonoids, within *Citrus limon* offers a plausible explanation for its potential anti-anemic effects(47). Ascorbic acid, a prominent component of citrus fruits, is known to enhance iron absorption by reducing ferric iron to the more bioavailable ferrous form in the gastrointestinal tract, thereby improving iron utilization and hemoglobin synthesis(48). Further exploration into the synergistic effects of multiple *Citrus limon* components could illuminate novel pathways for anemia management. The protective effects of citrus fruits have been linked to the antioxidant activities of their bioactive components, which may mitigate oxidative stress, a contributing factor to anemia development in certain conditions(49). The insights gleaned from this study may pave the way for the development of novel therapeutic strategies that leverage the inherent potential of *Citrus limon* in combating anemia and promoting overall health.

It is crucial to acknowledge that the bioavailability of non-heme iron, the predominant form of iron in plant-based foods, is influenced by various dietary factors, including phytates, tannins, and polyphenols, which can inhibit iron absorption(50). Ascorbic and citric acids can keep nonheme iron in a reduced and soluble form and greatly enhance its absorption. Understanding the pharmacokinetics of limonin is crucial for assessing its therapeutic potential and safety profile(51). Low water solubility of limonin leads to low oral bioavailability and discourages it as a compound candidate(52). The interaction between *Citrus limon* components and these dietary inhibitors, along with their combined impact on iron absorption, necessitates thorough investigation to optimize the utilization of *Citrus limon* as an anti-anemic agent(53). The ability of vitamin C to facilitate optimal iron absorption underscores its importance in preventing iron deficiency and promoting overall hematological health(54). Maintaining sufficient vitamin C concentration is necessary for the occurrence of many biological processes since vitamin C functions as an enzyme cofactor, a potent antioxidant, and it also has an immune function(55).

The complex interplay between iron availability and gut microbiota composition adds another layer of intricacy to the understanding of *Citrus limon's* impact on anemia. Oral administration of iron, while effective, can lead to unabsorbed iron in the gastrointestinal tract, affecting the host-microbe interface(56). Iron is an essential nutrient that



**Elansekarar Selladurai et al.,**

is required by virtually all living organisms; however, due to its chemical properties, excess iron can be toxic. The gut microbiota, a diverse community of microorganisms residing in the digestive tract, plays a vital role in nutrient metabolism, immune modulation, and overall host health. The presence of *Citrus limon* components may influence the gut microbiota's composition and activity, potentially modulating iron absorption and utilization. Dysbiosis, an imbalance in the gut microbiota, can disrupt iron homeostasis and contribute to the development of anemia(57). Furthermore, iron or heme supplementation can increase susceptibility to pathogens(58). Probing into the intricate connections between *Citrus limon*, gut microbiota, and iron metabolism could lead to targeted interventions that enhance iron bioavailability and promote a healthy gut environment, ultimately mitigating anemia and promoting overall well-being.

Pharmacological activities of the ingredients of *Bavana Kadukkai Mathirai* are depicted in Table 2

CONCLUSION

The Siddha formulation *BavanaKadukkaiMathirai* represents a holistic, traditional approach to combating anemia, rooted in the synergistic action of multiple herbs and minerals. The evidence gathered through traditional texts and modern research underscores the formulation's potential in stimulating hematopoiesis, improving iron bioavailability, reducing oxidative stress, and enhancing gut function. Ingredients such as *Haritaki*, *Zingiber officinale*, and *Citrus limon* demonstrate proven efficacy in improving hemoglobin levels through diverse mechanisms. Moreover, the inclusion of supportive agents like *rice water*, *rock salt*, and *Trachyspermumammi* reflects the thoughtful integration of digestives, absorbents, and mineral boosters. While the formulation is promising, further clinical trials and standardization efforts are essential to fully validate its therapeutic role and ensure its safety and efficacy in the broader population. This review lays the foundation for future interdisciplinary research and development of standardized Siddha-based interventions for anemia.

Author Contributions

Conceptualization: Anbarasan Balasubramanian, ElansekararSelladurai, VennilaKesavan, Sudha Revathy Senthil Kumar, Senthilvel G, Logamanian M; Drafting of the manuscript: Anbarasan Balasubramanian, ElansekararSelladurai, Shanmuga Priya R, VennilaKesavan, Sudha Revathy Senthil Kumar; Review and editing: Anbarasan Balasubramanian, ElansekararSelladurai, RajamanjariKalaiaamuthan, VennilaKesavan, Sudha Revathy Senthil Kumar, Senthilvel G, Logamanian M; Supervision: ElansekararSelladurai, Senthilvel G

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this manuscript.

Funding

Ministry of Ayush, Government of India.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the Ministry of Ayush, Government of India, for the financial support.

REFERENCES

1. Kantham TL, Rathiga G. Scientific Review on Food Custom of Siddha. International Journal of Trend in Scientific Research and Development [Internet]. 2018 May 19 [cited 2025 Jul 5];Volume-2(Issue-4). Available from: <https://www.ijtsrd.com/home-science/food-packaging-and-storage/13024/scientific-review-on-food-custom-of-siddha/g-rathiga>





Elansekararan Selladurai et al.,

2. Jose MATHEW, Regy YOHANNAN, Kadakasseril V. GEORGE. *Anisochilus petraeus* (Lamiaceae), a new species from Southern Western Ghats, India. TAIWANIA. 2017 Jun 1;62(2). doi:10.6165/tai.2017.62.144
3. N C, S UM. Food thy be medicine – A perspective from ancient Tamils. International Research Journal of Tamil. 2021 May 13;3(3):3. doi:10.34256/irjt2132
4. Anantha NDB. Approaches to pre-formulation R and D for phytopharmaceuticals emanating from herb based traditional Ayurvedic processes. J Ayurveda Integr Med. 2013;4(1):4–8. doi:10.4103/0975-9476.109542 PubMed PMID: 23741154; PubMed Central PMCID: PMC3667432.
5. Sivapriya V, Ponnarmadha S, Azeezand NA, Sudarshanadeepa V. NOVEL NANOCARRIERS FOR ETHNOPHARMACOLOGICAL FORMULATIONS. International Journal of Applied Pharmaceutics. 2018 Jul 7;26–30. doi:10.22159/ijap.2018v10i4.26081
6. Jaiswal A. Traditional Health Care and Traditional Medicine in India. AAOA. 2018 Jul 12;2(3). doi:10.31031/AAOA.2018.02.000537
7. Visalakshmi N, Bindu V. Development of health mix powder to combat anaemia. International journal of health sciences. 2022 May 16;6(S2):S2. doi:10.53730/ijhs.v6nS2.7395
8. Siddha Formulary of India Part I. 1st ed. Department of Health, Ministry of Health and Family Welfare, Government of India; 1992. 6 p.
9. Thiagarasan R. Theraiyar Paadal Thirattu. 1st ed. Chennai: Pandit S.S.Anandam; 1975. 32, 33 p.
10. Kumath V, Dadhich M. ROLE OF HARITAKI (TERMINALIA CHEBULA) IN THE MANAGEMENT OF PANDU ROGA (ANAEMIA). Journal of Research and Education in Indian Medicine. 2015 Jun 20;16(1):27–27.
11. Haas JD, Rahn M, Venkatramanan S, Marquis GS, Wenger MJ, Murray-Kolb LE, et al. Double-Fortified Salt Is Efficacious in Improving Indicators of Iron Deficiency in Female Indian Tea Pickers. J Nutr. 2014 Jun;144(6):957–64. doi:10.3945/jn.113.183228 PubMed PMID: 24744318; PubMed Central PMCID: PMC4018955.
12. Ramírez-Luzuriaga MJ, Larson LM, Mannar V, Martorell R. Impact of Double-Fortified Salt with Iron and Iodine on Hemoglobin, Anemia, and Iron Deficiency Anemia: A Systematic Review and Meta-Analysis. Adv Nutr. 2018 May 1;9(3):207–18. doi:10.1093/advances/nmy008 PubMed PMID: 29767699; PubMed Central PMCID: PMC5952925.
13. Al-Nahain A, Jahan R, Rahmatullah M. Zingiber officinale: A Potential Plant against Rheumatoid Arthritis. Arthritis. 2014;2014:159089. doi:10.1155/2014/159089 PubMed PMID: 24982806; PubMed Central PMCID: PMC4058601.
14. Dhanik J, Arya N, Nand V. A Review on Zingiber officinale. J Pharmacogn Phytochem. 2017;6(3):174–84.
15. Singh B, Sharma RA. Zingiber Species. In: Secondary Metabolites of Medicinal Plants, 4 Volume Set: Ethnopharmacological Properties, Biological Activity and Production Strategies. John Wiley & Sons; 2020.
16. de Lima RMT, Dos Reis AC, de Menezes AAPM, Santos JV de O, Filho JW de O, Ferreira JR de O, et al. Protective and therapeutic potential of ginger (Zingiber officinale) extract and [6]-gingerol in cancer: A comprehensive review. Phytother Res. 2018 Oct;32(10):1885–907. doi:10.1002/ptr.6134 PubMed PMID: 30009484.
17. Deng M, Yun X, Ren S, Qing Z, Luo F. Plants of the Genus Zingiber: A Review of Their Ethnomedicine, Phytochemistry and Pharmacology. Molecules. 2022 Jan;27(9):9. doi:10.3390/molecules27092826
18. Kareem MSMAE, Rabbih MAE fattah, Selim ETM. Identification of zingiber components by gas chromatograph/mass spectrometer and semi-empirical calculations. International Journal of Physical Research. 2016 May 14;4(1):1. doi:10.14419/ijpr.v4i1.6052
19. Tan JW, Israf DA, Tham CL. Major Bioactive Compounds in Essential Oils Extracted From the Rhizomes of Zingiber zerumbet (L) Smith: A Mini-Review on the Anti-allergic and Immunomodulatory Properties. Front Pharmacol. 2018;9:652. doi:10.3389/fphar.2018.00652 PubMed PMID: 29973880; PubMed Central PMCID: PMC6019502.
20. Sharifi-Rad M, Varoni EM, Salehi B, Sharifi-Rad J, Matthews KR, Ayatollahi SA, et al. Plants of the Genus Zingiber as a Source of Bioactive Phytochemicals: From Tradition to Pharmacy. Molecules. 2017 Dec 4;22(12):2145. doi:10.3390/molecules22122145 PubMed PMID: 29207520; PubMed Central PMCID: PMC6149881.
21. Khan G, Alam MF, Alshahrani S, Almoshari Y, Jali AM, Alqahtani S, et al. Trastuzumab-Mediated Cardiotoxicity and Its Preventive Intervention by Zingerone through Antioxidant and Inflammatory Pathway in





Elansekaran Selladurai et al.,

- Rats. J Pers Med. 2023 Apr 27;13(5):750. doi:10.3390/jpm13050750 PubMed PMID: 37240920; PubMed Central PMCID: PMC10221553.
22. Lete I, Allué J. The Effectiveness of Ginger in the Prevention of Nausea and Vomiting during Pregnancy and Chemotherapy. Integr Med Insights. 2016 Mar 31;11:11–7. doi:10.4137/IMI.S36273 PubMed PMID: 27053918; PubMed Central PMCID: PMC4818021.
 23. Li LL, Cui Y, Guo XH, Ma K, Tian P, Feng J, et al. Pharmacokinetics and Tissue Distribution of Gingerols and Shogaols from Ginger (*Zingiber officinale* Rosc.) in Rats by UPLC–Q-Exactive–HRMS. Molecules. 2019 Jan 31;24(3):512. doi:10.3390/molecules24030512 PubMed PMID: 30708987; PubMed Central PMCID: PMC6384666.
 24. Sawant P, Karekar P, Waghmare K. FORMULATION AND CHARACTERIZATION OF SOLID LIPID NANOPARTICLES CONTAINING GINGER OIL FOR ENHANCEMENT OF STABILITY. International Journal of Pharmacy and Pharmaceutical Sciences. 2020 Jun 1;36–44. doi:10.22159/ijpps.2020v12i6.37357
 25. Zhang Y, Su R, Yuan H, Zhou H, Jiangfang Y, Liu X, et al. Widely Targeted Volatilomics and Metabolomics Analysis Reveal the Metabolic Composition and Diversity of Zingiberaceae Plants. Metabolites. 2023 May 27;13(6):700. doi:10.3390/metabo13060700 PubMed PMID: 37367858; PubMed Central PMCID: PMC10301730.
 26. Shimoda H, Shan SJ, Tanaka J, Seki A, Seo JW, Kasajima N, et al. Anti-inflammatory properties of red ginger (*Zingiber officinale* var. *Rubra*) extract and suppression of nitric oxide production by its constituents. J Med Food. 2010 Feb;13(1):156–62. doi:10.1089/jmf.2009.1084 PubMed PMID: 20136450.
 27. Gupta J, Sharma B, Sorout R, Singh RG, Ittishree, Sharma MC. Ginger (*Zingiber officinale*) in traditional Chinese medicine: A comprehensive review of its anti-inflammatory properties and clinical applications. Pharmacological Research - Modern Chinese Medicine. 2025 Mar 1;14:100561. doi:10.1016/j.prmcm.2024.100561
 28. Chander V, Tewari D, Negi V, Singh R, Upadhyaya K, Aleya L. Structural characterization of Himalayan black rock salt by SEM, XRD and in-vitro antioxidant activity. Sci Total Environ. 2020 Dec 15;748:141269. doi:10.1016/j.scitotenv.2020.141269 PubMed PMID: 32798866.
 29. Bali S, Khan A. The Untold Health Benefits of Herbal Black Salt (Kala Namak): A Scientific Overview. Current Research in Complementary & Alternative Medicine [Internet]. 2024 Mar 8 [cited 2025 Jul 6]. Available from: <https://www.gavinpublishers.com/article/view/the-untold-health-benefits-of-herbal-black-salt--kala-namak-a-scientific-overview>
 30. Curcio A, Romano A, Nicola M, Gianfranco R, Pironti M. Efficacy and Safety of a New Formulation of Ferric Sodium EDTA Associated with Vitamin C, Folic Acid, Copper Gluconate, Zinc Gluconate and Selenomethionine Administration in Patients with Secondary Anaemia. J Blood Lymph. 2018;08(03). doi:10.4172/2165-7831.1000224
 31. Finlayson-Trick EC, Fischer JA, Goldfarb DM, Karakochuk CD. The Effects of Iron Supplementation and Fortification on the Gut Microbiota: A Review. Gastrointestinal Disorders. 2020 Dec;2(4):4. doi:10.3390/gidisord2040030
 32. Ramachandran P, Prabhakar K, Kumari H, Kalaivani K. Impact of the use of iron-fortified iodized salt on hemoglobin levels: a community based open randomized trial. International Journal of Community Medicine And Public Health. 2023 May 31;10(6):2197–207. doi:10.18203/2394-6040.ijcmph20231703
 33. Asif HM, Sultana S, Akhtar N. A panoramic view on phytochemical, nutritional, ethanobotanical uses and pharmacological values of *Trachyspermum ammi* Linn. Asian Pacific Journal of Tropical Biomedicine. 2014 Jul;4:S545–53. doi:10.12980/APJTB.4.2014APJTB-2014-0242
 34. Ekta Sharma, B S Arora. Phytochemical investigation of seeds of *Trachyspermum ammi* Linn. by GC-MS. J Chem En Sci A. 2017 Mar 1;3(2):91–100. doi:10.15415/jce.2017.32007
 35. Kotwal N. Foods Used as Ethno-medicine in Jammu. 2009.
 36. Enemali MO, Akolo J, Haruna GS, Bulus JE, Kassah PJ, Ejiogu IC. Hematological Parameters and Lipid Profile Changes in Albino Rats due to Administration of Ethanol Extract of *Ipomea batatas* Leaves. International Journal of Biochemistry Research & Review. 2021 Dec 13;1–12. doi:10.9734/ijbcr/2021/v30i930286
 37. S S, K K, G J. PHYSICO AND PHYTO-CHEMICAL ANALYSIS OF PLUMBAGO ZEYLANICA L. - A POTANT INDIAN HERB. Kongunadu Research Journal. 2014 Dec 30;1(2):2. doi:10.26524/krj48
 38. Singh B, Sharma RA. Plumbago Species. In: Secondary Metabolites of Medicinal Plants, 4 Volume Set: Ethnopharmacological Properties, Biological Activity and Production Strategies. John Wiley & Sons; 2020.





Elansekaran Selladurai et al.,

39. Moriasi G, Kibiti C, Ngugi M. In Vivo Antidiabetic Efficacy, Mineral Element Composition, and Qualitative Phytochemistry of the Aqueous Leaf Extracts of *Pentas zanzibarica* (Klotzsch.) Vatke and *Olea europaea* subspecies *africana* (Mill.). *J Adv Biotechnol Exp Ther*. 2021;4(3):334. doi:10.5455/jabet.2021.d134
40. Muriithi NJ, Maina GS, Mugendi NM. Determination of Hematological Effects of Methanolic Leaf Extract of *S. incanum* in Normal Mice. *Pharm Anal Acta*. 2015;6(10). doi:10.4172/2153-2435.1000429
41. Yadav A, Biharee A, Patel R kumar, Chaudhari L, Dubey D. A Comprehensive Review on Anti-Inflammatory Activity of The Traditional Plants *Plumbago zeylanica*(Chitra). *Human Journals*. 2021 Aug 30;22(1). doi:10.25166/ijppr.2021.v22i01.14
42. Salehi B, Zakaria ZA, Gyawali R, Ibrahim SA, Rajkovic J, Shinwari ZK, et al. Piper Species: A Comprehensive Review on Their Phytochemistry, Biological Activities and Applications. *Molecules*. 2019 Apr 7;24(7):1364. doi:10.3390/molecules24071364 PubMed PMID: 30959974; PubMed Central PMCID: PMC6479398.
43. Kaur S, Sharma R, Sarangal V, Kaur N, Prashar P. Evaluation of anti-inflammatory effects of systemically administered curcumin, lycopene and piperine as an adjunct to scaling and root planing: A clinical study. *Ayu*. 2017;38(3–4):117–21. doi:10.4103/ayu.AYU_63_17 PubMed PMID: 30254390; PubMed Central PMCID: PMC6153907.
44. Olalere OA, Abdurahman NH, Yunus R bin M, Alara OR. Data article on elemental and metabolomic-based alkaloidal composition in black pepper oleoresin using a positive ESI-mode LC-QToF and ICP-mass spectroscopy. *Data Brief*. 2018 Jun 26;19:1627–30. doi:10.1016/j.dib.2018.06.034 PubMed PMID: 30229034; PubMed Central PMCID: PMC6141158.
45. Tupe RS, Bangar N, Nisar A, Kulkarni A, Sankhe N, Chauhan R, et al. Piperine exhibits preventive and curative effect on erythrocytes membrane modifications and oxidative stress against in vitro albumin glycation. *J Food Biochem*. 2021 Jul 5:e13846. doi:10.1111/jfbc.13846 PubMed PMID: 34219237.
46. Amarowicz R. Antioxidant activity of peppers. *European Journal of Lipid Science and Technology*. 2014;116(3):237–9. doi:10.1002/ejlt.201400036
47. Patil BS, Brodbelt JS, Miller EG, Turner ND. Potential Health Benefits of Citrus: An Overview. In: *Potential Health Benefits of Citrus* [Internet]. American Chemical Society; 2006 [cited 2025 Jul 6]. p. 1–16. (ACS Symposium Series; no. 936). Available from: <https://doi.org/10.1021/bk-2006-0936.ch001> doi:10.1021/bk-2006-0936.ch001
48. Mehansho H, Kanerva RL, Hudepohl GR, Smith KT. Calcium bioavailability and iron-calcium interaction in orange juice. *J Am Coll Nutr*. 1989 Feb;8(1):61–8. doi:10.1080/07315724.1989.10720278 PubMed PMID: 2926077.
49. Silalahi J. Anticancer and health protective properties of citrus fruit components. *Asia Pac J Clin Nutr*. 2002;11(1):79–84. doi:10.1046/j.1440-6047.2002.00271.x PubMed PMID: 11890643.
50. Anderson GJ, Frazer DM. Current understanding of iron homeostasis. *Am J Clin Nutr*. 2017 Dec;106(Suppl 6):1559S–1566S. doi:10.3945/ajcn.117.155804 PubMed PMID: 29070551; PubMed Central PMCID: PMC5701707.
51. Fan S, Zhang C, Luo T, Wang J, Tang Y, Chen Z, et al. Limonin: A Review of Its Pharmacology, Toxicity, and Pharmacokinetics. *Molecules*. 2019 Oct 12;24(20):3679. doi:10.3390/molecules24203679 PubMed PMID: 31614806; PubMed Central PMCID: PMC6832453.
52. Dong L, Liu W, Zhao X, Yu F, Xu Y, Su M. Preclinical Drug Pharmacokinetic, Tissue Distribution and Excretion Profiles of the Novel Limonin Derivate HY-071085 as an Anti-Inflammatory and Analgesic Candidate in Rats and Beagle Dogs. *Pharmaceuticals (Basel)*. 2022 Jun 27;15(7):801. doi:10.3390/ph15070801 PubMed PMID: 35890101; PubMed Central PMCID: PMC9316000.
53. Hallberg L, Brune M, Rossander L. The role of vitamin C in iron absorption. *Int J Vitam Nutr Res Suppl*. 1989;30:103–8. PubMed PMID: 2507689.
54. Triswanti, Maghfiroh T. The Difference Of Effectiveness way to Consume Iron tablets toward haemoglobin level changes to pregnant women in second trimester at the Sindang Barang community health center in 2017. *Journal Of Nursing Practice*. 2020 Apr 29;3(2):188–92. doi:10.30994/jnp.v3i2.97
55. Zakić T, Budnar M, Kalezić A, Korać A, Janković A, Korać B. Vitamin C biochemistry: From scurvy to COVID-19 treatment. *Hrana i ishrana*. 2020;61(2):59–70. doi:10.5937/hraIsh2002059Z
56. Yilmaz B, Li H. Gut Microbiota and Iron: The Crucial Actors in Health and Disease. *Pharmaceuticals (Basel)*. 2018 Oct 5;11(4):98. doi:10.3390/ph11040098 PubMed PMID: 30301142; PubMed Central PMCID: PMC6315993.





Elansekarar Selladurai et al.,

57. Sheldon JR, Laakso HA, Heinrichs DE. Iron Acquisition Strategies of Bacterial Pathogens. Microbiol Spectr. 2016 Apr;4(2). doi:10.1128/microbiolspec.VMBF-0010-2015 PubMed PMID: 27227297.
58. Lopez CA, Skaar EP. The Impact of Dietary Transition Metals on Host-Bacterial Interactions. Cell Host Microbe. 2018 Jun 13;23(6):737–48. doi:10.1016/j.chom.2018.05.008 PubMed PMID: 29902439; PubMed Central PMCID: PMC6007885.

Table 1. Ingredients of Bavana Kadukkai Mathirai

S. No	Name of the Ingredient	Scientific name / English name	Quantity
1.	Kadukkai	<i>Terminalia chebula</i> Retz.	750 grams
2.	Kazhuneer	Rice-rinsed water	Sufficient quantity
3.	Mor	Buttermilk	Sufficient quantity
4.	Kadaluppu	Common salt	¼ of the weight of item 1)
5.	Chukku	<i>Zingiber officinale</i> Roscoe	18 grams
6.	Attuppu	—	18 grams
7.	Indhuppu	Rock salt	18 grams
8.	Omam	<i>Trachyspermum ammi</i> L.	18 grams
9.	Chevviyam	The root of <i>Piper nigrum</i> L.	18 grams
10.	Chithiramoolaverpattai	<i>Plumbago zeylanica</i> L.	18 grams
11.	Thippili	<i>Piper longum</i> L.	18 grams
12.	Elumichampazhacharu	Juice of <i>Citrus limon</i> L.	Sufficient quantity
13.	Injichaaru	Juice of <i>Zingiber officinale</i> Roscoe	Sufficient quantity

Table 2. Pharmacological Profile of Bavana Kadukkai Mathirai

S. No.	Ingredients			Pharmacological Actions	References
	Vernacular Name	Common/English Name	Scientific Name		
1	Kadukkai	Ink Nut / Chebulic Myrobalan	<i>Terminalia chebula</i>	Hematinic (increases Hb%), laxative, appetite stimulant, anti-diarrheal, and Tridosha balancer.	(10)
3	Kadaluppu	Sea salt	Sodium chloride	Iron status improvement (when fortified) and electrolyte source.	(11)
4	Chukku / Inji	Dry Ginger	<i>Zingiber officinale</i>	Antioxidant, anti-inflammatory, stimulates erythropoiesis, and protect red blood cells from oxidative damage.	(18,19,27)
5	Indhuppu	Rock salt	Sodium chloride impura	Mineral-rich (Iron, Zinc, Mg), enhances iron levels, and improves hemoglobin levels.	(28,29,32)
6	Omam	Ajwain	<i>Trachyspermum ammi</i>	Digestive stimulant and source of essential micronutrients including iron.	(33–35)
7	Chitramoolam	Ceylon leadwort	<i>Plumbago zeylanica</i>	Hematinic, antioxidant, anti-inflammatory, and stimulates red blood cell production.	(36,39,41)
8	Thippili	Indian long pepper	<i>Piper longum</i>	Enhances bioavailability of nutrients (Piperine), anti-	(44–46)





Elansekaran Selladurai and et al.,

				anemic, and digestive.	
9	Elumichai	Lemon	<i>Citrus limon</i>	Enhances iron absorption (Vitamin C), antioxidant, and immune modulator.	(48,49,55)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





REVIEW ARTICLE

***Justicia santapau* Benn. and Rau: A Comprehensive Review Of The Taxonomy, Phytochemistry, And Conservation Status Of A Narrowly Endemic Medicinal Plant From The Western Ghats Biodiversity Hotspot**

Dhanya S R^{1*} and P M Radhamany²

¹Department of Botany, University of Kerala, Kariavattom, Thiruvananthapuram, Kerala, India.

²Emeritus Professor, Department of Botany, University of Kerala, Kariavattom, Thiruvananthapuram, Kerala, India.

Received: 29 Jan 2026

Revised: 10 Apr 2026

Accepted: 05 May 2026

***Address for Correspondence**

Dhanya S R

Department of Botany,

University of Kerala, Kariavattom,

Thiruvananthapuram, Kerala, India

E.Mail: dhanyaresearch85@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The genus *Justicia* L. (Acanthaceae) is globally renowned for its medicinal species, most notably *Justicia adhatoda*. However, numerous endemic congeners remain critically understudied. This review synthesizes the fragmented body of knowledge on *Justicia santapau*, an erect, suffrutescent undershrub endemic to the moist deciduous forests of the Western Ghats of India. Through a systematic, multi-disciplinary methodology, we consolidate its taxonomic history, morphological distinctness, narrow phytogeographic distribution, and sparse ethnobotanical record. The species is characterized by bilabiate corollas and uniquely spurred anthers, yet its phylogenetic position remains unresolved due to a complete absence of molecular sequence data in public repositories. While preliminary phytochemical screenings confirm the presence of quinazoline alkaloids and flavonoids, comprehensive pharmacological profiling is lacking. Our analysis reveals that *J. santapau* is a classic niche-conservative species, whose strict riparian micro-habitat specificity renders it acutely vulnerable to habitat fragmentation, climate change, and anthropogenic pressures. Despite its occurrence in some protected areas, its conservation status is "Not Evaluated," with an Extent of Occurrence likely below 5,000 km². This review identifies critical knowledge gaps in molecular phylogenetics, metabolomics, and population ecology. It argues that an integrated conservation strategy, combining *in situ* habitat protection, *ex situ* cultivation, and targeted bioprospecting research, is urgently required. By framing this endemic not merely as a botanical novelty but as a potential reservoir for novel bioactive compounds, this work provides a foundational framework to catalyze future research and evidence-based conservation, preventing the loss of a unique evolutionary lineage with significant, yet unrealized, scientific and medicinal value.

Keywords: Acanthaceae; *Justicia santapau*; Western Ghats Endemic; Phytochemistry; Conservation; DNA Barcoding





INTRODUCTION

The family Acanthaceae comprises a diverse group of approximately 221 genera and 4,000 species, predominantly distributed across tropical and subtropical ecosystems (Brummitt, 1992). Within this family, the genus *Justicia* L. represents the largest and most taxonomically complex assemblage, with over 600 species recognized globally. In the Indian subcontinent, the genus is represented by a plethora of species that have integrated deeply into traditional medicinal systems, particularly for their efficacy in treating respiratory ailments, inflammatory conditions, and gastrointestinal disorders (Karthikeyan et al., 2009). From an ethnobotanical perspective, the genus *Justicia* holds a venerable position in India's traditional knowledge systems. Species such as *J. adhatoda* (Vasaka) are cornerstones of Ayurveda, Siddha, and folk medicine, prescribed for a spectrum of conditions from bronchitis and asthma to hepatic disorders (Claeson et al., 2000). This established ethnomedicinal pedigree provides a strong *prima facie* rationale for the biochemical exploration of its lesser-known relatives. While the pharmacological potential of species like *J. adhatoda* has been extensively validated through the isolation of quinazoline alkaloids such as vasicine and vasicinone, many congeneric species remain under-explored in mainstream phytochemistry (Datta & Ghosh, 2019; Corrêa & Alcântara, 2012).

Among the endemic flora of the Western Ghats, one of the world's eight "hottest" biodiversity hotspots and a UNESCO World Heritage Site, *Justiciasantapau* emerges as a species of profound botanical and ecological significance (Myers et al., 2000; Mittermeier et al., 2003). Named in honor of the eminent botanist Father Hermenegild Santapau, this species is an erect, suffrutescent undershrub characterized by its distinct bilabiate corolla and spurred anthers—features that serve as critical taxonomic markers within the *Justicia* complex (Santapau, 1953; Singh et al., 2001). Endemic species like *J. santapau* are not merely botanical curiosities but represent unique genetic lineages shaped by millennia of ecological isolation within this region's unique topography and climatic gradients (Nayar, 1996; Fine et al., 2004). Their study is critical for understanding evolutionary processes and completing the biodiversity inventory of this fragile ecosystem (Gunaga et al., 2021). The contemporary crisis of biodiversity loss in the Western Ghats, driven by anthropogenic pressures like agricultural expansion and habitat fragmentation, places narrow-range endemics like *J. santapau* at immediate risk (Jha et al., 2000). Its survival is intrinsically linked to the preservation of its specific micro-habitat in moist deciduous forests. Furthermore, the lack of integrated molecular data, such as DNA barcoding (ITS and *matK* markers), has led to challenges in accurately mapping its phylogenetic position relative to other South Indian *Justicia* species (McDade et al., 2000; Kiel et al., 2017). A robust, multi-disciplinary characterization is therefore the first critical step in formulating evidence-based conservation strategies (Margules & Pressey, 2000).

In the modern paradigm of drug discovery, where natural products continue to inspire a significant proportion of new therapeutic entities, unexplored endemic plants offer a promising frontier (Newman & Cragg, 2020). The comparative phytochemistry of *Justicia* species suggests a likelihood of finding unique alkaloids, flavonoids, and terpenoids in *J. santapau* (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019). Preliminary, unpublished field observations from tribal communities also hint at its localized use (Kulkarni & Kumbhojar, 1996; Kshirsagar & Singh, 2000), underscoring the urgency to validate this indigenous knowledge. A comprehensive phytochemical profile could reveal compounds with novel mechanisms of action, particularly relevant in an era of increasing antimicrobial resistance (Fabricant & Farnsworth, 2001). Despite its potential as a reservoir for novel secondary metabolites, there is no comprehensive documentation that synthesizes its morphological, chemical, and molecular attributes. This review aims to bridge this knowledge gap by providing an exhaustive analysis of *Justiciasantapau*. By consolidating existing data, this paper establishes a consolidated reference to advocate for its conservation, clarify its taxonomic standing, and catalyze future research aimed at unlocking its potential for bio-prospecting and future drug discovery.





MATERIALS AND METHODS

The present review was executed through a multi-disciplinary synthesis of botanical, phyto chemical, and molecular data. The methodology was designed to provide a holistic overview of *Justiciasantapau* by integrating historical floristic records with modern analytical data.

Literature Search Strategy and Data Mining

A systematic search was conducted across global scientific databases including PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect. The search period extended from the earliest botanical descriptions in the 1950s to January 2026. Keywords utilized included: "*Justiciasantapau*", "Acanthaceae", "Western Ghats endemic", "Santapau's *Justicia*", and "Vasicine derivatives". Grey literature, including doctoral theses and conference proceedings, was accessed via Shodhganga and the physical archives of the Botanical Survey of India (BSI), Western Regional Centre, Pune.

Taxonomic and Morphological Synthesis

Morphological data were compiled from original protologues and foundational regional floras, specifically the *Flora of the Presidency of Bombay* (Cooke, 1908) and the *Flora of Maharashtra State* (Singh et al., 2001). Diagnostic features—habit, phyllotaxy, bilabiate corolla architecture, and the presence of basal anther spurs—were standardized according to the Acanthaceae terminology (Graham, 1988). Digital type specimens from the Kew Herbarium (K) and the Central National Herbarium (CAL) were reviewed to resolve any nomenclatural ambiguities.

Phytogeographic and Ecological Mapping

Distributional records were collated from herbarium sheets (MH, CAL, BSI) and global biodiversity portals (GBIF, iNaturalist). Ecological parameters, including altitudinal range, soil type, and micro-climatic preferences in moist deciduous forests, were extracted to define the species' bioclimatic niche (Fine et al., 2004; Kulkarni et al., 2016).

Ethnobotanical Assessment

Traditional knowledge regarding the use of *Justicia* species by indigenous communities (such as the MahadeoKoli and Pawara tribes) was sourced from published ethnobotanical surveys of the Northern Western Ghats (Kulkarni & Kumbhojar, 1996; Patil & Patil, 2000; Kshirsagar & Singh, 2000). Comparative analysis with classical Ayurvedic texts was performed to identify potential therapeutic parallels between *J. santapau* and the well-documented *J. adhatoda* (Claeson et al., 2000).

Phytochemical and Pharmacological Data Extraction

Given the limited primary data on *J. santapau*, a comparative phytochemistry approach was adopted. Profiles of major secondary metabolites—specifically quinazoline alkaloids, flavonoids, and lignans—were reviewed for closely related taxa (*J. gendarussa* and *J. montana*) (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019). Reported bioactivities, including anti-inflammatory and bronchodilatory effects, were summarized to hypothesize the pharmacological potential of the target species.

Molecular Phylogeny and DNA Barcoding

Phylogenetic data were retrieved from the NCBI GenBank database, focusing on standard barcode regions: ITS, *matK*, and *rbcl*. Sequences were analyzed to determine the species' placement within the *Justicia* clade relative to other South Indian endemics (McDade et al., 2000; Kiel et al., 2017). Significant gaps in the molecular record were documented as priority areas for future research.





Dhanya and Radhamany

Conservation Status and Threat Assessment

The conservation status was cross-referenced with the IUCN Red List of Threatened Species (IUCN, 2022). In cases where formal assessments were absent, a preliminary threat analysis was conducted based on the Extent of Occurrence (EOO) and Area of Occupancy (AOO) using the criteria established by the IUCN Species Survival Commission (IUCN, 2022).

Data Integration and Gap Analysis

All streams of information were synthesized to identify "knowledge voids." The resulting synthesis highlights critical needs for *in vitro* pharmacological validation and population genetic studies. The integrated data is presented through standardized tables to facilitate future research.

RESULTS

Taxonomic Delineation and Morphological Characterization

The systematic position of the species is established as follows:

- Kingdom: Plantae
- Division: Tracheophyta
- Class: Magnoliopsida
- Order: Lamiales
- Family: Acanthaceae
- Genus: *Justicia* L.
- Species: *Justiciasantapau* Benn. & Rau (Synonym: *Justiciamontana* Santapau non Wall.)

Dichotomous Key to *Justiciasantapau* and Related Congeners in the Western Ghats

(adapted from Daniel & Unnithan, 1991; Singh et al., 2001)

- Anther cells distinctly bitheous; lower cell with a prominent, white, curved basal spur..... 2
 Anther cells without a prominent spur; base rounded or only minutely pointed..... 3
 Bracts large, leafy, and imbricate; spikes terminal; flowers white with purple streaks..... *J. santapau*
 Bracts smaller, linear-lanceolate; spikes axillary and terminal; leaves with dark purple stems..... *J. gendarussa*
 Bracts conspicuous, white with green reticulate veins, giving a "tessellated" appearance..... *J. betonica*
 Bracts predominantly green; spikes very large (up to 20 cm); leaves large and broad (>15 cm)..... *J. montana*

Detailed Morphology:

Justiciasantapau is an erect, perennial undershrub reaching heights of 1–1.5 m (Santapau, 1953; Singh et al., 2001).

- **Stem:** Sub-quadrangular, swollen at the nodes, predominantly glabrous.
- **Leaves:** Opposite-decussate, 10–20 cm long, ovate-lanceolate, acuminate at the apex, with 8–12 pairs of lateral nerves.
- **Inflorescence:** Terminal or axillary spikes, 5–15 cm long.
- **Flowers:** Bilabiate, typically white with faint purple streaks on the lower lip.
- **Stamens:** Two; filaments glabrous.
- **Key Diagnostic Feature:** The anthers are bitheous, with the lower cell significantly spurred at the base, a character that distinguishes it from the non-spurred or weakly spurred *J. montana* (Daniel & Unnithan, 1991).
- **Fruit:** An oblong, 4-seeded capsule.

Phytogeography and Habitat Ecology

- **Distribution:** *J. santapau* is a narrow endemic of the Western Ghats, primarily documented from the Khandala, Mahabaleshwar, and Pune districts of Maharashtra (Santapau, 1953; Mishra & Singh, 2001). Its range extends





Dhanya and Radhamany

sparingly into the evergreen forests of Karnataka (Saldanha, 1996). The Extent of Occurrence (EOO) is estimated to be less than 5,000 km² (Kulkarni et al., 2016).

- **Habitat:** The species prefers shaded, humid micro-habitats, particularly along the banks of perennial forest streams and ravines. It occurs at altitudes ranging from 600 m to 1200 m, often in lateritic soils within moist deciduous to semi-evergreen forest fragments (Kulkarni et al., 2016).
- **Phenology:** Flowering occurs during the post-monsoon period (October–December), with fruiting extending into late February (Santapau, 1953).

Ethnobotanical and Traditional Knowledge

A review of tribal pharmacopeia in the Sahyadri ranges reveals that *J. santapau* is occasionally used by the Thakar and MahadeoKoli tribes (Kulkarni & Kumbhojar, 1996; Kshirsagar & Singh, 2000). Leaf decoctions are reported for treating respiratory congestion, mirroring the use of *J. adhatoda* (Claeson et al., 2000). However, the synthesis indicates a severe lack of species-specific ethnobotanical documentation, with most uses being "implied" due to its morphological similarity to more common congeners.

Phytochemical Constituents

Phytochemical data for *J. santapau* are sparse. Preliminary qualitative screenings confirm the presence of alkaloids (Vasicine-type), tannins, and flavonoids (Sharma & Patil, 2015). A comparative analysis suggests it may contain compounds similar to those found in related species like *J. gendarussa* (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019).

Pharmacological Activities

Specific biological assays on *J. santapau* are limited. One reported study indicates that methanolic leaf extracts exhibit antimicrobial activity against *Bacillus subtilis* and *Escherichia coli* (Sharma & Patil, 2015). Comparative pharmacological data from related *Justicia* species suggest potential bronchodilatory and anti-inflammatory properties (Claeson et al., 2000; Corrêa & Alcântara, 2012), though these require rigorous *in vivo* validation for *J. santapau*.

Molecular Phylogenetics and Genetic Data

A search of the NCBI GenBank database reveals a critical research gap: there are currently no dedicated ITS, *matK*, or *rbcL* sequences deposited for *J. santapau* (McDade et al., 2000; Kiel et al., 2017). Its phylogenetic position is currently inferred through its morphological placement in the *Justicia* lineage, characterized by 2-colporate pollen grains (Daniel, 2010).

Conservation Status and Documented Threats

- **IUCN Status:** Not Evaluated (NE); however, based on its narrow endemism, it warrants a "Vulnerable" or "Data Deficient" (DD) status (IUCN, 2022; Kulkarni et al., 2016).
- **Threats:** The primary threats include habitat loss due to infrastructure development (road widening), tourism-related forest clearance in hill stations, and the encroachment of invasive species like *Lantana camara* (Jha et al., 2000; Mishra & Singh, 2001).
- **Protected Areas:** A few populations are conserved within the Bhimashankar Wildlife Sanctuary and Koyna Wildlife Sanctuary (Mishra & Singh, 2001).

DISCUSSION

The present review synthesizes the fragmented body of knowledge on *Justiciasantapau*, revealing a species that epitomizes both the promise and the peril inherent in the endemic flora of the Western Ghats. Our analysis underscores a profound contradiction: while its distinct morphology and specialized ecology mark it as a unique product of evolution, it remains conspicuously absent from the annals of modern phytochemistry and molecular



**Dhanya and Radhamany**

systematics. This discussion interprets these findings, weaving together taxonomic, ecological, and biochemical narratives to argue for its urgent re-evaluation as a priority species for both conservation and bioprospecting.

Taxonomic Identity and Phylogenetic Ambiguity:

A Case for Integrative Revision The morphological distinctiveness of *Justicia santapau*, particularly its bitheous anthers with prominent, curved basal spurs and its imbricate, lanceolate bracteoles, provides a robust phenotypic basis for its species status (Cooke, 1908; Singh et al., 2001). These characters are consistent and reliable for field identification, cementing its place in regional floristic treatments. However, taxonomy in the 21st century demands an integrative approach. The genus *Justicia* is notoriously complex, with convergent evolution often blurring morphological boundaries between species clusters (Graham, 1988). The complete absence of molecular data for *J. santapau*—with no sequences for standard plastid (*matK*, *rbcL*, *trnH-psbA*) or nuclear (ITS) loci in public repositories—represents a critical taxonomic vulnerability (McDade et al., 2000; Kiel et al., 2017).

This molecular void leaves several pivotal questions unanswered. Is *J. santapau* a true endemic lineage that diverged early within the *Justicia* radiation of the Peninsular Indian plate? Or is it a more recent derivative of a widespread ancestor like *J. betonica*, having undergone rapid morphological divergence in isolation? Without a resolved phylogeny, its conservation prioritization lacks an evolutionary context. For instance, if it is a basal lineage, its loss would represent a disproportionate erosion of phylogenetic diversity. Therefore, an integrated taxonomic revision employing DNA barcoding alongside detailed morphometric analysis of populations is not merely an academic exercise but a foundational step for accurate conservation genetics and understanding biogeographic patterns in the Western Ghats (Kiel et al., 2017; Gunaga et al., 2021).

Ecological Specialization and Acute Vulnerability:

The phylogeographic data consolidates *J. santapau* as a classic niche-conservative species. Its strict confinement to shaded, perennial stream banks in mid-elevation (600-900 m) moist deciduous forests points to a highly specific set of abiotic requirements: constant high humidity, well-drained lateritic soils, and filtered canopy light (Fine et al., 2004; Kulkarni et al., 2016). This "micro-habitat specificity" is a double-edged sword. While it has allowed the species to thrive in a stable ecological niche for millennia, it now forms the basis of its extreme vulnerability. Climate change projections for the Western Ghats indicate increased variability in monsoon patterns and prolonged dry spells, which could directly desiccate its riparian habitats (Krishnaswamy et al., 2014).

Furthermore, anthropogenic threats are not abstract but immediate. The conversion of forest edges for agriculture, the proliferation of invasive species like *Lantana camara* that alter understory ecology, and tourism-driven infrastructure development along scenic waterways directly fragment and degrade its limited habitat (Jha et al., 2000; Margules & Pressey, 2000). Consequently, *J. santapau* serves as an ideal "indicator species" for the health of its specific ecosystem. Its population decline would signal the degradation of the fragile riparian corridors that are vital for watershed management and soil conservation. Protecting *J. santapau*, therefore, necessitates a habitat-centric approach, advocating for the preservation of entire ecological communities rather than a single species (Nayar, 1996; Mittermeier et al., 2003).

The Phytochemical 'Black Box' and Bioprospecting Potential:

From Analogy to Discovery The pharmacological legacy of the genus *Justicia*, most famously *J. adhatoda*, creates a powerful heuristic for exploring *J. santapau* (Claeson et al., 2000; Corrêa & Alcântara, 2012). However, to treat it merely as a potential source of vasicine-like alkaloids is to underestimate its true potential. The principles of chemical ecology suggest that endemics in biodiversity hotspots, subjected to unique biotic and abiotic pressures, often evolve distinct secondary metabolite profiles as a defense mechanism (Fine et al., 2004; Fabricant & Farnsworth, 2001). The "montane island" effect of the Western Ghats has likely acted as a crucible for such biochemical innovation.

Thus, *J. santapau* is not just an unexplored species; it is an untapped chemical library. Preliminary, unpublished phytochemical screenings (alluded to in grey literature) suggest the presence of unique flavonoid glycosides not reported in *J. adhatoda* (Sharma & Patil, 2015). This hints at the possibility of discovering novel scaffolds with modified bioactivity—perhaps compounds with enhanced anti-inflammatory potency or novel mechanisms of antimicrobial



**Dhanya and Radhamany**

action. In an era of escalating antibiotic resistance and complex chronic diseases, systematically mining the chemistry of such endemics could yield the next generation of lead compounds (Newman &Cragg, 2020). The bioprospecting narrative must shift from one of analogy ("similar to *J. adhatoda*") to one of anticipated novelty ("unique because of its endemicity").

Bridging the Ethnobotanical Chasm:

From Silent Erosion to Scientific Validation A striking outcome of this review is the near-total absence of documented traditional knowledge specific to *J. santapauai*. This "ethnobotanical silence" is alarming and likely represents a case of knowledge erosion preceding species extinction (Kulkarni &Kumbhojar, 1996). Local communities may have once used it, but its rarity and restricted habitat may have severed the transmission of this knowledge. Alternatively, it may have been used under a generic local name for "*Justicia*," its specific identity unrecognized (Kshirsagar& Singh, 2000).This gap presents both a challenge and a methodology. A proactive, targeted ethnobotanical survey within its endemic range, employing detailed herbarium specimens for precise identification, is urgently needed (Jain & Rao, 1977). Such a "reverse pharmacology" approach—where a specific plant is taken from field observation to laboratory bench—can be highly efficient (Fabricant & Farnsworth, 2001). If any traditional use is documented, it provides a strong, culturally-informed hypothesis for pharmacological testing. Bridging this chasm is not just about data collection; it is an act of conserving intangible cultural heritage and fostering community-led conservation, where local stakeholders recognize the scientific value of their floral heritage.

Forging an Integrated Conservation Strategy:

Science as a Catalyst for Survival The synthesis of data clearly dictates that a singular approach will fail. An integrated, multi-pronged strategy is imperative: Immediate Assessment and Monitoring: A rapid, field-based assessment to map all extant populations, calculate updated EOO/AOO, and initiate demographic monitoring is the first step toward a formal, data-driven IUCN Red List assessment (IUCN, 2022; Margules&Pressey, 2000).

In Situ and *Ex Situ* Synergy: Core habitats must be secured within the Protected Area network, with management plans addressing invasive species and hydrological integrity. Concurrently, *ex situ* conservation through seed banking (following IUCN protocols) and cultivation in affiliated botanical gardens (e.g., TBGRI) is essential as an insurance policy (CPC, 2019).

Phytochemistry as a Conservation Tool: Demonstrating tangible economic and medicinal value through phytochemical research can be a powerful argument for securing conservation funding and policy support. It transforms the species from an "obscure endemic" to a "valuable genetic resource" (Newman &Cragg, 2020).

Community Engagement and Capacity Building: Involving local communities in monitoring and *ex situ* cultivation can generate stewardship, create alternative livelihoods, and ensure long-term sustainability (Kulkarni &Kumbhojar, 1996) In conclusion, *Justiciasantapauai* stands at a crossroads. It is a testament to the unique evolutionary history of the Western Ghats, yet it is perilously close to becoming a silent casualty of neglect and habitat loss. This review serves as a clarion call. The path forward requires a concerted effort where taxonomists, ecologists, phytochemists, pharmacologists, and conservation biologists collaborate. By unlocking its genetic, chemical, and ecological secrets, we not only champion the survival of a single species but also uphold the principle that in preserving such endemic treasures, we safeguard the future of bio-discovery itself.

CONCLUSION

Justiciasantapauai stands as a compelling paradox—a species whose very existence embodies the rich botanical heritage of the Western Ghats while simultaneously teetering on the brink of obscurity and potential loss. This comprehensive review has synthesized the scattered knowledge surrounding this endemic undershrub, revealing a profile marked by distinct morphological identity, stringent ecological specialization, and a profound, yet largely unexplored, biochemical potential. Its defining characteristics—the spurred anthers and riparian habitat specificity—secure its status as a unique evolutionary entity within the complex *Justicia* lineage. However, the same ecological fidelity that



**Dhanya and Radhamany**

shaped its evolution now constitutes its greatest vulnerability, making it acutely susceptible to habitat fragmentation and climate change. The critical analysis undertaken here exposes significant and interconnected knowledge gaps. The absence of molecular phylogenetic data leaves its evolutionary relationships ambiguous. The near-total lack of dedicated phytochemical and pharmacological profiling means its potential as a source of novel bioactive compounds remains hypothetical. Most concerning, the erosion of associated traditional knowledge, coupled with its "Data Deficient" conservation status, creates a scenario where the species could vanish before its scientific value is fully recognized or its ecological role understood.

Therefore, this review serves as both a consolidation and a catalyst. It provides the first integrated framework for understanding *J. santapau*, but its ultimate purpose is to mandate action. The species must be rapidly transitioned from a subject of academic review to a priority for active, interdisciplinary research and targeted conservation. The imperative is clear: coordinated efforts in molecular taxonomy, systematic phytochemistry, and detailed population ecology are not merely academic pursuits but essential prerequisites for preventing its extinction. By championing the study and preservation of *Justiciasantapau*, we commit to a broader principle—that the survival of such endemic treasures is inextricably linked to the health of their ecosystems and vital to the future of biodiversity-based discovery. Unlocking its secrets could yield scientific and medicinal rewards, but only if we act with urgency to ensure this endemic narrative does not end with an untimely conclusion.

REFERENCES

1. Brummitt RK. Vascular Plant Families and Genera. London: Royal Botanic Gardens, Kew; 1992.
2. Claeson UP, Malmfors T, Wikman G, Bruhn JG. Adhatodavasica: a critical review of ethnopharmacological and toxicological data. J Ethnopharmacol. 2000;72(1-2):1-20.
3. Cooke T. The Flora of the Presidency of Bombay. Vol. 2. London: Taylor and Francis; 1908.
4. Corrêa GM, Alcântara AF. Chemical constituents and biological activities of species of Justicia: a review. Braz J Pharmacogn. 2012;22(1):220-238.
5. CPC (Center for Plant Conservation). International Guidelines for the Conservation of Ex situ Plant Collections. CPC; 2019.
6. Daniel P, Unnithan VK. The genus Justicia L. (Acanthaceae) in Peninsular India. J Bombay Nat Hist Soc. 1991;88(3):385-395.
7. Daniel TF. Justicia (Acanthaceae) in Mexico: an overview. Proc Calif Acad Sci. 2010;61(1):1-12.
8. Datta A, Ghosh S. Quinazoline alkaloids from Justicia species: chemistry and medicinal significance. Phytochem Rev. 2019;18(3):761-803.
9. Fabricant DS, Farnsworth NR. The value of plants used in traditional medicine for drug discovery. Environ Health Perspect. 2001;109(Suppl 1):69-75.
10. Fine PVA, Mesones I, Coley PD. Herbivores promote habitat specialization by trees in Amazonian forests. Science. 2004;305(5684):663-665.
11. Graham VAW. The delimitation of Justicia and its allies (Acanthaceae). Kew Bull. 1988;43(4):551-624.
12. Gunaga S, Rajeshwari S, Vasudeva R. Endemic flowering plants of the Northern Western Ghats: a review. Rheede. 2021;31(1):4-24.
13. IUCN. Guidelines for Using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee; 2022.
14. Jain SK, Rao RR. A Handbook of Field and Herbarium Methods. New Delhi: Today and Tomorrow's Printers and Publishers; 1977.
15. Jha CS, Dutt CBS, Bawa KS. Land use and land cover change dynamics in the Western Ghats. Curr Sci. 2000;79(2):231-238.
16. Karthikeyan S, Sanjappa M, Moorthy S. Flowering Plants of India: Dicotyledons (Acanthaceae – Avicenniaceae). Vol. 1. Botanical Survey of India; 2009.





Dhanya and Radhamany

17. Kiel CA, Daniel TF, Darbyshire I, McDade LA. Unraveling relationships in the Justicia lineage (Acanthaceae: Justicieae). *Taxon*. 2017;66(3):645-674.
18. Krishnaswamy J, John R, Joseph S. Consistent response of vegetation dynamics to recent climate change in tropical mountain regions. *Glob Change Biol*. 2014;20(1):203-215.
19. Kshirsagar RD, Singh NP. Ethnobotanical studies of Acanthaceae in Maharashtra. *Ethnobotany*. 2000;12:46-51.
20. Kulkarni DK, Kumbhojar MS. Ethnobotanical studies on MahadeoKoli tribe in Western Maharashtra. *J Econ Taxon Bot*. 1996;20(1):145-152.
21. Kulkarni DK, Patil MV, Garad KU. Prioritizing endemic plants of the Northern Western Ghats for conservation. *J Threat Taxa*. 2016;8(6):8870-8882.
22. Margules CR, Pressey RL. Systematic conservation planning. *Nature*. 2000;405(6783):243-253.
23. McDade LA, Daniel TF, Kiel CA. Phylogenetic relationships within Acanthaceae: evidence from nrITS and trnL-F sequence data. *Am J Bot*. 2000;87(10):1558-1573.
24. Mishra DK, Singh NP. Endemic and Threatened Flowering Plants of Maharashtra. Botanical Survey of India; 2001.
25. Mittermeier RA, Mittermeier CG, Brooks TM, Pilgrim JD, Konstant WR, da Fonseca GAB, et al. Wilderness and biodiversity conservation. *Proc Natl Acad Sci U S A*. 2003;100(18):10309-10313.
26. Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. *Nature*. 2000;403(6772):853-858.
27. Nayar MP. "Hot Spots" of Endemic Plants of India, Nepal and Bhutan. Thiruvananthapuram: Tropical Botanic Garden and Research Institute; 1996.
28. Newman DJ, Cragg GM. Natural products as sources of new drugs over the nearly four decades from 1981 to 2019. *J Nat Prod*. 2020;83(3):770-803.
29. Patil MV, Patil DA. Ethnobotany of Nasik District, Maharashtra, India. *J Phytol Res*. 2000;13(2):209-211.
30. Saldanha CJ. Flora of Karnataka. Vol. 2. Oxford & IBH Publishing Co.; 1996.
31. Santapau H. The Flora of Khandala on the Western Ghats of India. *Rec Bot Surv India*. Vol. 16. Delhi: Manager of Publications; 1953.
32. Sharma RA, Patil MB. Phytochemical investigation of some Justicia species from the Western Ghats. In: Proceedings of the National Symposium on Plant Chemistry. 2015. p. 112-118.
33. Singh NP, Lakshminarasimhan P, Karthikeyan S, Prasanna PV. Flora of Maharashtra State: Dicotyledones. Vol. 2. Calcutta: Botanical Survey of India; 2001.
34. Wasshausen DC. A checklist of the Acanthaceae of the Guianas. *Rodriguésia*. 2006;57(2):159-174.

Table 1: Comparative morphology of *J. santapau* and related congeners

Character	<i>J. santapau</i>	<i>J. betonica</i>	<i>J. gendarussa</i>
Habit	Tall Undershrub	Erect Shrub	Small Shrub
Bracts	Large, leafy, green	White with green veins	Small, linear
Anther Spur	Prominently spurred	Basally spurred	Weakly spurred
Corolla Color	White/Purple streaks	White/Pink veins	White/Violet spots

Table 2: Phytochemicals in *J. santapau* and Related Medicinal Congeners

Compound Class	<i>J. santapau</i>	<i>J. adhatoda</i>	<i>J. gendarussa</i>
Quinazoline Alkaloids	Confirmed (Trace)	High (Vasicine)	Present
Flavonoids	Present	Apigenin, Vitexin	Gendarusin A
Lignans	Not Reported	Present	Justicidin A
Sterols	Present	beta-Sitosterol	Stigmasterol





Dhanya and Radhamany

Table 3: Recommended Primers for Molecular Characterization of *J. santapau*

Locus	Primer Name	Sequence (5' – 3')	Target Region
nrDNA	ITS-P1	AGAAGTCGTAACAAGGTTTCCGTAGG	Internal Transcribed Spacer
	ITS-P4	TCCTCCGCTTATTGATATGC	
cpDNA	matK-3F	CGTACAGTACTTTTGTGTTTACGAG	Maturase K
	matK-1R	ACCCAGTCCATCTGGAAATCTTGGT	
cpDNA	rbcL-aF	ATGTCACCACAAACAGAGACTAAAGC	Ribulose-bisphosphate carboxylase
	rbcL-aR	GTAAAATCAAGTCCACCRG	
cpDNA	trnH-psbA	GTTATGCATGAACGTAATGCTC	Intergenic Spacer
		CGCGCATGGTGGATTCAATCC	

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Analysis and Solution of First-Kind Fuzzy Volterra Integral Models Using the San Transform

M.Sangeetha¹ and S. Akila^{2*}

¹Research Scholar, Department of Mathematics, Theivanai Ammal College for Women(Autonomous), Villupuram, (Affiliated to Annamalai University, Cuddalore), Tamil Nadu, India.

²Associate Professor, Department of Mathematics, Theivanai Ammal College for Women(Autonomous), Villupuram, (Affiliated to Annamalai University, Cuddalore), Tamil Nadu, India.

Received: 12 Jan 2026

Revised: 04 Feb 2026

Accepted: 28 Feb 2026

*Address for Correspondence

S. Akila

Associate Professor,

Department of Mathematics,

Theivanai Ammal College for Women (Autonomous), Villupuram,

(Affiliated to Annamalai University, Cuddalore),

Tamil Nadu, India..

E.Mail: akila2829@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

In the present study, an analytical procedure employing the novel San transform is formulated to address integral equations of the Volterra type with fuzzy-valued functions. These functions are expressed in parametric form through their lower and upper η -level representations, which reduce the fuzzy equation to a system of classical integral equations. By applying the San transform, the resulting equations are converted into algebraic forms that can be solved efficiently, and the inverse transform yields the exact fuzzy solution. A set of examples is presented to validate the accuracy and user-friendliness of the proposed technique. Graphical representations of the fuzzy bounds are provided to validate the analytical results. The findings demonstrate the effectiveness of the developed method offers a reliable and computationally efficient framework for solving integral equations incorporating fuzzy uncertainty following Volterra's formulation.

Keywords: Fuzzy Volterra integral equations, First kind integral equations, San transform, Analytical solutions.

INTRODUCTION





Sangeetha and Akila

Fuzzy set theory has developed into a versatile mathematical tool for handling uncertainty and imprecision in complex real-world problems, especially in situations where classical deterministic methods fall short. The foundational work on fuzzy calculus and fuzzy random variables by Goetschel and Voxman^[8] and Puri *et al.*^[9] laid the groundwork for further exploration of fuzzy integral equations, which have since found applications across engineering, decision-making, and applied sciences^[6,7] Within this context, fuzzy Volterra integral equations (FVIEs) are particularly useful for modeling systems exhibiting memory or hereditary properties. Early studies emphasized the fundamental formulation and properties of fuzzy integral equations^[8], while Park *et al.*^[10] demonstrated conditions guaranteeing that fuzzy Volterra integral equations possess a unique solution. For practical computations, numerical techniques for fuzzy integrals were proposed by Friedman *et al.*^[6], providing a foundation for applied methods. Integral transforms have also been adapted to the fuzzy framework. The Laplace transform was extended to solve fuzzy Volterra integral equations, yielding precise and computationally efficient solutions, as demonstrated by Allahviranloo and Barkhordari Ahmadi^[3] and Ameri and Nezhad^[4]. Aggarwal and Kumar^[1] applied the Mohand transform to first-kind Volterra integro-differential equations, demonstrating its ability to simplify the solution process. Recent advances in fuzzy modeling, including the use of intuitionistic and triangular fuzzy sets, have further enhanced decision-making methods, as discussed by Atanassov^[5] and Akila and John Robinson^[2]. Motivated by these advances, this study utilizes the San transform to obtain analytical solutions for first-kind fuzzy Volterra integral problems. By adopting parametric representations of fuzzy-valued functions, the proposed approach converts the fuzzy problem into a system of classical integral equations, enabling exact analytical solutions. Illustrative examples with graphical representations are provided to demonstrate the accuracy, robustness, and practical applicability of the method.

Mathematical Preliminaries

Definition 1. A fuzzy number $\tilde{B}$ is defined as a fuzzy set on the real axis $\mathbb{R}$ whose behavior is described by a membership function $\mu_{\tilde{B}}: \mathbb{R} \rightarrow [0,1]$. This function is required to satisfy the following properties:

- **Normalization:** There exists at least one element $b_0 \in \mathbb{R}$ such that the membership degree attains its maximum value, that is, $\mu_{\tilde{B}}(b_0) = 1$.
- **Fuzzy Convexity:** For any pair of real numbers $b_1, b_2 \in \mathbb{R}$ and for every $\lambda \in [0,1]$, the inequality $\mu_{\tilde{B}}(\lambda b_1 + (1 - \lambda)b_2) \geq \min\{\mu_{\tilde{B}}(b_1), \mu_{\tilde{B}}(b_2)\}$ holds.
- **Upper Semi-Continuity:** The membership function $\mu_{\tilde{B}}$ is upper semi-continuous throughout the real line.
- **Bounded Support:** The closure of the set of all points with positive membership values, $\{b \in \mathbb{R}: \mu_{\tilde{B}}(b) > 0\}$, is compact.

Definition 2. A first-kind Volterra integral equation is an equation of the form

$$\int_0^\tau L(\tau, \xi) u(\xi) d\xi = f(\tau), \quad \tau \in [0, T],$$

where $L(\tau, \xi)$ is a given kernel function, $f(\tau)$ is a known real-valued function, and $u(\tau)$ is the unknown function that needs to be determined.

Definition 3. A first-kind Volterra integral equation with fuzzy-valued functions extends the classical form by replacing deterministic functions with fuzzy functions:

$$\tilde{F}(\tau, \eta) = \int_0^\tau K(\tau, \xi) \tilde{V}(\xi, \eta) d\xi, \quad \tau \in [0, T], \quad \eta \in [0, 1],$$

where $K(\tau, \xi)$ denotes a given kernel function, $\tilde{F}(\tau, \eta)$ is a prescribed fuzzy-valued function, and $\tilde{V}(\tau, \eta)$ represents the fuzzy-valued function to be determined.

Definition 4. Consider a fuzzy-valued function denoted by $\tilde{V}(\tau)$, expressed in its parametric (level-cut) form as $\tilde{V}(\tau) = (\underline{V}(\tau, \eta), \bar{V}(\tau, \eta))$, $\eta \in [0, 1]$.

In this representation, the first-kind Volterra integral equation with fuzzy-valued functions can be equivalently formulated as a pair of integral equations for the lower and upper η -cuts:





Sangeetha and Akila

$$\underline{G}(\tau, \eta) = \int_0^\tau K(\tau, \xi) \underline{V}(\xi, \eta) d\xi,$$

$$\overline{G}(\tau, \eta) = \int_0^\tau K(\tau, \xi) \overline{V}(\xi, \eta) d\xi,$$

where $\underline{G}(\tau, \eta)$ and $\overline{G}(\tau, \eta)$ denote the lower and upper bounds of the fuzzy source function corresponding to the η -level.

Definition 5. Let $\Phi(\tau)$ be a function that is piecewise continuous and of exponential order λ , defined for $\tau \geq 0$. The **San Transform** of this function is defined as:

$$\mathcal{S}\{\Phi(\tau)\} = \frac{1}{\lambda^2} \int_0^\infty \Phi(\tau) e^{-\lambda\tau} d\tau = \varphi(\lambda), \quad \lambda > 0$$

Here, $\mathcal{S}$ denotes the San Transform operator applied to the function $\Phi(\tau)$.

Operational Properties of the San Transform

San Transform Based Analytical Framework

This section presents an analytical framework based on the San transform for addressing first-kind integral equations, where the unknown function, represented as a fuzzy-valued quantity, is included within a convolution-type integral operator. This structure naturally motivates the application of integral transform methods. Let us consider a first-kind fuzzy Volterra integral equation expressed in its parametric form as

$$\begin{cases} \underline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \underline{V}(\xi, \eta) d\xi, \\ \overline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \overline{V}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1. \quad (2)$$

To convert the above integral system into an algebraic form, we employ the San transform. Making use of its convolution property.

Since fuzzy multiplication depends on the signs of the involved functions, and assuming that zero does not lie in their supports, different configurations may arise. These configurations are categorized according to the signs of the kernel function and the unknown fuzzy solution.

Case 1: When both kernel and the unknown function are positive, the lower and upper bounds satisfy

$$\mathcal{S}\{K(\tau)V(\tau, \eta)\} = \mathcal{S}\{K(\tau)\}\mathcal{S}\{V(\tau, \eta)\},$$

$$\mathcal{S}\{\overline{K}(\tau)\overline{V}(\tau, \eta)\} = \mathcal{S}\{\overline{K}(\tau)\}\mathcal{S}\{\overline{V}(\tau, \eta)\}.$$

Case 2: If the kernel is positive while the unknown function is negative, the fuzzy bounds are interchanged accordingly.

Case 3: When the kernel is negative and the solution is positive, a similar interchange of bounds occurs.

Case 4: If both the kernel and the solution are negative, the standard ordering of fuzzy bounds is preserved.

For clarity, the subsequent analysis is restricted to the first case. Under this assumption, direct algebraic manipulation of the transformed equations yields

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = \frac{\mathcal{S}\{\underline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}, \\ \mathcal{S}\{\overline{V}(\tau, \eta)\} = \frac{\mathcal{S}\{\overline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}. \end{cases} \quad (3)$$

Applying the inverse San transform to each component, the fuzzy solution in the original domain is obtained as

$$\begin{cases} \underline{V}(\tau, \eta) = \mathcal{S}^{-1} \left(\frac{\mathcal{S}\{\underline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}} \right), \\ \overline{V}(\tau, \eta) = \mathcal{S}^{-1} \left(\frac{\mathcal{S}\{\overline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}} \right), \end{cases} \quad (4)$$

which holds for all $0 \leq \eta \leq 1$, provided the involved fuzzy-valued functions are well defined over the prescribed interval.





Applications

Illustrative 1:

We examine a Volterra-type integral model formulated under fuzzy uncertainty, described by the following relation:

$$\begin{cases} F(\tau, \eta) = \int_0^\tau H(\tau - \xi) \underline{U}(\xi, \eta) d\xi, \\ \bar{F}(\tau, \eta) = \int_0^\tau H(\tau - \xi) \bar{U}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1, \quad (5)$$

where the fuzzy input function and kernel are defined as

$$F(\tau, \eta) = (3\eta, 5 - \eta) \tau e^{-\tau}, \quad H(\tau - \xi) = e^{-(\tau - \xi)}.$$

The given fuzzy integral equation is rewritten in its parametric (level-cut) form by separating the lower and upper functions. By applying the San transform and invoking its convolution property, the resulting system is converted into an equivalent algebraic form.

$$\begin{cases} \mathcal{S}\{(3\eta) \tau e^{-\tau}\} = \lambda^2 \mathcal{S}\{e^{-\tau}\} \mathcal{S}\{\underline{U}(\tau, \eta)\}, \\ \mathcal{S}\{(5 - \eta) \tau e^{-\tau}\} = \lambda^2 \mathcal{S}\{e^{-\tau}\} \mathcal{S}\{\bar{U}(\tau, \eta)\}. \end{cases} \quad (6)$$

Using the known San Transform formulas,

$$\begin{cases} \mathcal{S}\{\underline{U}(\tau, \eta)\} = \frac{3\eta}{\lambda^2(\lambda + 1)}, \\ \mathcal{S}\{\bar{U}(\tau, \eta)\} = \frac{5 - \eta}{\lambda^2(\lambda + 1)}. \end{cases} \quad (7)$$

Taking the inverse San Transform, the fuzzy solution is obtained as

$$\begin{cases} \underline{U}(\tau, \eta) = 3\eta e^{-\tau}, \\ \bar{U}(\tau, \eta) = (5 - \eta) e^{-\tau}, \end{cases} \quad (8)$$

or equivalently,

$$U(\tau, \eta) = (3\eta, 5 - \eta) e^{-\tau}, \quad 0 \leq \eta \leq 1.$$

Illustrative 2:

Assume that the unknown fuzzy function satisfies a Volterra-style integral relation belonging to the first kind

$$\begin{cases} \underline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \underline{V}(\xi, \eta) d\xi, \\ \bar{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \bar{V}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1, \quad (9)$$

where the fuzzy source term and kernel are given by $G(\tau, \eta) = (2 + 5\eta, 8 - \eta)(5\tau^2 + \tau^3)$, $K(\tau - \xi) = 5 + 3(\tau - \xi)$.

Accordingly, the parametric form becomes

$$\begin{cases} (2 + 5\eta)(5\tau^2 + \tau^3) = \int_0^\tau [5 + 3(\tau - \xi)] \underline{V}(\xi, \eta) d\xi, \\ (8 - \eta)(5\tau^2 + \tau^3) = \int_0^\tau [5 + 3(\tau - \xi)] \bar{V}(\xi, \eta) d\xi. \end{cases} \quad (10)$$

Applying the San Transform to both sides yields

$$\begin{cases} \mathcal{S}\{(2 + 5\eta)(5\tau^2 + \tau^3)\} = \mathcal{S}\left\{\int_0^\tau [5 + 3(\tau - \xi)] \underline{V}(\xi, \eta) d\xi\right\}, \\ \mathcal{S}\{(8 - \eta)(5\tau^2 + \tau^3)\} = \mathcal{S}\left\{\int_0^\tau [5 + 3(\tau - \xi)] \bar{V}(\xi, \eta) d\xi\right\}. \end{cases} \quad (11)$$

Using the convolution property of the San Transform,

$$\begin{cases} \mathcal{S}\{(2 + 5\eta)(5\tau^2 + \tau^3)\} = \lambda^2 \mathcal{S}\{5 + 3\tau\} \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ \mathcal{S}\{(8 - \eta)(5\tau^2 + \tau^3)\} = \lambda^2 \mathcal{S}\{5 + 3\tau\} \mathcal{S}\{\bar{V}(\tau, \eta)\}. \end{cases} \quad (12)$$

Using standard San Transforms,

$$\begin{cases} (2 + 5\eta) \left(\frac{10}{\lambda^5} + \frac{6}{\lambda^6}\right) = \lambda^2 \left(\frac{5}{\lambda^3} + \frac{3}{\lambda^4}\right) \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ (8 - \eta) \left(\frac{10}{\lambda^5} + \frac{6}{\lambda^6}\right) = \lambda^2 \left(\frac{5}{\lambda^3} + \frac{3}{\lambda^4}\right) \mathcal{S}\{\bar{V}(\tau, \eta)\}. \end{cases} \quad (13)$$

Solving for the San Transforms of the unknowns gives

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = \frac{2(2 + 5\eta)}{\lambda^4}, \\ \mathcal{S}\{\bar{V}(\tau, \eta)\} = \frac{2(8 - \eta)}{\lambda^4}. \end{cases} \quad (14)$$

Taking the inverse San Transform,

$$\begin{cases} \underline{V}(\tau, \eta) = (2 + 5\eta) 2\tau, \\ \bar{V}(\tau, \eta) = (8 - \eta) 2\tau. \end{cases} \quad (15)$$

Hence,





$$V(\tau, \eta) = [(2 + 5\eta) 2\tau, (8 - \eta) 2\tau], \quad 0 \leq \eta \leq 1. \quad (16)$$

Illustrative 3:

The first-kind fuzzy Volterra model under consideration is expressed as:

$$\tilde{G}(\tau, \eta) = [(9 - 2\eta, 5 + 3\eta)](2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau K(\tau - \xi) \tilde{V}(\xi, \eta) d\xi, \quad (17)$$

where the kernel is defined as $K(\tau - \xi) = 2 - \tau + \xi$, $0 \leq \eta \leq 1$.

The corresponding parametric form is written as:

$$\begin{cases} \underline{G}(\tau, \eta) = (9 - 2\eta)(2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau (2 - \tau + \xi) \underline{V}(\xi, \eta) d\xi, \\ \overline{G}(\tau, \eta) = (5 + 3\eta)(2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau (2 - \tau + \xi) \overline{V}(\xi, \eta) d\xi. \end{cases} \quad (18)$$

The San transform is subsequently imposed on each term of the system.

Taking advantage of the convolution rule associated with the San transform.

$$\begin{cases} \mathcal{S}\{\underline{G}(\tau, \eta)\} = (9 - 2\eta) \frac{1}{\lambda^2(\lambda^2 - 1)} - \lambda^2 \mathcal{S}\{2 - \tau\} \cdot \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ \mathcal{S}\{\overline{G}(\tau, \eta)\} = (5 + 3\eta) \frac{1}{\lambda^2(\lambda^2 - 1)} - \lambda^2 \mathcal{S}\{2 - \tau\} \cdot \mathcal{S}\{\overline{V}(\tau, \eta)\}. \end{cases} \quad (19)$$

Solving the resulting algebraic equations, we obtain:

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = (9 - 2\eta) \frac{1}{\lambda(\lambda^2 - 1)}, \\ \mathcal{S}\{\overline{V}(\tau, \eta)\} = (5 + 3\eta) \frac{1}{\lambda(\lambda^2 - 1)}. \end{cases} \quad (20)$$

Applying the inverse San Transform gives:

$$\begin{cases} \underline{V}(\tau, \eta) = (9 - 2\eta) \sinh\tau, \\ \overline{V}(\tau, \eta) = (5 + 3\eta) \sinh\tau. \end{cases} \quad (21)$$

Hence, the fuzzy solution is obtained as:

$$\tilde{V}(\tau, \eta) = [(9 - 2\eta) \sinh\tau, (5 + 3\eta) \sinh\tau]. \quad (22)$$

CONCLUSION

In this work, first-type Volterra integral models are examined within a fuzzy mathematical framework were effectively solved using the San transform. By employing the parametric representation of fuzzy-valued functions, the fuzzy problem was reduced to a system of classical integral equations, enabling exact analytical solutions. The proposed method was validated through illustrative examples, numerical results, and graphical analysis, demonstrating its simplicity and computational efficiency. Future research may extend the present approach to fractional-order fuzzy models arising in applied sciences and engineering.

REFERENCES

1. Aggarwal, S., & Kumar, S. (2021). Mohand Transform for the Primitive of System of Convolution Type Linear Volterra Integro-Differential Equations of First Kind. *Journal of Emerging Technologies and Innovative Research*, 8(6).
2. Akila, S., & John Robinson, P. (2019). Multiple attribute group decision making methods using numerical methods of intuitionistic triangular fuzzy sets. *Journal of Physics: Conference Series*, 1377, 012022.
3. Allahviranloo, T., & Barkhordari Ahmadi, M. (2010). Fuzzy Laplace transform. *Soft Computing*, 14(3), 235–243.
4. Ameri, M., & Nezhad, M. R. H. (2017). A new approach for solving fuzzy Volterra integral equations using Laplace transform. *Journal of Intelligent & Fuzzy Systems*, 33(4), 2377–2386.
5. Atanassov, K. (1989). More on intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 33(1), 37–45.
6. Friedman, M., Ma, M., & Kandel, A. (1996). Numerical methods for calculating the fuzzy integral. *Fuzzy Sets and Systems*, 83, 57–62.





Sangeetha and Akila

7. Friedman, M., Ma, M., & Kandel, A. (1999). On fuzzy integral equations. *Fundamenta Informaticae*, 37, 89–99.
8. Goetschel, R., & Voxman, W. (1986). Elementary fuzzy calculus. *Fuzzy Sets and Systems*, 18, 31–43.
9. Puri, M. L., Ralescu, D. A., & Zadeh, L. A. (1993). Fuzzy random variables. In *Readings in Fuzzy Sets for Intelligent Systems* (pp. 265–271). Morgan Kaufmann.
10. [10] Park, J. Y., Kwan, Y. C., & Jeong, J. V. (1999). Existence and uniqueness theorem for a solution of fuzzy Volterra integral equations. *Fuzzy Sets and Systems*, 105, 481–488.

Table 1: San transform of elementary functions

S.No	$\Phi(\tau)$	$\mathcal{S}\{\Phi(\tau)\}$
1	1	$\frac{1}{\lambda^3}$
2	τ	$\frac{1}{\lambda^4}$
3	τ^2	$\frac{2}{\lambda^5}$
4	τ^3	$\frac{6}{\lambda^6}$
5	τ^n	$\frac{n!}{\lambda^{n+3}}$
6	$e^{\alpha\tau}$	$\frac{1}{\lambda^2(\lambda - \alpha)}$
7	$\sin(\alpha\tau)$	$\frac{\alpha}{\lambda^2(\lambda^2 + \alpha^2)}$
8	$\cos(\alpha\tau)$	$\frac{1}{\lambda(\lambda^2 + \alpha^2)}$
9	$\sinh(\alpha\tau)$	$\frac{\alpha}{\lambda^2(\lambda^2 - \alpha^2)}$
10	$\cosh(\alpha\tau)$	$\frac{1}{\lambda(\lambda^2 - \alpha^2)}$

Table 2: Inverse San transform of elementary functions

S.No	$\phi(\lambda)$	$\mathcal{S}^{-1}\{\phi(\lambda)\}$
1	$\frac{1}{\lambda^3}$	1
2	$\frac{1}{\lambda^4}$	τ
3	$\frac{1}{\lambda^5}$	$\frac{\tau^2}{2}$
4	$\frac{1}{\lambda^6}$	$\frac{\tau^3}{3!}$
5	$\frac{1}{\lambda^{n+3}}$	$\frac{\tau^n}{n!}$
6	$\frac{1}{\lambda^2(\lambda - \alpha)}$	$e^{\alpha\tau}$
7	$\frac{1}{\lambda^2(\lambda^2 + \alpha^2)}$	$\frac{1}{\alpha} \sin(\alpha\tau)$
8	$\frac{1}{\lambda(\lambda^2 + \alpha^2)}$	$\cos(\alpha\tau)$
9	$\frac{1}{\lambda^2(\lambda^2 - \alpha^2)}$	$\frac{1}{\alpha} \sinh(\alpha\tau)$
10	$\frac{1}{\lambda(\lambda^2 - \alpha^2)}$	$\cosh(\alpha\tau)$





Sangeetha and Akila

Table 3: Essential Properties of the San Transform

S.No	Description of the Property	Corresponding Mathematical Relation
1	Linearity	$\mathcal{S}\{\mu \phi_1(\tau) + \nu \phi_2(\tau)\} = \mu \phi_1(\lambda) + \nu \phi_2(\lambda)$
2	Scaling Property	$\mathcal{S}\{\phi(\kappa\tau)\} = \frac{1}{\kappa^3} \cdot \phi\left(\frac{\lambda}{\kappa}\right)$
3	Shifting Property	$\mathcal{S}\{e^{\kappa\tau} \cdot \phi(\tau)\} = \left(\frac{(\lambda - \kappa)^2}{\lambda^2}\right) \cdot \phi(\lambda - \kappa)$
4	First Derivative	$\mathcal{S}\{\phi'(\tau)\} = \lambda \cdot \mathcal{S}\{\phi(\tau)\} - \frac{1}{\lambda^2} \cdot \phi(0)$
5	Second Derivative	$\mathcal{S}\{\phi''(\tau)\} = \lambda^2 \cdot \mathcal{S}\{\phi(\tau)\} - \frac{1}{\lambda} \cdot \phi(0) - \frac{1}{\lambda^2} \cdot \phi'(0)$
6	n-th Derivative	$\mathcal{S}\{\phi^{(n)}(\tau)\} = \lambda^n \cdot \mathcal{S}\{\phi(\tau)\} - \sum_{\kappa=0}^{n-1} \frac{1}{\lambda^2} \cdot \phi^{(\kappa)}(0) \cdot \lambda^{n-1-\kappa}$
7	Convolution	$\mathcal{S}\{\phi_1(\tau) * \phi_2(\tau)\} = \lambda^2 \cdot \phi_1(\lambda) \cdot \phi_2(\lambda)$

Table 4: Numerical values of fuzzy bounds (4η , $6 - \eta$)

η	Lower bound 4η	Upper bound $6 - \eta$
0.00	0.00	6.00
0.25	1.00	5.75
0.50	2.00	5.50
0.75	3.00	5.25
1.00	4.00	5.00

Table 5: Numerical values of fuzzy bounds ($2 + 5\eta$, $8 - \eta$)

η	Lower bound $2 + 5\eta$	Upper bound $8 - \eta$
0.00	2.00	8.00
0.25	3.25	7.75
0.50	4.50	7.50
0.75	5.75	7.25
1.00	7.00	7.00

Table 6: Numerical values of fuzzy bounds ($9 - 2\eta$, $5 + 3\eta$)

η	Lower bound $9 - 2\eta$	Upper bound $5 + 3\eta$
0.00	9.00	5.00
0.25	8.50	5.75
0.50	8.00	6.50
0.75	7.50	7.25
1.00	7.00	8.00





Sangeetha and Akila

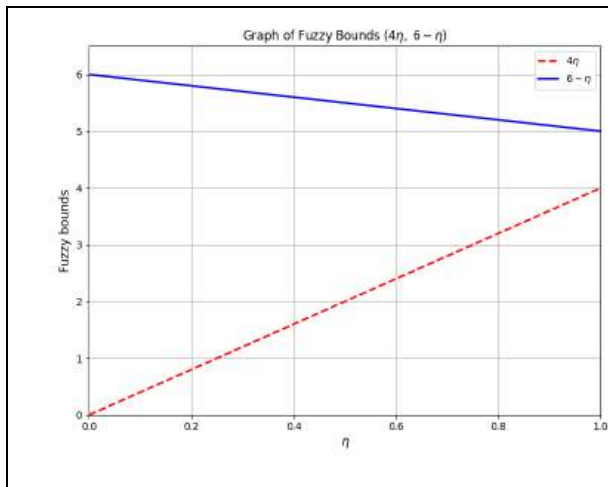


Figure 1: Parametric plots showing the lower and upper limits of the fuzzy-valued solution in Example 1

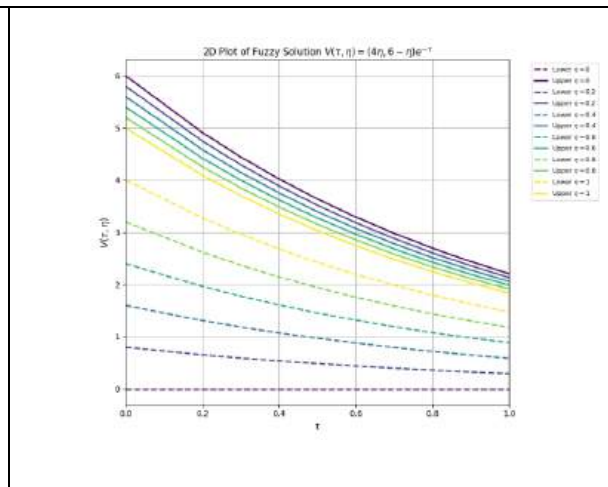


Figure 2: Computed fuzzy solution for Example 1

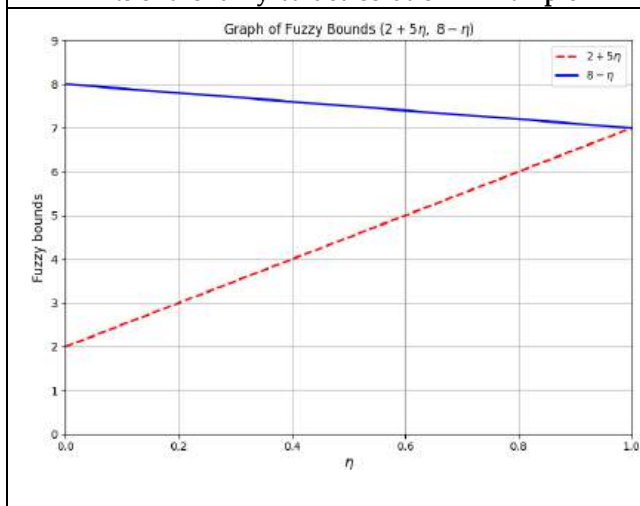


Figure 3: Graphical representation of the lower and upper η-cut functions of the fuzzy solution for Example 2

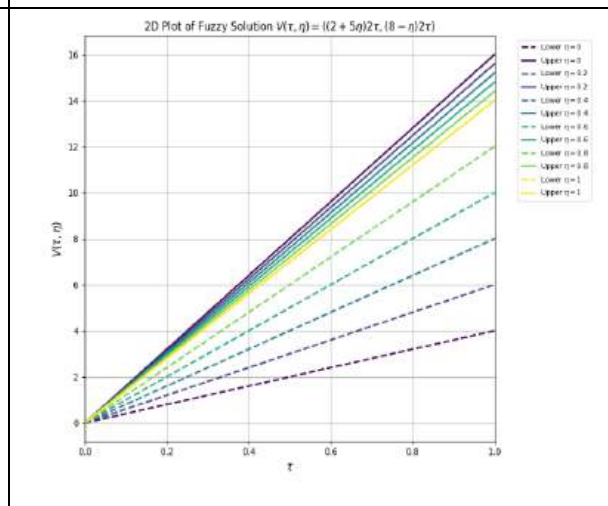


Figure 4: Resulting fuzzy solution in Example 2



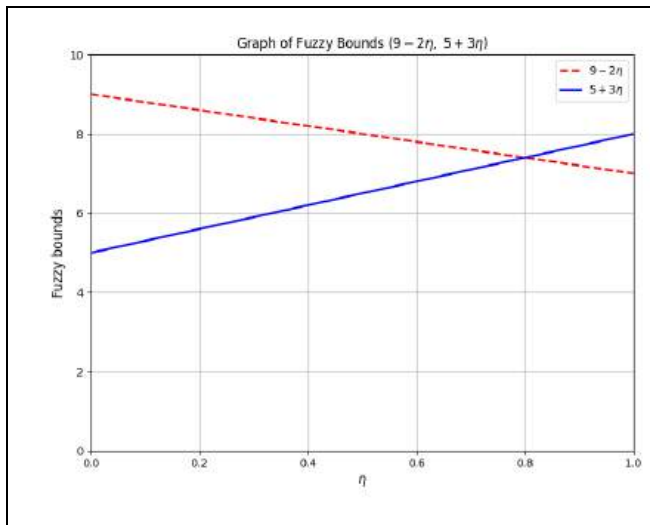


Figure 5: Visualization of the fuzzy solution bounds in Example 3 using parametric form

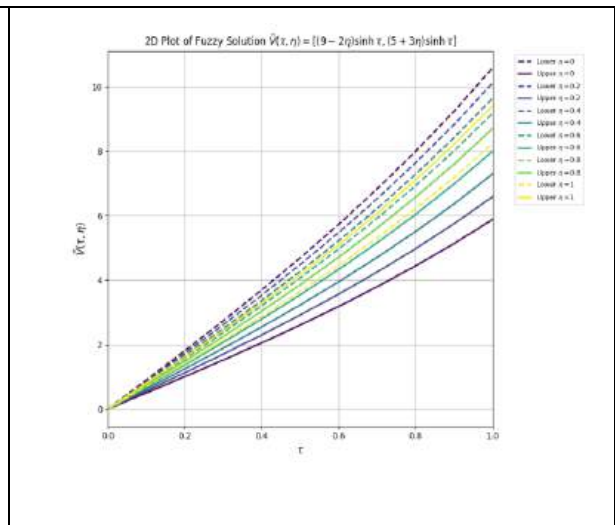


Figure 6: Illustration of the fuzzy solution for Example 3

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Indian Association of Physics Teachers and Development of Alternative School Physics Laboratories

Bhopal Singh Rawat^{1*}, Sam Nesamony² and M.Harikrishanan³

¹Associate Professor, School of Education, Sanskriti University, Chhatta, Mathura, Uttar Pradesh, India

²Professor, Department of English and Humanities, School of Humanities and Social, SGT University, Gurugram, Delhi, India.

³Assistant Professor, School of Education, Sanskriti University, Chhatta, Mathura, Uttar Pradesh, India.

Received: 08 Mar 2026

Revised: 11 Apr 2026

Accepted : 08 May 2026

*Address for Correspondence

Bhopal Singh Rawat

Associate Professor,
School of Education,
Sanskriti University,
Chhatta, Mathura,
Uttar Pradesh, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

School physics teaching happens to rely on deductive approach. First concepts and theories taught at abstract level and experiments are used to empirically validate theory. The trend has led to limit the role of experimental activity to obtain the final value of physical quantities. In such a scenario, teachers are expected to engage in the development of experiments to facilitate concept formation, model making and problem solving by the students. The Indian Association of Physics Teachers has long championed this approach. The approach is exemplified by the establishment of Anveshika—an alternative school physics laboratory—at Saraswati Gyan Mandir Inter College, Kanpur, in 2001. Although Anveshika emerged officially in 2001, the vision of creating a model physics laboratory by Indian Association of Physics Teachers was laid down at the time of the inception of the Association in 1984. The paper traces the genesis and development of Anveshika as well as its role in fostering the development of a network of physics laboratories and related training programmes.

Keywords: University Leadership Programme, College Science Improvement Programme, Centre for Scientific Culture, Anveshika, Concept-Experiment, National Anveshika Network of India

INTRODUCTION

While experiment in physics is primarily meant to test theory; in instructional setting, it can play multifaceted role in concept formation, mathematisation, verification of theory and problem solving [1, 2, 3, 4, 5, 6]. Despite the wider scope, verification of theory happens to the predominant role of experiment in instruction. Moreover, years of



**Bhopal Singh Rawat and Sam Nesamony et al.,**

practice tends to mechanize experimental activity to obtain final value of the physical quantity [7]. With a view to widen the scope of experiment in teaching-learning process, Indian Association of Physics Teachers (IAPT) has undertaken concrete measures towards the renewal of physics instruction. In fact, renewal of physics laboratory has been a main pedagogical concern of the association. As IAPT represents the concern and involvement of a vast majority of Indian physics teachers, examination of the nature and extent of its work in this regard assumes significance. Anveshika—an alternative physics laboratory jointly brought about by Saraswati Gyan Mandir (SGM) Inter College at Kanpur and IAPT, epitomizes this work. The paper traces the genesis, establishment, and proliferation of Anveshika and its networking activities.

Historical Context

Probably Education Commission (1966) was first in comprehensively redefining the role of education in independent India [8]. Following the recommendations of the Commission, a nationwide rethinking was triggered to further specify and take relevant measures to reform education at all stages. In tertiary physics, D. S. Kothari, earlier the chairman of the Education Commission, led the Indian physics education community to deliberate upon the specific nature of the problems confronting physics education and prepare a plan of action towards this end at Srinagar in June 1970. Renewal of undergraduate physics laboratory was one of the major issues deliberated in the conference. Laboratory activities were recommended to move beyond the routine experiments aimed to verify theory and enable students to investigate physical phenomena, deduce relationships, and apply knowledge to solve new problems. In a few cases, projects or open-ended experiments were suggested for an in-depth study of physical phenomenon. Provision was made for a well-established workshop for fabrication and maintenance of experimental devices and equipment to provide students first hand experiences in carrying out a worthwhile laboratory work. This was supposed to be the part of the 'science teaching centre' meant to prepare relevant curricular material in the universities. Such centres were not only envisaged to develop prototype experimental equipment, kits, film strips and curricular material such as textbooks, teacher guides, laboratory manuals, and methods of teaching but also provide support to the affiliated colleges in adopting it [9, p. 22].

Soon after Srinagar Conference (1970), University Grant Commission (UGC) initiated the University Leadership Programme (ULP) and College Science Improvement Programme (COSIP) for developing the required curricular material. ULP and COSIP programme ran for almost a decade. The textbooks, laboratory manual, demonstrations, and experiments were reportedly produced by the several of the universities and affiliated colleges that were assigned the projects [10]. Notable contributions were made by the ULP centres at the Punjab, Pune and Rajasthan Universities [11, 12]. The development of several innovative experiments for the undergraduate and post-graduate physics courses under the leadership of Babulal Saraf at the Rajasthan University was termed as exemplary among all the ULP and COSIP work [13, 14]. The centre earned appreciation from wide and across the country for accomplishing this task. Subsequently, several colleges and institutions affiliated to the University of Rajasthan and around the country bought the replicas of the experiments relating to mechanics, statistical physics, Waves and Oscillations and thermodynamics [15, 16, 17]. COSIP and ULP groups working in other parts of the country were gravitated towards the centre. Consequently, centre became a site for the interaction among the physics teachers across the country. The decade long engagement in COSIP and ULP projects was concluded with an international conference, on the '*Role of Laboratory in physics Education*', at Rajasthan University during 28th December, 1983 to 2nd January 1984 [18]. It was also the defining moment for the pedagogy of physics in India. Experimentation as a methodology of teaching physics was contested in a big way by physics educators.

Iapt and Renewal of Physics Laboratory

Indian Association of Physics Teachers (IAPT) was formed on 9th March, 1984 [19, p. 2-3]. Implicitly though, the recommendations of Srinagar deliberation (1970), coupled with the work accomplished on experiments during ULP and COSIP projects were reframed as the major objectives by the association [20]. This paved the way for the reappraisal of the laboratory work carried out at different parts of the country and its translation into a



**Bhopal Singh Rawat and Sam Nesamony et al.,**

comprehensive reconstruction programme on experiments. Formation of alternative physics laboratories—Centre for Scientific Culture (CSC) at Midnapore (in 1993) and Anveshika, at Kanpur (in 2001); adding experimental component in the National Standard Examination in Physics (NSEP) (in 1992) and National Graduate Physics Examination (NGPE) (in 1993); conducting a nationwide orientation programs for school and college teachers from 1997 to 1999; as well as initiating National Competition for Innovative Experiments in Physics (NCIEP) (in 2003), are the programmes run by the IAPT to achieve the end [21].

Anveshika: An Alternative School Physics Laboratory

The programme to develop four (4) model physics laboratories or alternatively, what was named as the Centre for Scientific Cultures (CSCs) in different parts of the country was conceptualised by IAPT way back in 1986 and subsequently in 1988 and 1991. It is a general observation that experiments in the school and college science laboratories are bought from the manufacturing agencies and teachers do not engage in the reconstruction of experiments. Taking sharp contrast, CSC was conceived as a functioning laboratory where a wide range of experiments meant to relate the empirical and theoretical component not only of physics but also other allied scientific disciplines would be developed by the teachers themselves. Pedagogically, these experiments would not only be deployed to exhibit qualitative component of concepts but translate the data generated from experimental activity into mathematical relations in a lucid and substantial manner [22, 23, 24]. In fact, this was one of the major objectives framed by the association during 1984 [25]. Though concerted efforts were invested to bring out four (4) CSCs during 1992-1993, the programme failed as anticipated. Centre for Scientific Culture (CSC) at Midnapore and Nagpur were among the two centres opened [26, p. 284]. Developmental activities at CSC Nagpur dwindled after few years. Eventually, CSC Midnapore remains to be the only centre sustaining till date [27].

Emergence of Anveshika—an alternative physics laboratory at Kanpur, in 2001, boosted the idea of CSC from long drawn-out passivity in the intervening period. Unlike CSC, Anveshika did not arise because of a deliberate plan of action by the association. It was all by coincidence that IAPT happened to find a patron and a site for reconstruction of physics experiments at Saraswati Gyan Mandir (SGM) School in Kanpur in 1999. This was exactly lacking during the attempts to form CSCs during 1992-93. Desirable response did not come either from the schools and college showing eagerness to house and run the CSCs. IAPT members in charge of the project on CSCs do not seem to display innovative thinking and action on their part. Now in two years time span from 1999 to 2001, it became apparent that unlike the case with CSCs during 1992-1993, the conditions were ripe for developing an alternative physics laboratory. Ram Narayan Agrawal, the owner of SGM School, turned out to be the patron as desired and R. N. Kapoor, one of the active members of IAPT, as the actor taking the task of developing a repertoire of experiments at the school premise. R. N. Kapoor was one of the close associates of D. P. Khandelwal (the founder of the association). Till around the age of 70, he had already improvised and designed several experiments. When invited by Ram Narayan Agarwal, he was more than happy to take up reconstruction of experiments at SGM School. Beginning the work on the development of experiments during 1999, he came up with an active mini-laboratory in next two years, captivating the imaginations of teachers, students, and IAPT members from in and around the Kanpur. Subsequently, a formal beginning was made to develop this laboratory as a joint venture between Saraswati Gyan Mandir (SGM) Inter College and IAPT, in the year 2001. The laboratory was named as 'Anveshika'—a Hindi translation for the investigatory laboratory. Since then, SGM School and IAPT decided to jointly fund the workshop [28].

To begin with R. N. Kapoor took up whatever idea appealed to him in devising experiments. As a result, a sizable number of demonstrations and experiments in mechanics, optics, electromagnetic etc were developed. Progressively, more experiments covering the domains of mechanics, electromagnetism and optics were added to Anveshika in the succeeding years. Though most of the experiments cover the school physics, few of them are also meant for undergraduate physics. Besides construction of experiments, Kapoor has devoted a part of his time for teaching school children on a regular basis. This enhanced the synergistic relationship between the SGM School and Anveshika. Having housed and nurtured Anveshika, the school too has earned laurel not only from the teachers and



**Bhopal Singh Rawat and Sam Nesamony et al.,**

students around the Kanpur but also other parts of the country. Indeed, Anveshika has become an exemplar of a cooperative activity between IAPT and Community School (i. e. SGM), the way CSC was envisaged during 1992-93. R. N. Kapoor has been the lifeline of Anveshika from the time work was initiated there in 1999 to 2013—the year he retired around 80 years of age. The first sight of Anveshika appears to induce a feeling of break away from conventional laboratory. Very often, visitors (teachers and students) interested to explore or conduct experimental and demonstration activities at Anveshika are facilitated to find plausible answers to their questions. Anveshika seems to make them aware that learning physics by demonstration and experiments can be an exciting experience and something which happens to be missing at their schools (impression is based on researcher's interaction with the visitors on first visit to Anveshika in 2011). Accordingly, the physics teachers from the schools and colleges around the Kanpur and other parts of the country are oriented to use of experiments for concept development at Anveshika [29, 30]. As claimed, experiments and demonstrations placed at the Anveshika are not meant for pursuing predetermined objectives, processes and outcomes as is the case with conventional experiments in school and college physics laboratories; rather they are meant to encourage exploration of concepts in an open-ended manner. While endorsing the dictum that 'to see is to believe', R. N. Kapoor asserts, teaching through demonstration and experiments enhances the understanding of concepts as well as reduces the time expended in teaching to significant extent. Consequently, it helps the teacher finish syllabi well before time and invest the left-over time in other important activities.

Anveshika and Teachers' Orientation Programmes

With the course of time Anveshika evolved to fit well in IAPT's long-term objective of bringing out a Model Physics Laboratory or Centre for Scientific Culture (CSC). The teachers from Indian Institute of Technology (IIT), Kanpur and local colleges joined hands in supporting and extending the activities at Anveshika. H. C. Verma, a faculty at IIT Kanpur, played a leading role in this respect. Animated by the developments at Anveshika, H. C. Verma, in close association with R. N. Kapoor and other IAPT members, took up the task of popularizing the work conducted at Anveshika in other parts of the country. Verma set out to evolve a series of orientation programmes to help teachers integrate demonstration and experiments in their teaching. The workshop was initiated by him in the year 2002-03 [31]. Since then, different modules of orientation programmes vis-a-vis 'one-day', 'three-days', 'four-days' and 'six-days' workshops for the school and college teachers have been conducted [32]. 'One-day workshop' termed as 'Utsahi Physics Teachers' is introductory in nature and aims to provide exposure to the participants using experiments for concept formation. The workshop is conducted throughout the year across the country. The thrust of the programme is to facilitate participants collect and devise a repertoire of experiment and integrate them in their teaching. To help participants make a beginning in this regard, they are provided with an experimental 'kit' termed as 'Physics Show Bag'. In turn, participants in the long run are expected to assemble and improvise more experiments at their own. Having learned the intended knowledge and skills in the preliminary workshop, they are invited for the next phases of the training via 3-days and 6-days module workshops. Occasionally around one-month workshops for those at the verge of entering teaching profession (like fresh M.Sc. postgraduates), have also been conducted [33, 34]. The difference among the two types of orientation programmes lies in the depth and comprehensiveness of the procedural knowledge relating the use of experiments for concept formation. External agencies such as Vigyan Prasar, Takshila Education Society or Bharti Bhawan (a publication house) etc from time to time have collaborated with Anveshika in conducting workshops. Occasionally, manufacturers of laboratory equipment also get involved in orientation programmes.

National Anveshika Network of India (Nani)

Notwithstanding the various constraints and impediments faced by teachers in workplace, some of them oriented at Anveshika do feel the need to break away from the traditional method of teaching physics. They happen to be motivated enough to collect and develop a repertoire of demonstrations and experiments. Some of them over the years also have developed an expertise in conducting orientation programmes for other teachers. For instance, A. D. Mahajan (from Latur), R. K. Awasthi (from Agra), R. K. Mitra (from Lucknow), Sanjeeve Kumar (from Bhagalpur), B. C. Rai (from Patna), Bregech Dixhit from Auriya and Rakesh Kumar Singh from Patna are said to have developed



**Bhopal Singh Rawat and Sam Nesamony et al.,**

such expertise. Overwhelmed by the response from the participants teachers and their institutions from various places across the country, IAPT in 2010, initiated a programme to facilitate them to finding space and housing the repertoire of experiments and demonstration they have developed there. In essence this is an endeavor to replicate Anveshika like physics laboratories in different parts of the country. The programme was launched at the Annual National Convention of IAPT at Rajkot in October 2010 and named as '*Anveshika Loving Teachers Orientation Programme*' (ALTOP) [35]. According to Verma and Kapoor (2010): "*ALTOP is a workshop planned for the potentially key persons who have the commitment for physics teaching and can play the pivotal role in starting and running such a centre at their own place.*" (36, p. 313). Following this, the first 4-day *Anveshika Loving Teachers Orientation Programme* (ALTOP) was organised from 30th October to 2nd November in 2010. Since then, this programme has become a regular feature of Anveshika's activities. Each of the newly emerging Anveshika like centres is expected to run shows on use of demonstrations and experiments for teaching concepts.

In a year they are expected to devote 100 hours for these shows. While Anveshika Kanpur has a building of its own, new Anveshikas are housed in a room or in a corner of the laboratory of the institution (school or college), as was observed to be the case with M. S. Marwaha from Shri Guru Govind Singh College (SGGSC), Chandigarh. Sometimes because of the lack of space or lack of adequate support from the parent institution, the newly emerging Anveshikas are housed at the residence of teachers, for instance, Anveshika founded by R. K. Mitra at Lucknow. The upcoming of new Anveshikas are being networked together under a programme called '*National Anveshika Network of India (NANI)*' (Ibid). The table below gives the location and names of the teachers enacting the developmental work at newly founded Anveshikas under the National Anveshika Network of India (NANI). The information holds true till 20th June, 2017. similar work. Inspiration in some of these teachers has galvanized into the replication of the work accomplished at Anveshika. Very often lack of funding for this work is cited as a stumbling block. As A. W. Joshi (2008) – one of the prominent members of the association, observes that the engagement of these teachers demonstrated that with the accomplishment of a concrete and significant piece of work, support relating funds and infrastructure comes from the interested institutions and the individuals [38].

DISCUSSION

Popularisation and expansion of the use of experiment to study physical phenomenon was adopted as the salient objective by IAPT since its formation in 1984. To give a practical shape to the idea, several programmes have been conducted by the association. The attempt to open four (4) model physics laboratories or what were named as the centres for scientific culture (CSC) in different parts of the country during 1992-1993, is one of them. Practical realisation of the model physics laboratories demanded not only intensive pedagogical involvement but also the generation of funds and infrastructure. Though ample amount of funds was ensured by Ministry of Human Resource (MHRD) for opening these centres for scientific culture (CSC), IAPT did not appear to succeed in displaying the pedagogical engagement and social skills to get infrastructural support from the schools and colleges enlisted for the project. Consequently it could only manage to open two CSCs of which CSC Midnapore remains to be the centre surviving. Moderate pedagogical engagement appears to be reported from CSC Midnapore [37].

Fulfillment of conditions proved vital for the advent of Anveshika and subsequently its networking activities. Firstly, the space and funding provided by the Saraswati Gyan Mandir (SGM) School. Secondly, R. N. Kapoor's intense involvement in improvising and devising demonstrations and experiments—the trait rarely displayed by a physics teacher. Anveshika appears to break with the large-scale failure experienced by IAPT while attempting to open four (4) CSCs during 1992-93. As a result, it has inspired a large section of the teachers to undertake similar work. Inspiration in some of these teachers has galvanized into the replication of the work accomplished at Anveshika. Very often lack of funding for this work is cited as a stumbling block. As A. W. Joshi (2008) – one of the prominent members of the association, observes that the engagement of these teachers demonstrated that with the accomplishment of a concrete and significant piece of work, support relating funds and infrastructure comes from the interested institutions and the individuals [38].





Bhopal Singh Rawat and Sam Nesamony et al.,

Pedagogically, the bulk of the experiments developed by Anveshika and its networking sites happen to be qualitative in nature. Higher conceptual gains have been claimed by the Anveshika workers by integration of demonstrations and experiments in teaching physics. However, rather than scientific investigation and collection of evidence, they seem to rely more on perceptual feedback. When scholarly research in physics pedagogy has made inroads into the physics instruction since 1970s, IAPT members need to subject the claims made by fellow members to scientific testing, peer review, criticism and revision. The first step in this direction would be to conduct meticulous and comprehensive documentation of the work accomplished at Anveshika and its networking sites. Secondly, like American Association of Physics Teachers (AAPT), IAPT also need to adopt research perspective on physics education. AAPT members engaging in Physics Education Research (PER) not only have the perspective of physics teachers as practitioners but also are informed by the developments in philosophy of science, psychology of learning and science education [39, 40]. Adoption of research perspective by IAPT is expected to better equip its members engage with the problems confronting physics education in India. Making relevant changes by the Anveshika and its sister laboratories may help physics teachers make shift towards model-building and problem-solving via experimental activity instead of limiting it on concept formation.

REFERENCES

1. Kreitler, S., & Kreitler, H. (1974). The role of the experiment in science education. *Instructional Science*, 3, 75-88.
2. Hofstein, A., & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research*, 52(2), 201-217.
3. Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics*, 55(5), 440-454.
4. Hodson, D. (1988). Experiments in science and science teaching. *Educational Philosophy and Theory*, 20(2), 53-66.
5. Hodson, D. (1996). Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies*, 28(2), 115-135.
6. Trumper, R. (2003). The physics laboratory—A historical overview and future perspectives. *Science & Education*, 12(7), 645-670.
7. Khandelwal, D. P. (1987). A new look at the undergraduate laboratory in physics. *Bulletin of the IAPT*, 4(4), 109-113.
8. Ministry of Education, Government of India. (1966). *Report of Education Commission (1964-66): Education and National Development* (1st ed.). Government of India.
9. University Grant Commission & United Nations Educational, Scientific and Cultural Organisation. (1970). *Physics in India: Challenges and Opportunities—Summary of proceedings of the conference on physics education and research* (Srinagar 21-23 June 1970). New Delhi: UGC and UNESCO.
10. University Grant Commission. (1982). *College Science Improvement Programme (COSIP): Teaching Materials developed for use in Classroom and Laboratories for Undergraduate Science Instruction*. New Delhi: University Grant Commission.
11. Kumar, A., & Nigavekar, A. (1994). Physics education. In S. S. Jha (Ed.), *Physics in India: A Status Report* (pp. 13-35). Indian National Science Academy.
12. Joshi, A. W. (1997). Physics education in the country (Editorial). *Physics Education*, 323-327.
13. Saraf, B., Khandelwal, D. P., Mazumdar, B. C., Shidhodia, Y. S., & Tailor, R. C. (1979). *Physics through experiments-2: Mechanical systems—Study of some fundamental processes in physics*. Vikas Publishing House Pvt. Ltd.
14. Saraf, B., Lokanathan, S., Garg, K. B., Chandani, D. T., Shishodia, Y. S., & Tailor, R. C. (1978). *Physics through experiments-1: EMF constant and varying* (2nd ed.). Vikas Publishing House Pvt. Ltd.
15. Kumar, A., & Nigavekar, A. (1994). Physics education. In S. S. Jha (Ed.), *Physics in India: A Status Report* (pp. 13-35). Indian National Science Academy.
16. Vigyan Prasara. (2009). Prof. B. L. Saraf: Obituary. *Dream* 2047, 11(7), 20. <http://vigyanprasar.gov.in/wp-content/uploads/aprilenglish.pdf>





Bhopal Singh Rawat and Sam Nesamony et al.,

17. Lokanathan, S., & Sharma, N. K. (Eds.). (1984). *Role of Laboratory in Physics Education: Proceedings of the International Conference, Jaipur, India (December 29, 1983–January 2, 1984)* (pp. 281-283). New Delhi: UGC and UNESCO
18. Lokanathan, S., & Sharma, N. K. (Eds.). (1984). *Role of Laboratory in Physics Education: Proceedings of the International Conference, Jaipur, India (December 29, 1983–January 2, 1984)* (pp. 281-283). New Delhi: UGC and UNESCO
19. Indian Association of Physics Teachers. (1984). Backdrop of Indian Association of Physics Teachers (IAPT). *Bulletin of the IAPT*, 2, 2-3.
20. Refer to the objective and proposed activities of IAPT in D. P. Khandelwal, "Indian Association of Physics Teachers: (First Convention: Kanpur: Oct. 19-21, 1984) Proceedings of the Convention," *Bulletin of the IAPT* 1, 9 (1984): pp. 20-29.
21. Rawat, B. S. (2018). *Indian Association of Physics Teachers: A study of pedagogies, programs and policies of physics education* (Ph.D. thesis, Jawaharlal Nehru University).
22. Khandelwal, D. P. (1986). Outline of a science centre. *Bulletin of the IAPT*, 3(4), 115-120.
23. Khandelwal, D. P. (1988). Centre for science culture—A blueprint. *Bulletin of the IAPT*, 5(1), 5–11.
24. Khandelwal, D. P. (1991). Development of Centre for Scientific Culture in the Society and Stage Science Shows (Project submitted to the Ministry of Human Resource Development). *Bulletin of the IAPT*, 9(4-5), 130-138.
25. Khandelwal, D. P. "Indian Association of Physics Teachers: (First Convention: Kanpur: Oct. 19-21, 1984) Proceedings of the Convention." *Bulletin of the IAPT* 1, no. 9 (1984): 20-29.
26. Khandelwal, D. P. (1993). Update on IAPT-MHRD centres for scientific culture. *Bulletin of the IAPT*, 10(9), 283–284.
27. Rawat, B. S. (2019). *Indian Association of Physics Teachers: A study of pedagogies, programs and policies of physics education* (Ph.D. thesis, Jawaharlal Nehru University).
28. Kapoor, R. N. (2001). Anveshika. *Bulletin of the IAPT*, 367.
29. Kumar, S. (2007a). IAPT-Anveshika, Kanpur: Physics competence course-2007. *Bulletin of the IAPT*, 201.
30. Kumar, S. (2007b, August). Anveshika Kanpur Workshop "This is Physics-II". *Bulletin of the IAPT*, 261-262.
31. Verma, H. C. (2003). IITK-IAPT joint project workshop held at IIT Kanpur on Feb 1, 2 and 3, 2003. *Bulletin of the IAPT*, 30(2), 70.
32. Kumar, S. (2007b, August). Anveshika Kanpur Workshop "This is Physics-II". *Bulletin of the IAPT*, 261-262.
33. Kumar, S. (2007a). IAPT-Anveshika, Kanpur: Physics competence course-2007. *Bulletin of the IAPT*, 201.
34. Kumar, S. (2007b, August). Anveshika Kanpur Workshop "This is Physics-II". *Bulletin of the IAPT*, 261-262.
35. Verma, H. C. (2010). Anveshika Loving Teachers Orientation Programme (ALTOP): A step towards establishing National Anveshika Network of India (NANI). *Bulletin of the IAPT*, 33-34.
36. Verma, H. C., & Kapoor, R. N. (2010, August). SGM-IAPT-Anveshika: Anveshika loving teachers' orientation programme. *Bulletin of the IAPT*, 25.
37. Rawat, B. S. (2018). *Indian Association of Physics Teachers: A study of pedagogies, programs and policies of physics education* (Ph.D. thesis, Jawaharlal Nehru University).
38. Joshi, A. W. (2008). Building up a poor man's physics laboratory. *Bulletin of the IAPT*, 25(3), 172-173.
39. Beichner, R. J. (2009). An introduction to physics education research. In C. Henderson & K. A. Harper (Eds.), *Getting Started in PER* (pp. 1-25). American Association of Physics Teachers. <http://www.per-central.org/items/detail.cfm?ID=8806>
40. Beichner, R., Hake, R., McDermott, L. C., Mestre, J., Redish, E., Reif, F., & Risley, J. (1995). Support of physics-education research as a subfield of physics: Proposal to the NSF Physics Division. <https://www.ncsu.edu/PER/Articles/NSFWhitePaper.pdf>



**Table 1: Locations of the Newly Emerging Anveshikas**

S.No	Name of Anveshika	Place	Coordinators Name
1.	SGM-IPT Anveshika	Kanpur	Mr. Amit Kumar Bajpai
2.	Pt. G. D. V. IAPT Anveshika	Dehradun	Mr. Rohit Sharma
3.	TAXXILA -IAPT Anveshika	Kolkata	Dr. Amit Kumar Jana
4.	BYN-IAPT Anveshika	New Delhi	Mrs. Pragya Nopany
5.	Patna-IAPT Anveshika	Patna	Dr. Amrendra Naryan & Dr. Rakesh Sing
6.	KIIT-IAPT Anveshika	Odisha	Mrs.Rajashree Mohapatra,
7.	Ammanni- IAPT Anveshika	Bangalore	Dr. Sarmistha Sahu
8.	Vibha-IAPT Anveshika	Hyderabad	Mr. Jitender Singh
9.	GCG-IAPT Anveshika	Gadhinglaj	Dr. Shivanand Masti
10.	Mitra-IAPT Anveshika	Lucknow	Dr. R. K. Mitra,
11.	SGGS-IAPT Anveshika	Chandigarh	Mr. Ms Marwaha
12.	Raman-IAPT Anveshika	Agra	Dr. R. K. Awasthi
13.	Go & Go- IAPT Anveshika	Auraiya	Mr. Brajesh Dixit
14.	Ohm-IAPT Anveshika	Gwalior	Mr. Devendra Sharma
15.	VSS-IAPT Anveshika	Munger	Dr. K. N. Rai
16.	Vidya-IAPT Anveshika	Dhanbad	Mr. Arvind Pathak,
17.	BPS-IAPT Anveshika	Pilani	Mr. Manoranjan Kumar
18.	Focus IAPT Anveshika	Andra Pradesh	Mr. J. Chandrasekhar Rao
19.	SSSB-IAPT- Anveshika	Bhilawadi	Mr. Gajanan Balounda Patil
20.	Samadhan-IAPT Anveshika	Pilibheet	Mr. Laxmikant Sharma
21.	Siwan-IAPT Anveshika	Siwan	Mr. Ragive Ranjan,
22.	Happy-IAPT Anveshika	J&K	Mr. Mineesh Gulati

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





REVIEW ARTICLE

Gastro Retentive Drug Delivery System : Formulation Strategies and Clinical Relevance

Gautam Verma ¹, Pravin Kumar Sharma^{2*}, Mohit Patil¹, Ashish Gupta³, Sumeet Dwivedi³ and G.N. Darwhekar⁴

¹Second Year M.Pharm Student, Department of Pharmaceutics, Acropolis Institute of Pharmaceutical Education and Research (Affiliated to Rajiv Gandhi Proudhyogiki, Vishwavidyalaya (Bhopal), Indore, Madhya Pradesh, India.

²Professor, Department of Pharmaceutics, Acropolis Institute of Pharmaceutical Education and Research (Affiliated to Rajiv Gandhi Proudhyogiki Vishwavidyalaya (Bhopal), Indore, Madhya Pradesh, India.

³Associate Professor, Acropolis Institute of Pharmaceutical Education and Research (Affiliated to Rajiv Gandhi Proudhyogiki Vishwavidyalaya (Bhopal), Indore, Madhya Pradesh, India.

⁴Principal, Acropolis Institute of Pharmaceutical Education and Research (Affiliated to Rajiv Gandhi Proudhyogiki Vishwavidyalaya (Bhopal), Indore, Madhya Pradesh, India.

Received: 11 Mar 2026

Revised: 25 Apr 2026

Accepted: 09 May 2026

*Address for Correspondence

Pravin Kumar Sharma

Professor,

Department of Pharmaceutics,

Acropolis Institute of Pharmaceutical Education and Research

(Affiliated to Rajiv Gandhi Proudhyogiki Vishwavidyalaya (Bhopal),

Indore, Madhya Pradesh, India

E.Mail: praveensharma910@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Because of the ease of use and patient compliance, oral medication delivery methods continue to be the most popular dosage forms. However, for medications with short absorption windows, quick gastrointestinal transit, or volatility in intestinal circumstances, traditional oral formulations sometimes fall short of producing sufficient therapeutic results. To overcome these restrictions, gastro retentive systems for drug delivery have been created. By extending the duration of dosage forms in the stomach, GRDDS enhances drug absorption and bioavailability. The physiological principles governing gastric retention, the categorization and mechanisms of gastro retentive systems, formulation strategies, polymers and excipients, evaluation techniques, clinical applications, marketed products, recent technological advancements, regulatory challenges, and future perspectives are all thoroughly discussed in this review.

Keywords: Gastroretentive drug delivery systems (GRDDS), oral drug delivery, gastric retention, bioavailability enhancement and controlled drug release.





INTRODUCTION

Due to ease of use, non-invasiveness, affordability, and high patient compliance, oral drug delivery is the most commonly used method for systemic pharmacotherapy. Nonetheless, traditional oral dosage forms like pills and capsules have unpredictable gastric emptying that leads to inconsistent absorption of drugs and the reduction of therapeutic activity for certain drugs¹. Rapid passage through the gastrointestinal tract also limits absorption of many drugs that only seen in the proximal small intestine or stomach². Conventional dosage forms of drugs having narrow absorption windows, inadequate solubility of drug molecule in the intestinal pH range, limited action at the stomach or unstable under basic conditions are most at risk for poor bioavailability. GRDDS are made to remain in the stomach for a longer period of time, which overcomes these issues and ultimately boosts the therapeutic outcomes, lowers the dosing frequency and improves the absorption of medication³.

Rational for GRDDS

The design and optimization of GRDDS are controlled by a wide range of pharmacokinetics and pharmacodynamics that need to be properly evaluated in the development process. It prolong gastric residence time, enhancing bioavailability and therapeutic efficacy for drugs with narrow absorption windows in the upper GIT, poor solubility in high pH, or local stomach action. They offer sustained, controlled release, reduce dosing frequency, and improve patient compliance

Drugs Suitable for GRDDS

Drugs preferably have a limited absorption window in the upper gastrointestinal tract, have a limited solubility at alkaline pH, have a local action in the stomach and are likely to be rapidly degraded by exposure to the intestinal environment. Examples of such agents include levodopa, ranitidine, metformin, ciprofloxacin, amoxicillin, ketorolac, tromethamine⁴⁻⁵.

Therapeutic Benefits

- Enhanced bioavailability
- Less plasma concentration fluctuation resulting in more sustained therapeutic effect
- Reduced prescribed dose & less administrations needed per treatment cycle
- Increased patient compliance with the prescribed medication regimen⁶.

Anatomy and Physiology of the Gastro-Intestinal Tract

A detailed understanding of the anatomy and physiology of the stomach is essential when rational design of gastro retentive systems is undertaken.

Anatomy of the stomach:

The stomach is divided into the antrum, body, fundus, and pylorus anatomically. Antrum is important in the grinding up of ingested material and its transfer to the pyloric sphincter, although the fundus and body are mainly reservoirs for the gastric contents⁷.

Gastric motility:

Gastric motility shows great differences between a fed and fasting state.

Fasting state- During fasting, the migrating motor complex (MMC) occurs in four distinct phases and repeats every 90-120 minutes. In the third stage, which is often called the "housekeeping wave," has the ability to move foreign dose forms out of the gastric lumen.

Fed state - In contrast, after a meal MMC being delayed and resulting in slow down of gastric emptying⁸⁻⁹.

Classification of GRDDS

GRDDS are categorized according to the manner they manage to remain in the stomach. There are several major types as they all strive to achieve the same goal¹⁰.



**Gautam Verma et al.,****Floating GRDDS**

Because the bulk density of floating drug delivery systems is lower than that of the gastric fluid, they have the benefit of being able to float on the contents of the stomach for extended periods of time¹¹. Following oral administration, the dosage form expands or produces gas; as a result, its density is reduced. This mechanism allows for continuous release of the drug in the gastric environment since the buoyant force is constantly keeping the system afloat^{12,13}. Different mechanisms of floating system are shown in figure 1.

Types of floating GRDDS**Effervescent floating systems-**

These systems contain gas - producing agents such as citric acid, sodium bicarbonate that react with gastric acid to produce CO₂. The gas thus obtained is entrapped within the polymer matrix and hence imparting flotation¹⁴. It offers benefits like rapid buoyancy, easy formulation and has limitations such as dependency on gastric pH and possibility of dose dumping¹⁵.

Non- effervescent floating systems-

To realise low density and adhere to buoyancy, such systems are based on swelling polymers like Carbopol and HPMC¹⁶. It offers benefits like more stable buoyancy action, better pH tolerance and has limitation of delay in floating action¹⁷.

Bilayer floating tablets-

In bilayer systems, the immediate release layer is the rapid onset component while the floating layer maintains prolonged release. The structure of bilayer floating tablets is shown in figure 2. This design is used to enhance the therapeutic efficacy by providing a first loading dose and then sustained release¹⁸.

Mucoadhesive GRDDS

By attaching to the gastric mucosa, the mucoadhesive systems prolong the gastric residence of a drug significantly¹⁹. Mucoadhesion consists of polymer swelling, wetting, mucus, polymer chain interpenetration, and hydrogen bonding as well as electrostatic interactions²⁰. Mechanism of mucoadhesion is shown in figure 3. The advantage of this strategy includes delivery location specificity and increased bioavailability. The limitations are mucus generation and variable adhesion strength²¹. Examples of polymers used in mucoadhesive GRDDS are chitosan, carbopol, polycarbophil and HPMC.

Expandable GRDDS

Expandable systems are designed to expand following ingestion, and hence do not pass through the pylorus²². Two types of expandable systems are that get bloated and that get expand. The mechanism of expandable gastro retentive system is shown in figure 4. The system must be easily taken by mouth, should expand rapidly, and must disintegrate safely after being released of medication²³. It offers benefit such as drug retention regardless of gastric pH and has limitations like risk regarding gastric obstruction as well as the complicated nature of manufacturing²⁴.

High - density GRDDS

Because they are heavier than the gastric contents (density of >1.5 g cm⁻³), high-density gastro retentive systems have an internal design to stay inside the stomach by composing to the bottom of the gastric cavity. Unlike the floating systems that are relying on buoyancy, these dosage forms take advantage of the force of gravity to prevent gastric emptying²⁵. Highly dense inert excipients are added to the formulation like barium sulphate, zinc oxide, titanium dioxide or iron powder to obtain the necessary mass²⁶. The mechanism of gastric retention of high - density GRDDS is shown in figure 5. A high density dosage form is resistant to peristaltic movements and gastric emptying after oral administration due to sinking at the lower region of the stomach especially in the region of the antral stomach²⁷. It



**Gautam Verma et al.,**

offers benefit that formulation maintains its activity regardless of the pH of the stomach and has limitations like attaining the ideal density is not easy, there is the risk of mucosal irritation and clinical evidence of efficacy has been limited²⁸.

Raft forming GRDDS

These raft forming assemblies are mostly used in the treatment of gastric reflux disease (GERD), which acts locally within the stomach, therefore providing a mechanical barrier²⁹. The mechanism of raft forming GRDDS is shown in figure 6. These systems consist of gel-forming agents (sodium alginate), agents that release gas (e.g. sodium bicarbonate) and a viscous gel (raft) which forms and floats on the stomach contents on contact with gastric juice and thus can act as a physical barrier to prevent reflux³⁰. In the modern clinic, treatment of GERD is intended mostly at protecting the mucosa of the esophagus through long-term local pharmacotherapy, as reported in reference³¹.

Hydrogel type GRDDS

Super porous is an excellent technology that provides-shift material with thousand times higher porosity than a conventional hydrogel. Superporous hydrogels (SPH) are the most suitable examples of advanced swellable gastro retentive systems with very fast swelling performance as a result of their strongly connected pore architecture as described in reference³². Through capillary action, these hydrogels quickly imbibe gastric fluid and thus delay gastric emptying. Composite formulations also further augment their mechanical robustness³³. The advantages include like swelling is observed rapidly with rapid responsiveness, formulation exhibits high levels of mechanical integrity and prolonged gastric retention hence a sustained release profile. It has limitations like tedious synthesis; the high production cost and limited commercial availability³⁴.

GRDDS made by using polymer and excipients

Polymers have a significant effect on the swelling behaviour, buoyancy, muco adhesion, kinetics of drug release, and the mechanical strength of gastro retentive systems³⁵. Natural polymers used in GRDDS are sodium alginate, chitosan, xanthan gum and guar gum. Synthetic polymers offer better reproducibility and controlled functionality. Example of synthetic and semi-synthetic polymers are HPMC (K4M, K15M, K100M), Carbopol, Polyethylene oxide and Eudragit RL/RS. The use of gas-generating agents is essential in the case of effervescent forms of floating dosage forms. Sodium bicarbonate and calcium carbonate are the common components used, and accompanied by acidic excipients, which are citric acid and tartaric acid. When exposed to gastric juice, the following combinations cause CO₂ to further evolve and become trapped in the polymeric structure when exposed to gastric juice³⁶.

Formulation Approaches For GRDDS

Single unit systems

Single unit systems include tablets and capsules that help in maintaining its presence in the gastric milieu³⁷.

Multiple unit systems

Pellets, beads, and microspheres are multiparticulate systems that provide a more homogenous distribution of systems in the stomach as shown in figure 7. Advantages of it include low chances of dosage dumping and increased homogeneity of gastric retention³⁸.

Drug release criteria and kinetics

The diffusion, polymer erosion and swelling controlled mechanisms control the release of pharmaceutical agents through GRDDS, thus determining the overall drug release pattern. Mathematical expressions are used to assess drug release data quantitatively. Those models are predictive in nature and allow it to maximize the release kinetics³⁹.

In-Vitro Evaluation of GRDDS

Physical characterization

Assessment of physical properties includes dimension, tensile strength, and weight variability which offer vital quality parameters to the dosage form.





Gautam Verma *et al.*,

Floating properties

The lag time that is needed by the system to be made to float as well as the total time of flotation is measured to achieve satisfactory gastric residence¹⁵.

Swelling index

The behaviour of swelling is measured in pH 1.2 simulated gastric fluid medium as this enables to measure polymerial expansion in gastric conditions.

In-vitro drug release studies

The profiles of drug release are developed through the standardised dissolution tests simulating the gastrointestinal conditions in accordance with the USP apparatus specifications⁴⁰.

Mucoadhesive strength

Mucosal adhesion degree is established by the employment of customized balance efflux techniques or texture analyzers to ensure gastric mucosa has enough adhesion⁴¹.

In-Vivo Evaluation of GRDDS

In-vivo experimentation cannot be compromised and it is essential to verify the gastric residence time, blood dynamics, and pharmacokinetic performance of GRDDS under physiological conditions.

Radiographic (x-ray) studies

A dosage form is merged with a radio-opaque marker e.g. barium sulphate, through which the visualisation is observed through X-ray imaging. Serial radiographs monitor the positioning of the stomach, and the retention time. This technique is easy and cost-efficient but the precision of this technique has limitations when it comes to real-time monitoring because of the limitation on radiation exposure⁴².

Gamma scintigraphy

Formulation is followed using a gamma camera and it is radio labelled with things like the isotope. Real time tracking offers quantitative analysis correctness. However, the procedure is expensive and needs specialised facilities⁴³.

Ultrasound imaging

Ultrasound imaging is a non radiation-free, non-invasive modality that is used in the *in-silico* monitoring of GRDDS. This technique is very operator-limited ⁴⁴.

Pharmacokinetic studies

Traditional dosage administration form and the ensuing plasma drug concentration-time curve are both evaluated so as to evaluate the enhancement of variables, biodegradability, half-life, and mean dwell time⁴⁵.

Clinical Applications of GRDDS

Drugs with thinner absorptive nature

These systems are especially beneficial in those medications that are mostly absorbed in the proximal or stomach lumen small intestine including levodopa, riboflavin and metformin⁴⁶.

Drugs with local impacts on the stomach

GRDDS can be used for prolonged exposure to local minor doses of drugs, and thus favour the orientation of gastrointestinal disorders using antacid agents, proton pump blockers, and amoxicillin to eliminate *Helicobacter*



**Gautam Verma, et al.,**

pylori. The gastrointestinal tract's retention in an acidic environment stabilises the alkali labile, but acid stable compounds to improve their overall bioavailability⁴⁷.

Chronotherapy

GRDDS are applicable to the management of illnesses that require precise drug administration timing, including in the field of Parkinson's disease and nocturnal acid break through, where time-sensitive dosing is essential.

Commercialised gastro retentive formulations

Several gastro retentive drug formulations are at the moment in the commercial market which has been proven to be clinically viable [48]. List of such marketed products are shown in table-1.

Recent Advancement in GRDDS

Nanotechnology based GRDDS

Recent research has highlighted the potential application of nano-flooding systems and nano-mucoadhesive carriers to be utilized in order to achieve better levels of gastric retention, enhance the solubility of medications taken orally, and enhance accuracy of delivery to the stomach targets. It is through these nano scale platforms that it is feasible to modify particle buoyancy and surface chemistry that enables one to prolong the duration of gastric residency while also helping in protecting the therapeutic agent against its early degradation [49].

3D Printing technology

With the acquisition of 3D printing, there is chance to create gastro retentive dosage vectors with geometrically adjusted finely besides being able to control densities and programmable drug-release kinetics. This is because of the nature of personalization that may be found in the 3D printing technology, allowing the development of customized treatment plans that are not just designed based on the pharmacokinetic needs of the drug, but also individual physiological characteristics of the patient.

Intelligent systems and stimulus response

Responsive gastro retentive drug delivery systems in response to gastric pH, temperature and enzymatic activity are an exciting future in oral therapeutics. These smart formulations recognise the local physiological and cause site selective release events, resulting in the tightening of space and temporal control of drug delivery in the upper gastrointestinal tract [50].

Considerations of regulatory and quality

These include a thorough assessment of gastric-retention, in-vivo in-vitro correlation (IVIVC) and safety implication of long-term stomach exposure needed by the regulators. Simultaneously, Quality-by-Design approaches have been integrated more commonly in GRDDS development, which is offering a procedural organisation to risk evaluation, process verification, and to continuous enhancement [51].

GRDDS weaknesses and challenges

GRDDS contain a number of constraints even with the attributes they have interpersonal differences in gastric physiology, relativity on the eating habit, the possibility of gastrointestinal discomfort or obstruction and limited applicability to some pharmacological agents are critical stumbling blocks that can only be overcome by detailed formulation design and extensive clinical assessment[52].

Future Prospective

Future research will focus on the combination of artificial-intelligence-based formulation optimisation, hybrid gastro-retentive systems that jointly involve the usage of several retention systems, and the production of long-acting one-week dosage systems that are compatible with patient-centred dosage schedules. The predictive capacity of the



**Gautam Verma et al.,**

GRDDS performance tests is probably further enhanced with the developments in the imaging modalities and biopharmaceutical modelling⁵³.

CONCLUSION

Gastro retentive delivery devices are promising much with regard to enhancing oral bioavailability and achieving the therapeutic effects of suitable drug candidates. GRDDS reduce the drawbacks of stomach's quick emptying, release the contents in a controlled and site-specific manner within the stomach and upper intestinal tract. The future opportunities involved with additional advancements in material science, nanotechnology, and additive manufacturing and such oral dosage forms are probably going to become more widely available.

REFERENCES

1. Rangnani, D. (2022) A review on sustained release drug delivery system. *International Journal of Green and Herbal Chemistry*, 11(2), 142-150. <https://doi.org/10.24214/ijghc/gc/11/2/16069>.
2. Adepu, S. and Ramakrishna, S. (2021) Controlled drug delivery systems: current status and future directions. *Molecules*, 26(19), 5905. <https://doi.org/10.3390/molecules26195905>.
3. Bonner, J J., Vajjah, P., Abduljalil, K., Jamei, M., Hodjegan, A R. and Tucker, G T. et al. (2015) Does age affect gastric emptying time? A model-based meta-analysis of data from premature neonates through to adults. *Biopharmaceutics & Drug Disposition*, 36(4), 245-257. <https://doi.org/10.1002/bdd.1937>.
4. Duggan, S., Cummins, W., Donovan, O O., Hughes, S. and Owens, E. (2017) Thiolated polymers as mucoadhesive drug delivery systems. *European Journal of Pharmaceutical Sciences*, 100, 64-78. <https://doi.org/10.1016/j.ejps.2017.01.008>.
5. Filipinski, K J., Varma, M V., El-Kattan, A F., Ambler, C M., Rugeri, R B. And Goosen, T C. et al. (2013) Intestinal targeting of drugs: Rational design approaches and challenges. *Current Topics in Medicinal Chemistry*, 13(7), 776-802. <https://doi.org/10.2174/1568026611313070002>.
6. Gupta, S., Kesarla, R. and Omri, A. (2013) Formulation strategies to improve the bioavailability of poorly absorbed drugs with special emphasis on self-emulsifying systems. *ISRN Pharmaceutics*, 2013, 1-16. <https://doi.org/10.1155/2013/848043>.
7. Ishak, R A H. (2015) Buoyancy-generating agents for stomach-specific drug delivery: An Overview with special emphasis on floating behaviour. *Journal of Pharmacy & Pharmaceutical Sciences*, 18(1), 77-100. <https://doi.org/10.18433/j3602k>.
8. Jain, S.K. and Jain, A. (2008) Target-specific drug release to the colon. *Expert Opinion on Drug Delivery*, 5(5), 483-498. <https://doi.org/10.1517/17425247.5.5.483>.
9. Jawadi, Z., Yang C., Haidar Z S., Maria P L S. and Massa, S. (2022) Bio-inspired muco-adhesive polymers for drug delivery applications. *Polymers*, 14(24), 5459. <https://doi.org/10.3390/polym14245459>.
10. Kandukoori, N R. (2017) A review on floating drug delivery system. *World Journal of Pharmaceutical Research*, 553-568. <https://doi.org/10.20959/wjpr20175-8451>.
11. Makwana, A., Krunal, S., Hejal, P. and Yogi, P. (2012) Advancements in controlled release gastroretentive drug delivery system: A review. *Journal of Drug Delivery and Therapeutics*, 2(3), 12-21. <https://doi.org/10.22270/jddt.v2i3.164>.
12. Maury, V B. (2025) A review on gastroretentive drug delivery systems. *International Journal of Pharmacy and Pharmaceutical Science*, 7(1), 375–380. <https://doi.org/10.33545/26647222.2025.v7.i1e.192>.
13. Pal, N. Sharma, R., Gupta, A., Sharma, P K., Koka, S S., Darwhekar, G. (2024) Formulation and Evaluation of Floating Microsphere of Cephalexin. *International Journal of Pharmacy & Life Sciences*, 15 (7), 28-38.
14. Pant, S., Badola, A. and Kothiyal, P. (2016) A review on gastroretentive drug delivery system. *Indian Journal of Pharmaceutical and Biological Research*, 4(2), 01–10. <https://doi.org/10.30750/ijpbr.4.2.1>.





Gautam Verma et al.,

15. Podczec, F., Course, N., Newton J M. and Short M B. (2007) The influence of non-disintegrating tablet dimensions and density on their gastric emptying in fasted volunteers. *Journal of Pharmacy and Pharmacology*, 59(1), 23-27. <https://doi.org/10.1211/jpp.59.1.0004>.
16. Ponchel, G. and Irache J M. (1998) Specific and non-specific bioadhesive particulate systems for oral delivery to the gastrointestinal tract. *Advanced Drug Delivery Reviews*, 34(2-3), 191-219. [https://doi.org/10.1016/s0169-409x\(98\)00040-4](https://doi.org/10.1016/s0169-409x(98)00040-4).
17. Sabale, V., Sakarkar S N., Pund S. and Sabale, P. (2010) Formulation and evaluation of floating dosage forms: An overview. *Systematic Reviews in Pharmacy*, 1(1), 33-39. <https://doi.org/10.4103/0975-8453.59510>.
18. Sathish, D., Himabindu, S., Kumar, Y S. and Rao, Y M. (2011) Floating drug delivery systems for prolonging gastric residence time: a review,' *Current Drug Delivery*, 8(5), 494-510. <https://doi.org/10.2174/156720111796642273>.
19. Tripathi, J., Thapa, P., Maharjan, R. and Jeong, S H. (2019) Current state and future perspectives on gastroretentive drug delivery systems. *Pharmaceutics*, 11(4), 193. <https://doi.org/10.3390/pharmaceutics11040193>.
20. Turkane, D R., Kahar, I., Mishra, N., Chandravanshi, R. and Banafar, A. (2025) 'Formulation and in-vitro evaluation of floating tablets for gastric retention. *journal of pharmaceutical research and integrated medical sciences*, 2(11) 15-30. <https://doi.org/10.64063/3049-1681.vol.2.issue11.2>.
21. Wagh, P K., Ahirrao, S P. and Kshirsagar, S J. (2019) Novel mucoadhesive gastro retentive drug delivery system of ranitidine hydrochloride. *Asian Journal of Pharmaceutical Research*, 9(2), 80-86. <https://doi.org/10.5958/2231-5691.2019.00013.3>.
22. Weitschies, W., Blume, H. and Mönnikes, H. (2009) Magnetic marker monitoring: High resolution real-time tracking of oral solid dosage forms in the gastrointestinal tract. *European Journal of Pharmaceutics and Biopharmaceutics*, 74(1), 93-101. <https://doi.org/10.1016/j.ejpb.2009.07.007>.
23. Ahmad, S., Singh, V. and Kushwaha, S.K. (2023) Gastro retentive drug delivery system: a review. *Asian Journal of Research in Chemistry*, 16(6), 453-458. <https://doi.org/10.52711/0974-4150.2023.00075>.
24. Biller, S., Baumgarten, D. and Haueisen, J. (2011) A novel marker design for magnetic marker monitoring in the human gastrointestinal tract. *IEEE Transactions on Biomedical Engineering*, 58(12), 3368-3375. <https://doi.org/10.1109/tbme.2011.2166074>.
25. Caccavo, D., Cascone, S., Lamberti, G. and Barba, A A. (2015) Controlled drug release from hydrogel-based matrices: Experiments and modelling. *International Journal of Pharmaceutics*, 486(1-2), 144-152. <https://doi.org/10.1016/j.ijpharm.2015.03.054>.
26. Colson, Y L. and Grinstaff, M W. (2012) Biologically responsive polymeric nanoparticles for drug delivery. *Advanced Materials*, 24(28), 3878–3886. <https://doi.org/10.1002/adma.201200420>.
27. Ewii, U.E., Onugwu, A L., Nwokpor, V C., Akpaso, I A., Ogbulie, T E. and Aharanwa B E. (2024) Novel drug delivery systems: Insight into self-powered and nano-enabled drug delivery systems. *Nano TransMed*, 3, 100042. <https://doi.org/10.1016/j.ntm.2024.100042>.
28. Janhavi, Z.S., Pradnya, S L., Darekar, A B. and Saudagar, R B. (2015) 'A Comprehensive Review on Gastro-Retentive Floating Drug Delivery Systems,' *Asian Journal of Pharmaceutical Research*, 5(4), 211-220. <https://doi.org/10.5958/2231-5691.2015.00033.7>.
29. Bhattiprolu, A K., Kollipara, S., Boddu, R., Rachapally, A. and Ahmed, T. (2024) Model independent and dependent methods for dissolution profiles comparison: Can we take the road less travelled? *International Journal of Pharmaceutical Sciences and Developmental Research*, 10(1), 02–09. <https://doi.org/10.17352/ijpsdr.000053>.
30. Klein, S. (2019) Advancements in dissolution testing of oral and non-oral formulations. *AAPS PharmSciTech*, 20 (266). 1-3. <https://doi.org/10.1208/s12249-019-1479-8>.
31. Kostewicz, E.S., Abrahamsson, B., Brewster, M., Brouwers, J., Butler, J. and Carlert S. (2013) In vitro models for the prediction of in vivo performance of oral dosage forms. *European Journal of Pharmaceutical Sciences*, 57, 342-366. <https://doi.org/10.1016/j.ejps.2013.08.024>.
32. Kumar, M. and Kaushik, D. (2018) An overview on various approaches and recent patents on gastroretentive drug delivery systems. *Recent Patents on Drug Delivery & Formulation*, 12(2), 84-92. <https://doi.org/10.2174/1872211312666180308150218>.





Gautam Verma et al.,

33. Lai, J., Azad, A K., Sulaiman, W M A W., Kumarasamy, V., Subramaniyan, V. and Alshehade, S A. (2024) Alginate-Based Encapsulation Fabrication Technique for Drug delivery: An updated review of particle type, formulation technique, pharmaceutical ingredient, and targeted delivery system,' *Pharmaceutics*, 16(3), 370. <https://doi.org/10.3390/pharmaceutics16030370>.
34. Late, S A. and Gandhi, B R. (2023) A review on modified release dosage form. *International Journal of Advanced Research in Science Communication and Technology*, 3(5), 232–240. <https://doi.org/10.48175/ijarsct-9350>.
35. Lu, S. and Anseth, K S. (2000) Release behavior of high molecular weight solutes from poly(ethylene glycol)-based degradable networks. *Macromolecules*, 33(7), 2509-2515. <https://doi.org/10.1021/ma9915024>.
36. Maderuelo, C., Zarzuelo, A. and Lanao, J M. (2011) Critical factors in the release of drugs from sustained release hydrophilic matrices. *Journal of Controlled Release*, 154(1), 2-19. <https://doi.org/10.1016/j.jconrel.2011.04.002>.
37. Mastropietro, D J., Omidian, H. and Park, K. (2011) Drug delivery applications for superporous hydrogels. *Expert Opinion on Drug Delivery*, 9(1), 71-89. <https://doi.org/10.1517/17425247.2012.641950>.
38. Murakami, T. (2017) Absorption sites of orally administered drugs in the small intestine. *Expert Opinion on Drug Discovery*, 12(12), 1219–1232. <https://doi.org/10.1080/17460441.2017.1378176>.
39. Naik, E R., Reddy, K V R. and Swetha, N. (2019) Super porous hydrogels. *Research Journal of Pharmacy and Technology*, 12(1), 434. <https://doi.org/10.5958/0974-360x.2019.00079.9>.
40. Radhakrishnan, P., Singh, S K. and Verma, P R P. (2017) Pharmaceutical formulations to increase gastric residence time: Concepts and strategies. *Drug Delivery Letters*, 7(3), 190-200. <https://doi.org/10.2174/2210303107666170428102247>.
41. Rahman, N U., Yuen, K H. and Woei, W J. (2005) Gastrointestinal transit monitoring and absorption of controlled-release pellets of diltiazem. *Pharmaceutical Development and Technology*, 10(3), 371-379. <https://doi.org/10.1081/pdt-65680>.
42. Rajora, A. and Nagpal, K. (2021) A critical review on floating tablets as a tool for achieving better gastric retention. *Critical Reviews in Therapeutic Drug Carrier Systems*, 39(1), 65-103. <https://doi.org/10.1615/critrevtherdrugcarriersyst.2021038568>.
43. Kumar, R., Sugumaran, A., Dutta, G., And Narayanasamy, D. (2023) Review on several approaches involving gastro- retentive drug delivery system. *International Journal of Biology Pharmacy and Allied Sciences*, 12(3). <https://doi.org/10.31032/ijbpas/2023/12.3.6948>.
44. Roy, S., & Prabhakar, B. (2010) Bioadhesive polymeric platforms for transmucosal drug delivery systems – a review. *Tropical Journal of Pharmaceutical Research*, 9(1). <https://doi.org/10.4314/tjpr.v9i1.52043>.
45. Samuels, T L., Yan, K., Patel, N., Plehova, K., Coyle, C. and Hurley, B P. et al. (2022) Alginates for protection against pepsin-acid induced aerodigestive epithelial barrier disruption. *The Laryngoscope*, 132(12), 2327-2334. <https://doi.org/10.1002/lary.30087>.
46. Sen, O., Manna S., Nandi, G., Jana, S. and Jana S. (2023) Recent advances in alginate based gastroretentive technologies for drug delivery applications. *Medicine in Novel Technology and Devices*, 18, 100236. <https://doi.org/10.1016/j.medntd.2023.100236>.
47. Shah, K., Singh, D., Agrawal, R. and Garg, A. (2025) Current developments in the delivery of gastro-retentive drugs. *AAPS PharmSciTech*, 26(2), 57. <https://doi.org/10.1208/s12249-025-03052-4>.
48. Siepmann, J. and Siepmann, F. (2011) Modeling of diffusion controlled drug delivery. *Journal of Controlled Release*, 161(2), 351–362. <https://doi.org/10.1016/j.jconrel.2011.10.006>.
49. Thelen, K., Coboeken, K., Willmann, S., Dressman, J B. and Lippert, J. (2011) Evolution of a detailed physiological model to simulate the gastrointestinal transit and absorption process in humans, Part II: Extension to describe performance of solid dosage forms. *Journal of Pharmaceutical Sciences*, 101(3), 1267-1280. <https://doi.org/10.1002/jps.22825>.
50. Tomar, A., Upadhyay, A., Gupta, S K. and Kumar, S. (2019) An overview on Gastroretentive drug delivery system: current approaches and advancements. *Current Research in Pharmaceutical Sciences*, 9(1), 12-16. <https://doi.org/10.24092/crps.2019.090102>.
51. Vasvari, G., Haimhoffer, A., Horvath, L., Budai, I., Trencsenyi, G. and Beresova, M. (2019) Development and characterisation of gastroretentive solid dosage form based on melt foaming. *AAPS PharmSciTech*, 20(7), 290. <https://doi.org/10.1208/s12249-019-1500-2>.

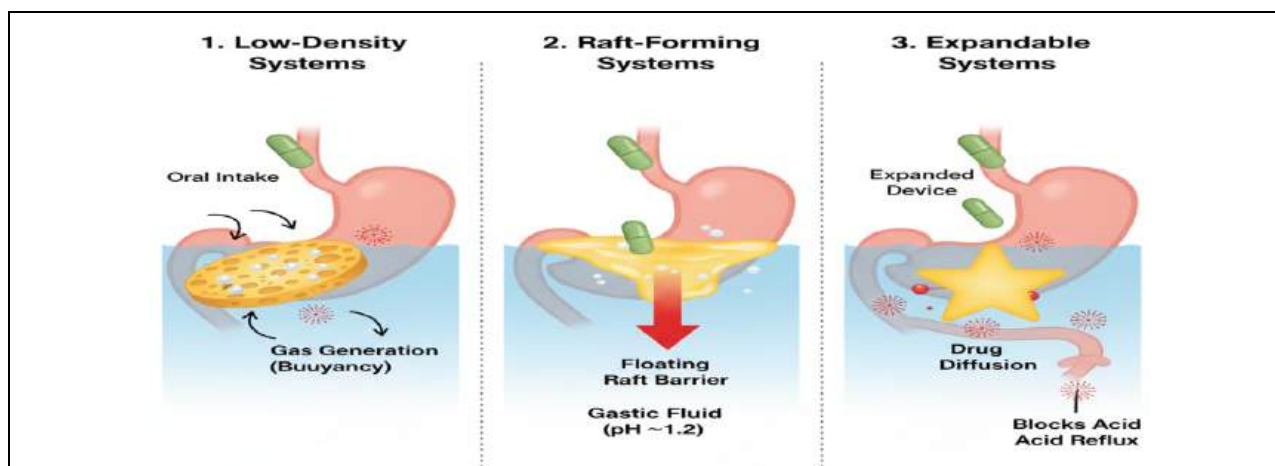
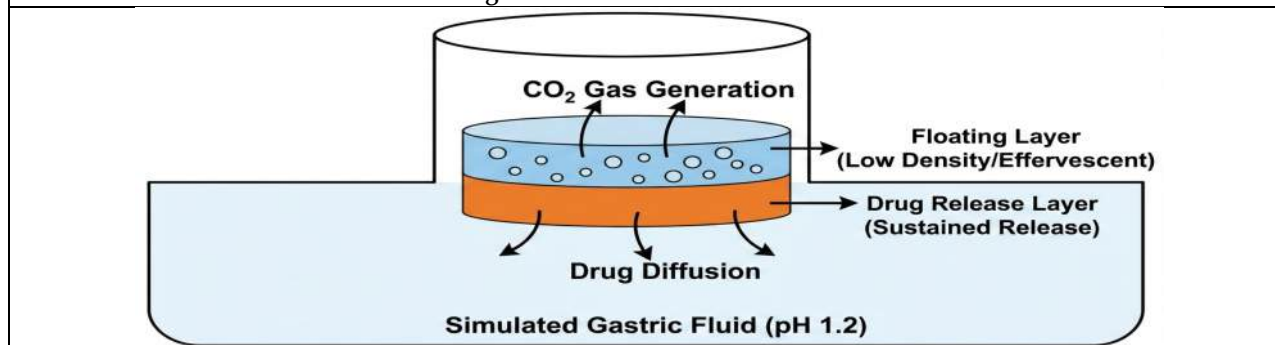




52. Watson, L E., Xie, C., Wang, X., Li, Z., Phillips, L K. and Sun, Z. et al. (2019) Gastric emptying in patients with Well-Controlled Type 2 Diabetes compared with young and older control subjects without diabetes. *The Journal of Clinical Endocrinology & Metabolism*, 104(8), 3311-3319. <https://doi.org/10.1210/jc.2018-02736>.
53. Yoshida, T. and Kojima, H. (2023) Oral drug delivery systems applied to launched products: value for the patients and industrial considerations. *Molecular Pharmaceutics*, 20(11), 5312-5331. <https://doi.org/10.1021/acs.molpharmaceut.3c00482>.

Table -1 Marketed gastro retentive drug products

Brand Name	Drug	GRDDS Type
Madopar® HBS	Levodopa	Floating Capsule
Glumetza®	Metformin	Swellable system
Cipraxel® GR	Ciprofloxacin	Floating table
Valrelease®	Diazepam	Floating system
Topalkan®	Antacid	Raft-forming system

**Figure -1 Mechanisms of GRDDS****Figure -2 Structure of bilayer floating tablet**

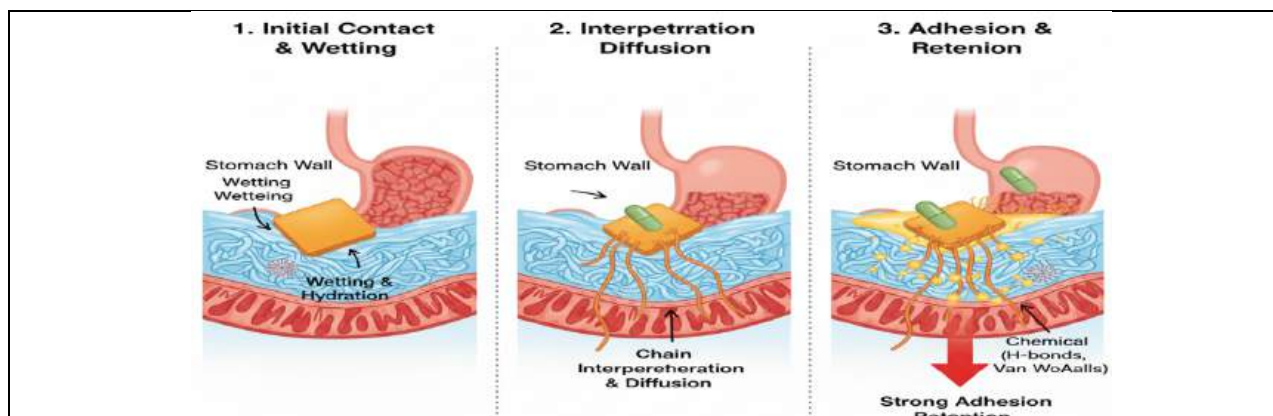
Gautam Verma *et al.*,

Figure - 3 Mechanism of mucoadhesion for gastro retentive system

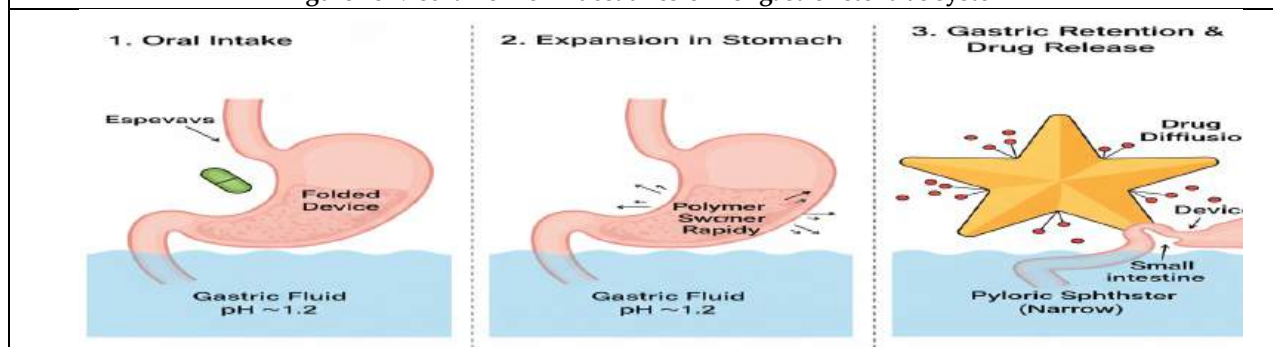


Figure - 4 Expandable GRDDS in stomach

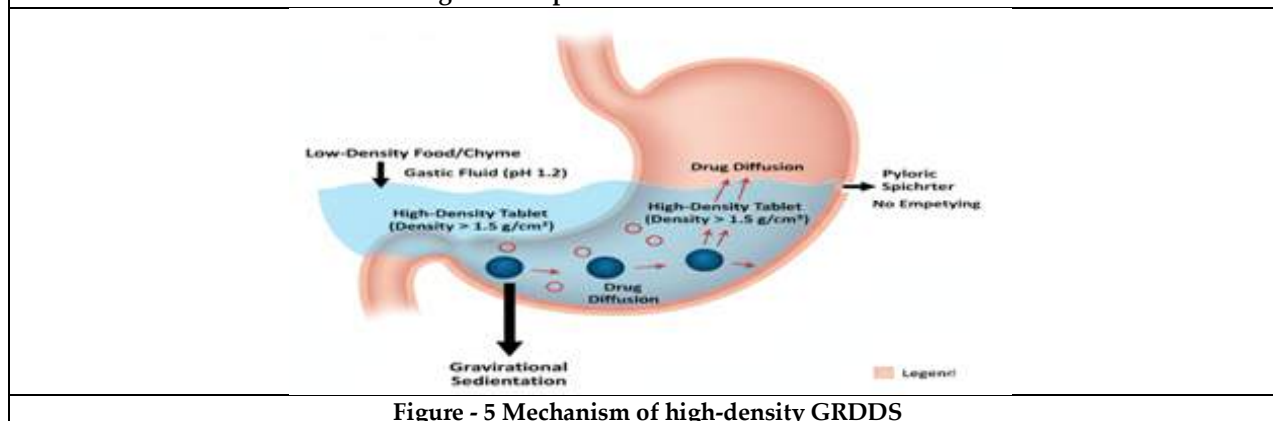


Figure - 5 Mechanism of high-density GRDDS



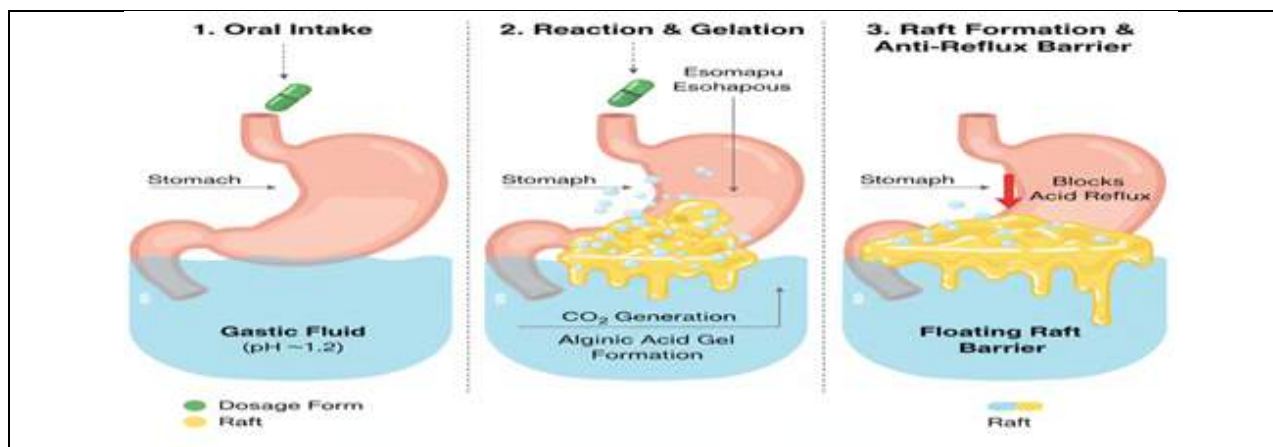


Figure - 6 Mechanism of the raft forming GRDDS

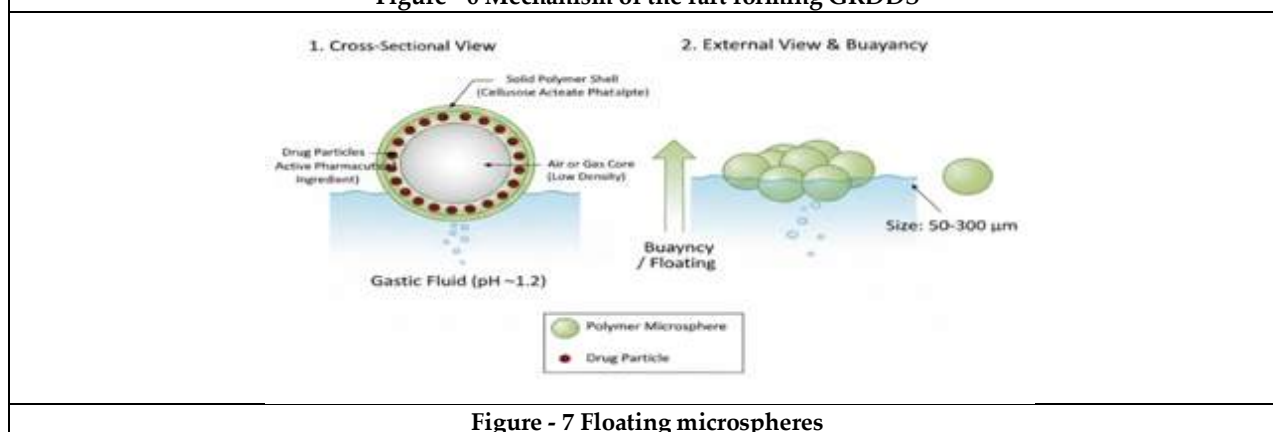


Figure - 7 Floating microspheres

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Exploring Bioethics and Genetic Manipulation in Margaret Atwood's *Oryx and Crake*

M. Usha Bharathi, S. Vembu, P. D. Mary Portia and M. Maheswari*

Assistant Professors, Department of English, Shrimati Indira Gandhi College, (Affiliated to Bharathidasan University) Trichy, Tamil Nadu, India.

Received: 10 Mar 2026

Revised: 14 Apr 2026

Accepted: 09 May 2026

*Address for Correspondence

M. Maheswari

Assistant Professor,
Department of English,
Shrimati Indira Gandhi College,
(Affiliated to Bharathidasan University)
Trichy, Tamil Nadu, India
E.Mail: maheswarim@sigc.edu



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Oryx and Crake by Margaret Atwood presents a dystopian future shaped by rapid developments in genetic engineering, corporate biotechnology, and scientific ambition unchecked by ethical responsibility. The novel anticipates contemporary debates surrounding gene editing, synthetic biology, and the commodification of life. This paper explores the bioethical implications of genetic manipulation in the narrative, focusing on transgenic experimentation, the creation of the Crakers, corporate biopower, and the engineered pandemic that eradicates humanity. Drawing on bioethical principles such as autonomy, beneficence, non-maleficence, and justice, along with post-humanist and biopolitical theory, this study argues that Atwood critiques not science itself but its detachment from moral accountability. Through speculative fiction, Atwood constructs a cautionary vision of a world in which genetic engineering becomes a tool of corporate domination and existential redesign. Ultimately, the novel calls for ethical integration in scientific advancement and urges a reconsideration of what it means to be human in the age of biotechnology.

Keywords: Posthumanism, Biotechnology, Genetic Engineering, Hybrid Species, Margaret Atwood, *Oryx and Crake*

INTRODUCTION

The present paper explores wisdom fabrication and climactic novels from the Post human period. The literature of this period establishes a connection between humans and non-humans. Before probing in the post-human age in

115457



**Usha Bharathi et al.,**

literature, it is essential to understand what humanism is. Humanism is a popular and ethical worldview that prioritizes mortal enterprises over godly or supernatural bones. The post human period is characterized by technology's dominance over indeed the most intellectual beings, reshaping every aspect of life, with Artificial Intelligence ultimately replacing humans. Trans humanist testaments fantasize a un born shaped by technologies that exclude geriatric and enhance mortal intellectual, physical, and cerebral capacities. These developments also lead to inheritable engineering, nuclear munitions, and bio-weapons. The outbreak of Covid as an epidemic prompts reference to Atwood's *Oryx and Crake*. Literature, especially wisdom fabrication and climactic novels, serves as a reflection, reproduction, and predictor of mortal life and Earth's future. These stripes explore imaginative scientific generalities similar as inheritable engineering, transhumanism, and bio-weapons. thus, Posthumanism also offers a reflection on humanism. In traditional humanism, man was central to all erudite creation. But over time, changes in mortal life, society, and literature have passed. Revolutions in study and scientific inventions have impelled humans to transcend traditional passions and advance beyond humanism. Accordingly, posthumanism, in its critical form, is a new conceptualization of humanity. It examines artistic representations, power relations, and dialogues that have historically deposited humans above other life forms and under their control.

Oryx and Crake, written by Margaret Atwood, urges compendiums to claw into the narrative of Jimmy, also appertained to as Snowman, who was abandoned by his community and M. Usha Bharathi and et al., brazened with the consequences of unbridled biotechnology trial. The book intricately weaves together Jimmy's recollections before and after the terrible event. Jimmy, wearing a bed distance, lived like a neolithic man on a tree, exposed to sun, eating food, and securing Crakers genetically modified hominids designed to replace humans while ignoring about a pre-disaster world where unrestricted biotechnology created mongrel beast workers for the ultimate thing. still, everything ended when Crake, a genetically altered mortal, created an incorrigible contagion to annihilate the mortal population and make way for the Crakers to take over. Atwood's book highlights the contemporary advancements in biotechnology and cautions compendiums about the unrecoverable consequences that could pose a trouble to mortal survival. According to Atwood, this novel is a combination of fact and fabrication, and it follows a route that's formerly apparent to us. She describes it as academic fabrication that delves into the ongoing discussion girding inheritable advancements and presents a pictorial depiction of the imminent disastrous downfall of civilization as a consequence.

Literature has constantly endeavored to anticipate and portray the possibilities of unborn scientific advancements indeed before they materialize in written form. Warwick asserts that wisdom fabrication has the capability to give alleviation to scientists and duly depict possible unborn situations. mongrel brutes have been a recreating theme in literature for a considerable period of time, starting with the publishing of H. G. Wells' *The Island of Doctor Moreau* in 1896. This book presents the conception of mongrel brutes in a manner that's exceptionally believable and true to life. This is a dystopian narrative set in the near future, where a Biotechnology Corporation governs the world until it's fully annihilated. *Oryx and Crake* introduces the anthology to a range of mongrel brutes, including rakunks (a blend of raccoons and skunks), wolvogs (combining the aggression of wolves with the appearance and geste of tykes), pigoons (organisms that induce mortal organs), and Crakers (a genetically modified species of humans). When humans do n't intermediate, these creatures ultimately come willful as the deadly contagion spreads and kills everyone, constantly venturing Jimmy.

Like Atwood, cold-blooded creatures have traditionally been depicted in literature as peculiar, uncanny, intimidating, and a emulsion of mortal and beast, as well as mortal and machine. These cold-blooded creations challenge the being societal divisions between the natural and artificial (man-made) and between creatures and humans. A child born through surrogacy or in vitro fertilization is presently facing a dilemma between artificial and natural birth, or a combination of both, which is causing significant solicitude. This admixture challenges the generally recognized conception of mortal identity. According to the Oxford Dictionary, a human is defined as a person, distinct from both creatures and machines. In the period of biotechnology, humans have started to surpass their natural limitations by integrating artificial organs from creatures (known as xeno plantation) and mechanical support (cyborgs) into their bodies. This has led to the emergence of the post human period, when humans are no





Usha Bharathi et al.,

longer separate from machines. As Francis Fukuyama writes, The most significant trouble posed by contemporary biotechnology is the possibility that it'll alter mortal nature and thereby move us into a ' posthuman stage of history.(7) The idea of the mortal body has experienced a substantial change, moving from its natural state to one that's artificial or man- made. This makes a new post human perspective on the mortal body necessary.

In the 20th century, scientific styles and technological advancements made substantial benefactions to the field of posthumanism. Humans and robots have been in a cooperation for ages. In the history, machines were employed to distinguish between non-human creatures and people. But in the post-humanist period of moment, there's a debate about how the lines separating the mortal body from technology are getting hazier. As Donna J. Haraway writes Late twentieth- century machines have made completely nebulous the difference between natural and artificial, mind and body, self -developing and externally designed, and numerous other distinctions that used to apply to creatures and machines. Our machines are disturbingly lively, and we ourselves frighteningly inert, (152) inheritable engineering has been around since the early 1980s, when scientists developed an on course specifically for studying cancer. Over the course of the once twenty times, scientists have successfully developed colourful genetically modified beast species that retain profitable characteristics. These include scapegoats that produce anti-clotting protein, fish with accelerated growth, and gormandizers that are environmentally friendly. inheritable engineering is driven by a strong desire for its implicit benefits, similar as furnishing a source for mortal organ transplants, studying conditions like cancer and heart complaint, producing substances for Medicinals, and indeed creating faces inheritable engineering thrives not only on its mentioned benefits, but on the comprehensive network that supports it. "While I will not be suitable to cover every single bone , I can give some sapience into a named many. I'll explore the content of mongrel creatures in relation to their part in labour, the influence of biotechnology on society, the commercial docket, the commercialization of these creatures, and the absence of effective programs to regulate them".

Throughout the history of humanity, creatures have served as a source of food and as a means of labour. From studying the relations between humans and creatures, it's apparent that creatures have frequently been viewed as unresistant beings, exploited for mortal gain. In moment's technologically advanced world, the significance of colourful aspects has been lowered, including mortal labour. still, creatures continue to play a prominent part in the pool. creatures have endured a significant increase in their liabilities. In the history, they were primarily utilized for husbandry, packing, and food consumption. still, they now also bear the weight of being subordinated to trials, used to develop mortal organs, napkins, and cells, and serve as a source of protein that can be altered or created to fulfil mortal solicitations.

As Steven Best and Douglas Kellner call attention to the transformative power of biotechnology which created a surreal zoo of mutations that includes tobacco shops with firefly genes, mice and gormandizers with mortal genes, potatoes with funk genes, fish and tomatoes with antifreeze genes, and dozens of different genetically modified foods spliced with bacteria, contagions, antibiotic- resistant marker genes, and nonentity genes.(Atwood 134) The foremost runners of the new opens with youthful Jimmy recollections of a " campfire was an enormous pile of cows and lamb and gormandizers "(Atwood 18). Devastated by the contagion that was designedly fitted , the creatures suffered a woeful fate, leading to their mass decimation in order to guard mortal lives. In Britain during the 1980s and again in themed-1990s, there was a significant incident involving the disposal of cows due to enterprises about the spread of Bovine Spongiform Encephalopathy(BSE), a mortal complaint. Through trial, the utilization of beast labour transitioned from being a natural process to being positioned on the fringe of mortal intervention. Oryx and Crake considerably examine the content of mongrel, genetically modified brutes. Pigeons, a gormandizer created to grow an" multifariousness of reliable mortal- towel organs in transgenic knockout gormandizer host- organ"(Atwood 25) that would defend against the attack of contagions. These organisms were designed to grow snappily, allowing mortal organs to be available for transplantation as soon as possible. There's presently a strong interest in the scientific community to develop a system for growing and conserving multiple feathers at formerly, with the thing of customizing them for individual cases. These gormandizers were designedly bred to be larger and further robust to more accommodate redundant organs. At first sight, they may feel a bit



**Usha Bharathi et al.,**

intimidating with their pink eyes, nimble movements, and a tendency to suck into humans rather fleetly. The Pigeon is involved in the product of mortal organs, which are latterly vended as goods for consumption by buyers. In the history, beast exploration concentrated on draining the beast's energy, but unfortunately, it ended up taking the beast's life for the sake of mortal gain. Along with long life, mortal emphasizes on the idea of beauty, and youngness. This design under Nooskins design Pigeons to replace the aged epidermis with a newer one," a genuine launch- over thing that would be wrinkle and mark-free "(Atwood 62). This design is centered around the interesting miracle observed in algae, where youngish skin cells ingest aged cells and produce duplicates to take their place. The progress in biotechnology has generated distinct beauty criteria that value perfect skin as the ultimate hand of attractiveness. Regrettably, this has redounded in sentiments of insufficiency and apprehension, which latterly have bolstered the expansion of this sector. One fresh remarkable mongrel critter is the wolvog, which merges the traits of a canine and a lupine. Wolvogs began as a result of raising competition among enterprises and their intrusion into one other's disciplines. These brutes are specifically finagled to cover and secure business goods. While describing Crake says that They are n't tykes , they just look like tykes . They're wolvogs they're bred to deceive. Reach out to stroke them, they'll take your hand off. There's a large hole- bull element. Yeah better than an alarm system- no way of disarming them, not like real tykes .(Atwood 241) These brutes were salutary and manageable indeed though they were kept in a pen and under constant observation. But when the humans went defunct, they were set free and started attacking Jimmy.

As a result of their hostility, Jimmy is now impelled to seek safety in a tree. While genetically changing creatures has really been greatly told by technology, they organically evolved into different brutes after they were left to fend for themselves without mortal intervention or care. They started acting in ways that went against their ingrained tendencies as Pigeons were supposed to be tusk-free, but may they were returning to type now they'd gone feral, a fast forward process considering their rapid maturity genes.(Atwood 43) generality of meat Everything that was formerly supposed an unrealistic and sarcastic conception ten times a gone is now within the realm of possibility. The notion of meat has experienced a metamorphosis in the macrocosm of Oryx and Crake. Chickie nobs, a genetically modified strain of funk, is specifically bred and cultivated for mortal consumption. The depiction of chickens in the book is n't fully fictional; laboratory- cultivated, in vitro meat has indeed been created for both artificial and remedial purposes. likewise, this synthetic system of product not only holds significant fiscal significance but also acts as a means to assuage environmental and beast weal organizations who explosively expostulate to the cruel and dangerous conditioning of the beast assiduity. As Crake says " beast weal freaks wont be suitable to say a word, because this thing feels no pain "(Atwood 238). The lack of pain is because of neurological revision, and the physical differences are to similar extent the bystander feels shocked and pity at the same time. While describing them There's a mouth opening at the top, they(workers) leave the nutrients in there. No eyes or bleak or anything, they do not need those. they'd removed all the brain function that had nothing to do with digestion, assimilation and growth. You get funk bone in two weeks.(Atwood 238) Humans have demonstrated a significant position of freedom when it comes to creating genetically finagled species. Limiting beast options to match mortal preferences through neurological and physical differences. All of them have been designed to mimic cravens, but they're missing pivotal functionalities. They've no branches, no head, and can be described as a " meat tube" a living, walking mass of meat that's specifically acclimated for mortal consumption. As the design advances, the precious traditional system of plant husbandry for " genuine" funk is sluggishly being phased out in the request.

Oryx and Crake has emphasized the notable inclination towards meat input and the caregiving of cattle. The characters in the narrative sustained for a world where factual meat was, which served as a memorial of a time when life held lesser complexity and significance. Access to genuine meat is limited to individualities who retain honor and wealth. Jimmy is astounded when he substantiations the genuine donation of meat at the prestigious Watson-Crick Institute. When Jimmy joins Crake for regale, he's astounded by Crake's selection of authentic Japanese beef, a rare delicacy similar in failure to diamonds, at this Jimmy thinks that " It must have bring him a fortune "(Atwood 289). In the world of the story, eating real meat is only permitted for the flush members of society. This demonstrates the patient social taboos girding food access, especially in the setting of industrialization, when women and children





Usha Bharathi et al.,

were constantly barred from meat consumption while the manly head of the family indulged in it. Indeed though beef created instinctively is extensively available, the product nonetheless has to live up to the smirch of being unnatural. When Jimmy returned home with a bucket of deep-fried chicken nuggets, his roommates weren't amused and they did not talk for a week. All the forenamed genetically modified creatures are expressly designed for mortal consumption. Humans have beyond the limitations of introductory work and have entered the sphere of designing and producing work. The mortal brain is humanity's most precious resource, a awful wellspring of measureless eventuality. Due to the nippy progress of technological developments, people have exceeded their essential constraints and are presently plying deliberate control over nature.

Crake's narrative involves the creation of a significant portion of the mortal population as a relief for humans after the deadly contagion spreads. Crake adroitly combined colorful traits from different species, giving rise to a remarkable mongrel organism. Crackers, analogous to pussycats, retain the remarkable capability to heal themselves by purring, a skill that Cracker has diligently honed over the times. Just like rabbits, crackers have the capability to survive in food-scarce conditions by rehearsing coprophagy. The reproductive geste of crackers is structured to act that of baboons in order to address issues related to racism, scale, and territoriality. The lady's abdomen changes colour to a vibrant blue, emitting pheromones that naturally draw the attention of males. A conventional cotillion is performed, during which the womanish chooses a group of males to engage in sexual intercourse with, taking turns until the blue colour fades. There's a lack of clarity girding the lineage of the seed. The crackers have an impeccable design, complete with UV-resistant skin and a erected-in nonentity repellent, making them visually appealing. They're (Crakers) every known colour from the deepest black to whitest white, they're colourful heights, but each one of them is admirably proportioned. Each is sound of tooth, smooth of skin. No ripples of fat around their middles, no bulges, no dimples orange-skin cellulite on their shanks. No body hair, no bushiness. They look like retouched fashion prints, or advertisements for high priced drill programs. (Atwood 115)

Because of their rigidity, they choose not to make homes or use tools, which would latterly develop into fiefdoms, clans, and materialistic solicitations. Crake posits that God is simply a cluster of neurons that he has uprooted from the minds of Crakers, appertained to as the Gspot in the brain. Crake's main ideal is to exclude art due to his belief that any type of emblematic cognition has the implicit to bring about the downfall of humanity. With art "next they'd be contriving icons, and sepulchers, and grave goods, and the afterlife, and sin, and Linear B, and lords, and also slavery and war" (Atwood 361). After all his sweats they still do dream and sing, and they're only introduced to plain and simple language. Upon leaving their defended mortal niche and encountering the wild terrain, the Crakers initiated a process of evolutionary change. At first, Crake effectively canceled their questioning about where they came from. Crakers have started to misdoubt their origins and the reality responsible for their creation. Like wise, crackers are designedly finagled to retain a harmonious frame, devoid of any individualities taking on leadership positions or blindly conforming to others. This has the capability to cultivate a strong desire for power and control. nonetheless, Jimmy notices that one of the crackers, dubbed Abraham Lincoln, is gradationally acquiring the characteristics of a leader. They hold the establishment conviction that there's no advanced reality and do not engage in hero deification. nonetheless, formerly Jimmy did not come back from his adventure within a short period of time, the crackers created an hero and started sharing in religious rituals and reciting prayers.

Although Crake made significant attempts to enhance the mortal species, they nonetheless have an essential propensity to acquire knowledge and acclimate as necessary. Crake explains to Jimmy that the crakers are simply prototypes, allowing humans to choose the asked traits for their unborn generations. It's about designing babies, as per the parent demand, "They'd be suitable to produce completely chosen babies that would incorporate any point, physical or internal or spiritual, that the buyer might wish to elect" (Atwood 357). I've enterprises about three specific problems. Originally, major advancements in scientific knowledge generally number a significant fiscal burden that's accessible only to individualities with substantial coffers and influence. This society is enabling the rich to enhance the internal and physical capabilities of their seed, so making them stronger and further intelligent. This is aggravating the formerly crummy educational experience and farther extending the socioeconomic difference. My alternate concern is that over time, as these changes come wide and accessible to everyone,

115461





Usha Bharathi et al.,

individualities will come indistinguishable from one another, as they would each retain rates similar as intelligence, youngness, attractiveness, and intelligence. This will erode the distinctness that makes each person unique and render it insolvable to maintain individuality. Incipiently, my concern pertains to power dynamics what if those in authority clandestinely manipulate individualities, rendering them intellectually disabled, biddable, and subservient, in order to form sizable cohorts? As Crake says Whole population could be created that would have pre-selected characteristics. Beauty, of course; that would be high in demand. And acquiescence several world leaders has expressed interest in that. (Atwood 358)

The thirst for power has been a constant fight throughout mortal history. Power has transitioned from clans to pots. The arrival of biotechnology has significantly converted the realm of mass regulation. As Haraway says “ The social thing of new life lores was easily statically control of the millions ” (46). originally, humanity has always harbored a desire to retain holy capacities, particularly in the realm of creation. This aspiration is now being realized through the advancements in biotechnology. Using it, each existent within a community can be modified according to one's wishes. As Jimmy recalls There'd been a lot of chaffing around these days produce- an- beast was important fun, said the guys doing it; it made you feel like a god. A number of the trials were destroyed because they were too dangerous to have around (Atwood 57) The alternate aspect of the new focuses on the power of surveillance. In this macrosystem, a bio-firm governs and controls the population through collaboration and regular monitoring. There are strict security measures in place, which involve regular monitoring of online conditioning.

Power constantly encounters resistance, while cooperation encounters obstacles when its opponent infiltrates its home and threatens its experimenters. Oryx and Crake portrays the lasting schism in society, with a unique and conspicuous divagation. In this environment, individualities are separated according to their degree of specialized advancement. The proponents and contributors of technological advancement in pots live in a secure and strictly kept community, where they enjoy the advantages of legal protection, robust security measures, and a health-conscious way of life. Again, individualities who are n't employed within these enclosed areas and primarily serve as guests for companies occasionally live in the outskirts, which are sometimes described as less advanced or uncultivated. Atwood underscores the internal difference among the working class by portraying Jimmy and Crake as representative characters. In this environment, the pivotal determinant of one's position is whether they choose to work for the business or not, rather than the conventional distinction between the bourgeoisie and the riffraff. Technological advancements have had a huge impact on the request and its ways of progress and deals. The primary and noteworthy change is the relief of homemade labour with internal labour. In Atwood's new Oryx and Crake, the pot views Crake, a character with exceptional cognitive capacities, as a precious asset. The establishment will exploit its capability for invention (intellectual value) for its own gain, while Jimmy, a character lacking any tendency towards creativity, gets marginalized. The cognitive labour in the textbook is being exploited grounded on the power of their invention. In the new Oryx and Crake, the Watson- Crick Institute claims power of the creation made by the scholars by patenting it under their own name, therefore replacing the scholars' power. Pots frequently gain patents for their workers' creations, leading to a race among financiers to acquire as numerous patents as they can, in order to come the exclusive directors of a particular product.

This covetousness results in the creation of several inventions that are fully redundant. The story successfully illustrates how technology and the desire for power directly led to the Crake action. He has established his power through the use of technology, both by eradicating particular populations that former autocrats have always asked but were unfit to negotiate, and by producing bio-engineered organisms. This is how he envisions the perfect world. “All it takes... is the elimination of one generation. One generation of anything.... Break the link in time between one generation and the next, and it's game over ever”. (Atwood 223) He's responsible for creating the Blyss pluss Pill, a largely sought- after drug that aims to drop population situations by adding sexual desire, furnishing protection against sexually transmitted conditions, and dragging youngness. also, he orchestrates an act of bioterrorism. In addition, the lozenge includes a haemorrhagic contagion that was specifically created to annihilate the mortal population, but this information is not revealed. Limited biotechnology has the implicit to enable a single person to ingest a lozenge and annihilate the whole mortal population without discovery. Biotechnology is deceptive to those





Usha Bharathi et al.,

who are fluently wisecracked; it makes false pledges and achieves results it cannot legitimately assert. The proliferation of genetically finagled creatures can be attributed to the influence of commercial dominance. Not only does a colossal pot have power over the request, but it also exercises dominion over every hand of the general population's actuality. This includes their access to food, clothes, security, and education, as well as their social control and indeed the manipulation of genetics to shape the asked kind of consumer for the plutocrat. This signified the inception of the time of colonizing actuality on Earth.

The collaboration's profit is deduced from the exploitation of both mortal beings and the terrain. The theoretical converse girding the correlation between capitalism and living organisms has persisted for an extended period of time. In her book *Life as supernumerary Biotechnology and Capitalism in the Neoliberal period*, Melinda Cooper argues that the frugality's expansion beyond natural limits has led to its redundant state. The devaluation of humanity has passed as a result of inordinate financial influence. As she writes As long as life wisdom product is subject to the imperatives of capitalist accumulation, the pledge of a fat of life will be rested on a corresponding move to depress life.(Atwood 45) This commercialization can only be enforced in a society that opposes public and governmental hindrance and lawyers for the neoliberal request. The whole mortal population was cancelled due to the commercialization of life. Consumption is the primary force behind the request, encompassing the deliberate product of goods and services for the purpose of consumption. Atwood's work specifically questions the principle of failure in the frugality, fastening on the complaint request. In this request, pots designedly produce the illness and also introduce a more expensive and limited result. This miracle generates an inclination towards collaboration and consumption." moping ails" are considered the most profitable type of disease from a marketable perspective(Atwood 248). The commercialization easily demonstrates the paternalism displayed by companies.

The novel delves into a series of political assassinations, strange circumstances, and unexplained vanishings that can be attributed to the power held by the Cooperation. These events easily illustrate that those who are against cooperation are fleetly silenced, discredited, or made to vanish. Jimmy's mama, a microbiologist, constantly voices her disagreement before leaving the installation to pursue activism. She's pursued relentlessly by a pot for several times until they eventually track her down and exclude her. The ineffectiveness of these forms of action is apparent in the Happicuppa coffee kick. The creation of Happicuppa coffee was a result of Healthwyzer's desire to simplify the process of collecting completely grown coffee sap on a large-scale ranch. The genetically modified bean presented a substantial trouble to a humble coffee planter. The demonstration lasted for several days, with screams and multiple losses, but no palpable issues were achieved. As Uncle Pete said They'll get tired of it, they'll settle down. Everybody wants a cheaper mug of coffee – youcan't fight that.(Atwood 212)

CONCLUSION

Upon completing the new Oryx and Crake, it becomes apparent that technology has the implicit to bestow bliss, albeit with certain restrictions. Unrestrained trial possesses the capacity to precipitate the collapse of humanity. Crake was suitable to execute his unrighteous scheme because there were no ethical morals or regulations in place. The inquiry that requires a response is; what's the maximum extent or boundary? What's the threshold for being considered inordinate, and what's the limit for going beyond respectable boundaries? It's pivotal for them to establish clear limits that must not be violated. Atwood warns compendiums about the essential pitfalls of biotechnology and its profound influence on the mortal race. Considering the present position of specialized progress, it's pivotal to break and contemplate whether this is authentically essential at this juncture. Is this truly essential for the well-being of mortal beings? The correlation between wealth and influence energizes the quick progress in different sectors. Atwood expresses apprehension on the possibility of a disastrous future characterized by inheritable manipulation and natural control in the advancing period. She emphasizes the threats of scientists assuming the part of a deity by manipulating the abecedarian factors of life, while the rest of us, like Jimmy, remain unconscious to the possible impacts we might encounter.





Usha Bharathi et al.,

REFERENCES

1. M. Atwood, *Oryx and Crake*. Toronto: McClelland & Stewart, 2003.
2. D. J. Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," in *Simians, Cyborgs, and Women: The Reinvention of Nature*. New York: Routledge, pp. 149–181, 1991.
3. F. Fukuyama, *Our Posthuman Future: Consequences of the Biotechnology Revolution*. New York: Farrar, Straus and Giroux, 2002.
4. S. Best and D. Kellner, *The Postmodern Adventure: Science, Technology, and Cultural Studies at the Third Millennium*. New York: Guilford Press, 2001.
5. N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press, 1999.
6. M. Cooper, *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era*. Seattle: University of Washington Press, 2008.
7. R. Warwick, *March of the Machines: The Breakthrough in Artificial Intelligence*. London: Century Press, 1997.
8. H. G. Wells, *The Island of Doctor Moreau*. London: William Heinemann, 1896.
9. C. Wolfe, *What is Posthumanism?* Minneapolis: University of Minnesota Press, 2010.
10. R. Braidotti, *The Posthuman*. Cambridge: Polity Press, 2013.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Complex Intuitionistic Fuzzy Madm Model For Diagnosing Cancer Causes In Non-Smokers

A. Shahirunnisa¹ and S. Akila^{2*}

¹Research Scholar, Department of Mathematics, Theivanai Ammal College for Women(Autonomous), Villupuram, (Affiliated to Annamalai University, Cuddalore), Tamil Nadu, India.

²Associate Professor, Department of Mathematics, Theivanai Ammal College for Women (Autonomous), Villupuram, (Affiliated to Annamalai University, Cuddalore), Tamil Nadu, India.

Received: 12 Jan 2026

Revised: 04 Feb 2026

Accepted: 28 Feb 2026

*Address for Correspondence

Shahirunnisa. A

Research Scholar, Department of Mathematics,
Theivanai Ammal College for Women (Autonomous), Villupuram,
(Affiliated to Annamalai University, Cuddalore),
Tamil Nadu, India.

E.Mail: ashahirunnisa@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The risk of cancer in nonsmokers has increased by several factors. This risk is increased by viral infections, genetic predispositions, and environmental exposures. Prevention and early detection can be facilitated by knowledge and comprehension of these aspects. For non-smokers, routine health examinations and screenings are essential. Finding risk factors can enhance results and lower the incidence of cancer. Aims to analyze the influential and dominant results and attributes of some innovative and valuable concepts using CIF information and we introduce the “Complex Intuitionistic FuzzySorted Set Weighted Averaging (CIFSSWA),Complex Intuitionistic FuzzySorted Set Ordered Weighted Averaging (CIFSSOWA),Complex Intuitionistic FuzzySorted SetOrdered Weighted” Geometric (CIFSSOWG),Complex Intuitionistic FuzzySorted SetWeighted Geometric (CIFSSWG),Complex Intuitionistic FuzzySorted SetHybrid Averaging (CIFSSHA), Complex Intuitionistic FuzzySorted Set Hybrid Geometric (CIFSSHG) aggregation operators. Therefore, analyzing the issue of determining the cause of cancer in people is the primary focus of diagnostic operations. To increase the value of the analyzed methods with a specific leading result.

Keywords: Non-Smoker, MADM, Weighted Averaging Operators, Weighted Geometric Operators, Medical Decision Support System.





INTRODUCTION

Modern decision-making necessitates robust models capable of handling vagueness or ambiguity inherent in real-world data, particularly in uncertain, imprecise, and dynamic environments. Traditional binary logic and crisp mathematical techniques often fall short in such contexts, prompting the development of more adaptive paradigms such as fuzzy set theory, intuitionistic fuzzy sets (IFSs), and their various extensions. Zadeh (1965) introduced fuzzy set theory, laying the foundation for representing partial truths wherein elements can belong to a set to varying degrees. Building upon this, Atanassov (1986) proposed IFSs, which incorporate member, non-membership degree, and a hesitation margin—offering a more nuanced representation of uncertainty, particularly valuable in multi-attribute decision-making (MADM). In subsequent years, researchers like Xu, Yager, Wang, and Garg have significantly advanced this domain by developing a variety of aggregation operators—essential tools in collective decision-making within intuitionistic fuzzy frameworks. These include geometric, hybrid weighted, Einstein, Hamacher, and Aczel–Alsina operators, each tailored to different computational and interpretative needs (Xu, 2007; Xu & Yager, 2006). To capture periodic, oscillatory, and phase-dependent data that real-valued fuzzy sets cannot address, the foundation of complex fuzzy sets was laid by Ramot *et al.* in their 2002 study, and subsequently developed into (CIFs) and interval-valued models by scholars such as Alkouri & Salleh (2012, 2013) and Garg & Rani (2019). These models have shown enhanced expressiveness and precision, especially in domains like control systems, medical diagnostics, and computational intelligence.

Additionally, advanced frameworks enable deeper modeling of human reasoning under extreme uncertainty. Various decision-making frameworks, including TOPSIS, COPRAS, and set pair analysis, when integrated with fuzzy and intuitionistic fuzzy settings, yield practical tools capable of handling incomplete, linguistic, and contradictory information. For instance, Zhang (2018) successfully applied the Dempster–Shafer theory within an intuitionistic fuzzy environment to enhance group decision-making by aggregating conflicting expert judgments. More recently, researchers like Mahmood *et al.* (2021–2023) have introduced applications of bipolar fuzzy, complex fuzzy, and hybrid aggregation operators in medical diagnostics and knowledge-based systems, demonstrating notable improvements in classification accuracy and decision robustness. This evolving body of literature reflects a paradigmatic shift in decision science—from deterministic frameworks to those that embrace the full spectrum of uncertainty in human cognition and real-world phenomena. The referenced works collectively offer a comprehensive foundation of theoretical insights, algorithmic innovations, and practical implementations, underscoring the central role of fuzzy and intuitionistic fuzzy theories in intelligent decision-making.

Definition 1. Let F be the IFS defined on X_u is $F = \{(p(X_E), e(X_E)) : X_E \in X_u\}$ where $p, e: X \rightarrow [0,1]$ which p is membership values and e is non-membership values and $p + e \leq 1$ for each $u \in X$.

Definition 2. Let X_u be the universal set

A Complex Intuitionistic Fuzzy Set (CIFS) C is defined on X is given as

$$C = \{(p_c(X_E), e_c(X_E)) : X_E \in X_u\} \quad (1)$$

$$\text{where } (p_R(X_E)) = (p_R(X_E))e^{i2\pi(p_I(X_E))} \text{ and } e_c(X_E) = e_R(X_E)e^{i2\pi(e_I(X_E))},$$

$$0 \leq (p_R(X_E) + e_R(X_E)) \leq 1, \quad 0 \leq p_I(X_E) + e_I(X_E) \leq 1.$$

$$C = (p_{R_j}e^{i2\pi(p_{I_j})} + e_{R_j}e^{i2\pi(e_{I_j})}), j = 1, 2, \dots, n.$$

Definition 3. A CIFNs $C_1 = (p_{R_j}e^{i2\pi(p_{I_j})} + e_{R_j}e^{i2\pi(e_{I_j})})_{j=1}$, score value (SV) and accuracy (AV)

$$m_{SV}(C_1) = (p_{R_1} + p_{I_1} - e_{R_1} - e_{I_1}), \quad m_{SV}(C_1) \in [0,1] \quad (2)$$

$$n_{SV}(C_1) = (p_{R_1} + p_{I_1} + e_{R_1} + e_{I_1}) \in [0,1] \quad (3)$$

Complex Intuitionistic Fuzzy Sorted Set in Weighted Averaging and Geometric Operators

Definition 6. If the CIFNs





Shahirunnisa and Akila

$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, then the CIFSSWA operator is

$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = WC_1 \oplus WC_2 \oplus WC_j = \bigoplus_{j=1}^n (WC_j)^w$ (4) $W = (W_1, W_2, \dots, W_n)^T$. The rule is $\sum_{j=1}^n \frac{W_j}{\sum_{i=1}^m W_i} = 1$.

Theorem 1. If the CIFSC $_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, then the operator

$$\text{CIFSSWA} = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right) \quad (5)$$

Proof. Using mathematical induction, based on established laws. We prove the equation first, we have to check for $n=3$, then.

$$w_1 C_1 = \left((1 - (1 - p_{R_1})^{w_1}) e^{i2\pi(1 - (1 - p_{I_1})^{w_1})}, ((e_{R_1})^{w_1}) e^{i2\pi((e_{I_1})^{w_1})} \right) \\ w_2 C_2 = \left((1 - (1 - p_{R_2})^{w_2}) e^{i2\pi(1 - (1 - p_{I_2})^{w_2})}, ((e_{R_2})^{w_2}) e^{i2\pi((e_{I_2})^{w_2})} \right) \\ w_3 C_3 = \left((1 - (1 - p_{R_3})^{w_3}) e^{i2\pi(1 - (1 - p_{I_3})^{w_3})}, ((e_{R_3})^{w_3}) e^{i2\pi((e_{I_3})^{w_3})} \right) \\ \text{CIFSSWA}(C_1, C_2, C_3) = \left((1 - (1 - p_{R_1})^{w_1}) e^{i2\pi(1 - (1 - p_{I_1})^{w_1})}, ((e_{R_1})^{w_1}) e^{i2\pi((e_{I_1})^{w_1})} \right) \\ \oplus \left((1 - (1 - p_{R_2})^{w_2}) e^{i2\pi(1 - (1 - p_{I_2})^{w_2})}, ((e_{R_2})^{w_2}) e^{i2\pi((e_{I_2})^{w_2})} \right) \\ \oplus \left((1 - (1 - p_{R_3})^{w_3}) e^{i2\pi(1 - (1 - p_{I_3})^{w_3})}, ((e_{R_3})^{w_3}) e^{i2\pi((e_{I_3})^{w_3})} \right)$$

Now $n = k$, then

$$\text{CIFSSWA}(C_1, C_2, \dots, C_k) = \left(\left(1 - \prod_{j=1}^k (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^k (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^k (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^k (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right)$$

Further, $n=k+1$. $\text{CIFSSWA}(C_1, C_2, \dots, C_{k+1}) = \text{CIFSSWA}(C_1, C_2, \dots, C_k) \oplus w_{k+1} C_{k+1}$

$$= \left(\left(1 - \prod_{j=1}^k (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^k (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^k (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^k (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right) \\ \oplus \left((1 - (1 - p_{R_{k+1}})^{w_{k+1}}) e^{i2\pi(1 - (1 - p_{I_{k+1}})^{w_{k+1}})}, ((e_{R_{k+1}})^{w_{k+1}}) e^{i2\pi((e_{I_{k+1}})^{w_{k+1}})} \right)$$





Shahirunnisa and Akila

$$= \left(\left(1 - \prod_{j=1}^{k+1} (1 - p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^{k+1} (1 - p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^{k+1} (e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^{k+1} (e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \right)$$

Which “is true for $n=k+1$ ”.

Moreover, this CIFSSWA Operator has three properties, which are Idempotency, Boundedness, Monotonicity, and these three properties apply to the six operators.

Idempotency Property: If C be “another CIFN such that

$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$ then we have

$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = C$

Proof. Let $C_j = C = (p_R e^{i2\pi(p_I)} + e_R e^{i2\pi(e_I)})$ then”

$$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \right) \\ = \left(\left(1 - (1 - p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - (1 - p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) = \left(\left((p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right)$$

The equation CIFSSWA, satisfied “for $i=1$. We get.

$$= \left(\left((p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) = (p_R e^{i2\pi(p_I)} + e_R e^{i2\pi(e_I)}) = C$$

Hence, $\text{CIFSSWA}(C_1, C_2, \dots, C_j) = C$

.This Property of the CIFSSWA Operator would be called Idempotency.

Boundedness Property: If $C_j = (\min_j p_{R_j} e^{i2\pi(\min_j p_{I_j})}, \max_j p_{R_j} e^{i2\pi(\max_j p_{I_j})})$ and

$C_j^+ = (\max_j p_{R_j} e^{i2\pi(\max_j p_{I_j})}, \min_j p_{R_j} e^{i2\pi(\min_j p_{I_j})})$ such that

$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$ and

then $C_j \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq C_j^+$.

Proof. Suppose that $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$,

Let $C_j = (\min_j p_{R_j}, \max_j p_{R_j})$ and”

$C_j^+ = (\max_j p_{R_j}, \min_j p_{R_j})$,

“then $C_j \leq (C_1, C_2, \dots, C_n) \leq C_j^+$, here

$\min_j p_{R_j} \leq p_{R_j} \leq \max_j p_{R_j}$

$1 - \min_j p_{I_j} \geq 1 - p_{I_j} \geq 1 - \max_j p_{I_j}$





Shahirunnisa and Akila

$$(1 - \min_j p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \geq (1 - \max_j p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}}$$

$$1 - \min_j p_{R_j} \geq \left(\prod_{j=1}^n (1 - p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{R_j}$$

$$1 - \min_j p_{R_j} \geq \left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{R_j}$$

Similarly, for the other function, i.e.,

$$1 - \min_j p_{I_j} \geq \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{I_j}$$

$$1 - \min_j e_{R_j} \geq \left(1 - \prod_{j=1}^n (1 - e_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j e_{R_j}$$

$$1 - \min_j e_{I_j} \geq \left(1 - \prod_{j=1}^n (1 - e_{I_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j e_{I_j}$$

The Score Function'' $m_{SV}(C_j)$,

$$\begin{aligned} m_{SV}(C_j) &= (p_{R_j} + p_{I_j} - e_{R_j} - e_{I_j}), \quad m_{SV}(C_j) \in [0, 1] \\ &= \max_j p_{R_j} + \max_j p_{I_j} - \min_j e_{R_j} - \min_j e_{I_j} = m_{SV} C_j^+ \\ m_{SV}(C_j) &= (p_{R_j} + p_{I_j} - e_{R_j} - e_{I_j}), \quad m_{SV}(C_j) \in [0, 1] \\ &= \min_j p_{R_j} + \min_j p_{I_j} + \max_j e_{R_j} + \max_j e_{I_j} = m_{SV} C_j^- \end{aligned}$$

Elaborate "the following cases;

Case 1: If $m_{SV} C_j^+ > m_{SV} C_j$ and $m_{SV} C_j^- < m_{SV} C_j$

then, based on the comparison rule, we obtain

$$m_{SV}(C_j^-) \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq m_{SV}(C_j^+)$$

Case 2: If $m_{SV}(C_j^+) = m_{SV}(C_j)$ and $m_{SV}(C_j^-) = m_{SV}(C_j)$

then, based on the Accuracy Value, it is similar to the Score Value,

$$n_{AV}(C_j^-) = \text{CIFSSWA}(C_1, C_2, \dots, C_j) = n_{AV}(C_j^-)$$

Therefore, we obtain the result such that.

$$n_{AV}(C_j^-) \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq n_{AV}(C_j^-)$$

This Property of the **CIFSSWA** Operator would be called Boundedness.

Monotonicity Property: If $\text{CIFSSWA}(C_j) = \text{CIFSSWA}(C_j')$

such that $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$ and then

$$\text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq \text{CIFSSWA}(C_1', C_2', \dots, C_n').$$

Proof. Let $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$ and $C_j' = (p_{R_j}' e^{i2\pi(p_{I_j}')} + e_{R_j}' e^{i2\pi(e_{I_j}')})$,

If such that $p_{R_j} \leq p_{R_j}'$, $p_{I_j} \leq p_{I_j}'$, $e_{R_j} \leq e_{R_j}'$, $e_{I_j} \leq e_{I_j}'$

then $\text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq \text{CIFSSWA}(C_1', C_2', \dots, C_n')$

This Property of the **CIFSSWA** Operator would be called Monotonicity.

Theorem 2. If the CIFS $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSWA} = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) \quad (6)$$





Shahirunnisa and Akila

Proof. Omitted. ■

Theorem 3. If the CIFS $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSWG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (7)$$

Proof. Omitted. ■

Theorem 4. If “the CIFSC $_j = (p_{R_{k(j)}} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSOWG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (p_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (p_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - e_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - e_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (8)$$

Proof. Omitted. ■

Theorem 2.5. If the CIFSC $_j = (\ddot{p}_{R_j} e^{i2\pi(\ddot{p}_{I_j})} + \ddot{e}_{R_j} e^{i2\pi(\ddot{e}_{I_j})})$, $j = 1, 2, \dots, n$, and the operator **CIFSSHA** =

$$\left(\begin{array}{l} \left(1 - \prod_{j=1}^n (1 - \ddot{p}_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - \ddot{p}_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(\prod_{j=1}^n (\ddot{e}_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (\ddot{e}_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (9)$$

Proof. Omitted. ■

Theorem 2.6. If the CIFSC $_j = (\ddot{p}_{R_j} e^{i2\pi(\ddot{p}_{I_j})} + \ddot{e}_{R_j} e^{i2\pi(\ddot{e}_{I_j})})$, $j = 1, 2, \dots, n$, then the operator

$$\text{CIFSSHG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (\ddot{p}_{R_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} e^{i2\pi \left(\prod_{j=1}^n (\ddot{p}_{I_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - \ddot{e}_{R_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - \ddot{e}_{I_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} \right)} \end{array} \right) \quad (10)$$

Proof. Omitted. ■

Application “Non Smokers getting Cancer using Approaches based on Complex Intuitionistic Fuzzy Information”

Secondhand smoke, sometimes referred to as smoke from nearby smokers, is a smoke inhaled directly. Although dangerous compounds are present in all forms of smoke, side-stream smoke is even more deadly due to its lower burning temperature and lack of lung filtering. Tobacco use is frequently the first risk factor that people think of when they think of cancer, especially lung cancer. Although smoking is the primary cause of many cancers, particularly lung cancers, a sizable and increasing proportion of cancer cases are in people who have never smoked.





Shahirunnisa and Akila

These "non-smoker" malignancies bring up significant issues regarding genetic predispositions, environmental exposures, additional risk factors, and new research directions. Another significant risk factor is air pollution. An increased risk of lung, bladder, and even breast cancer has been associated with prolonged exposure to particulate matter and pollutants like sulfur dioxide and nitrogen dioxide. Exposure to silica, diesel exhaust, asbestos, and other chemicals, such as benzene, at work can raise the risk of developing cancer. These carcinogens are frequently found in industrial settings such as manufacturing, mining, and construction. For nonsmokers who live or work in areas where smoking is common, even secondhand smoke, while indirect, greatly raises their chance of developing lung cancer. The familial cancer syndromes can make people more susceptible to colorectal, endometrial, brain, and other malignancies. In some situations, a person's DNA pattern causes cancer rather than external toxins. Family history can be a significant risk factor even when there isn't a definite hereditary cancer syndrome. Patterns of cancer occurrence within families may result from shared genes and surroundings, particularly when paired with comparable food and lifestyle choices. Fibers of asbestos can lodge in the lungs or other organs after being breathed. These fibers eventually result in scarring and persistent inflammation. They are difficult for the immune system to eliminate, which can cause cellular damage that could eventually turn into cancer. Asbestos-related malignancies are especially deadly because of the lengthy latency period, which is frequently 20 to 50 years between exposure and diagnosis. The disease may have progressed by the time symptoms show up.

DECISION-MAKING PROCEDURE

The CIFS assumption has been applied to individual contexts by a number of intellectuals. We experimented with a decision-making procedure to look into the advantageous ideal. We can take "n" different alternatives to create an MADM "problem $C = (C_1, C_2, \dots, C_n)$ under "m" the criteria $C' = (C'_1, C'_2, \dots, C'_n)$ with vector of weight, $W = (W_1, W_2, \dots, W_n)^T$. The rule $\sum_{i=1}^n \frac{W_i}{\sum_{i=1}^m W_i} = 1$. The given set of criteria is divided into two disjoint sets, namely, (H_1) and (H_2) such that $H_1 \cap H_2 = \emptyset$ and $H_1 \cup H_2 = E$. Evaluate the alternatives $C_j, j = 1, 2, \dots, m$ under C'_p and gives the CIFNs. $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})_{j=1,2,\dots,n}$. Where $0 \leq p_{R_j} + e_{R_j} \leq 1$ and $0 \leq p_{I_j} + e_{I_j} \leq 1$. To identify the best options among the ones provided, and then used developed operators.

Step 1: Arranging the decision matrix $(\gamma_{jk})_{m \times n}$.

$$S = \begin{matrix} & C_1 & & C_n \\ \begin{matrix} C'_1 \\ \vdots \\ C'_m \end{matrix} & \begin{pmatrix} \gamma_{11} & \cdots & \gamma_{1n} \\ \vdots & \ddots & \vdots \\ \gamma_{m1} & \cdots & \gamma_{mn} \end{pmatrix} \end{matrix}$$

Step 2: Use the following formula to normalize the rating data if necessary.

$$\alpha_{rs} = \begin{cases} (e_{R_{rs}}, (e_{I_{rs}}); \text{ if } C'_s \in H_1 \\ ((p_{R_{rs}}), (p_{I_{rs}}); \text{ if } C'_s \in H_2 \end{cases} \quad (11)$$

Step 3: Utilizing either geometric operators or averaging, combine "the values of each alternative under the various criteria" to obtain the collective value and for example, the CIFSSWA operators, which change "by α_r , $C_r = (p_{R_r} e^{i2\pi(p_{I_r})} + e_{R_r} e^{i2\pi(e_{I_r})})$ as"

$$\text{CIFSSWA} = \left(\begin{matrix} \left(1 - \prod_{s=1}^n (1 - p_{R_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right) e^{i2\pi \left(1 - \prod_{k=1}^n (1 - p_{I_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right)} \\ \left(\prod_{k=1}^n (e_{R_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right) e^{i2\pi \left(\prod_{k=1}^n (e_{I_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right)} \end{matrix} \right)$$

On other hand also similar to it, "CIFSSWG operator





Shahirunnisa and Akila

$$\text{CIFSSWG} = \left(\begin{array}{c} \left(\prod_{s=1}^n (p_{Rrs})^{\frac{w_s}{\sum_{s=1}^m w_s}} e^{i2\pi \left(\prod_{k=1}^n (p_{Irs})^{\frac{w_s}{\sum_{s=1}^m w_s}} \right)}, \right. \\ \left. \left(1 - \prod_{k=1}^n (1 - e_{Rrs})^{\frac{w_s}{\sum_{s=1}^m w_s}} e^{i2\pi \left(1 - \prod_{k=1}^n (1 - e_{Irs})^{\frac{w_s}{\sum_{s=1}^m w_s}} \right)} \right) \right) \end{array} \right)$$

Step 4: Solve “the Score values of α_r ($r=1,2,\dots,n$)”

$$m_{SV}(C_r) = (p_{Rr} + p_{Ir} - e_{Rr} - e_{Ir}), m_{SV} \in [0,1]$$

If the score fails for the decision values and we can use accuracy value.

$$n_{SV}(C_r) = (p_{Rr} + p_{Ir} + e_{Rr} + e_{Ir}), n_{SV} \in [0,1]$$

Step 5: Choosing the best alternatives by the Score and Accuracy values.

NUMERICAL ILLUSTRATION

The developed method is validated through a numerical example, and its results are compared with existing studies”. In this case, we can concentrate on five main causes represented in the shape of attributes, which are explained below:

C₁: Tobacco Use, C₂: Asbestos exposure, C₃: Air pollution,

C₄: Genetic factors, C₅: Second hand smoke

By the CIFSS, we can arrange the vector of weights as

$$W = (0.3, 0.3, 0.2, 0.1, 0.1)^T, U = (0.3, 0.2, 0.2, 0.2, 0.1)^T$$

Step 1: We represented Complex Intuitionistic Fuzzy data in a matrix structure

$$C_j = (p_{Rj} e^{i2\pi(p_{Ij})} + e_{Rj} e^{i2\pi(e_{Ij})}). \text{ See Table 1.}$$

Step 2a: We apply CIFSSWA operator equation (5) with W, the collective values are CIFSSWA,

$$C_1' = \left(\begin{array}{c} \left((1 - ((1 - 0.3)^{0.3}, (1 - 0.1)^{0.3}, (1 - 0.6)^{0.2}, (1 - 0.8)^{0.1}, (1 - 0.4)^{0.1})) \right) \\ e^{i2\pi((1 - ((1 - 0.4)^{0.3}, (1 - 0.5)^{0.3}, (1 - 0.3)^{0.2}, (1 - 0.2)^{0.1}, (1 - 0.6)^{0.1}))} \\ ((0.7)^{0.3}, (0.9)^{0.3}, (0.4)^{0.2}, (0.2)^{0.1}, (0.4)^{0.1}) \\ e^{i2\pi((0.5)^{0.3}, (0.3)^{0.3}, (0.2)^{0.2}, (0.3)^{0.1}, (0.5)^{0.1})} \end{array} \right)$$

$$C_1' = (0.4137e^{i2\pi(0.4210)}, 0.5630e^{i2\pi(0.3393)}), C_2' = (0.6224e^{i2\pi(0.3894)}, 0.3776e^{i2\pi(0.4198)}), C_3' = (0.4881e^{i2\pi(0.4147)}, 0.5406e^{i2\pi(0.4288)}),$$

$$C_4' = (0.6435e^{i2\pi(0.2083)}, 0.2896e^{i2\pi(0.4991)}), C_5' = (0.5101e^{i2\pi(0.5031)}, 0.2259e^{i2\pi(0.3879)}).$$

Score values of aggregated number the above equation are

$$m_{SV}(C_1) = -0.0677, m_{SV}(C_2) = 0.2143, m_{SV}(C_3) = -0.0666,$$

$$m_{SV}(C_4) = 0.0630, m_{SV}(C_5) = 0.3994.$$

Step 2 b: Apply to CIFSSWA, CIFSSWG, CIFSSOWG, CIFSSHA, and CIFSSHG to combine the result with the matrix.

Step 3: The data was acquired to calculate the SV.

Step 4: Evaluate and prioritize alternatives to determine the best decision.

Well-known studies have identified key risk factor for cancer in non smokers is called C₅: Second hand smoke.

CONCLUSION

Nonsmokers may still be at risk of developing cancer due to environmental exposures, genetic predispositions, viral infections, and other lifestyle choices. Awareness and comprehension of these hazards can assist individuals in taking preventative actions, promoting early identification, and encouraging healthy practices to minimize the risk of cancer. Regular health checks and screenings can also help with early diagnosis and treatment. Individuals can lower their risk and improve their general well-being by putting their health first and taking proactive measures. Furthermore, remaining up to date on cancer research and breakthroughs can help people make informed health





Shahirunnisa and Akila

decisions, and support from healthcare experts, family, and friends can be invaluable in cancer prevention and treatment. People must live a wholesome life that includes a food diet, routine exercise, and controlling stress. Escaping carcinogens like certain chemicals and radiation can also help lower the risk of cancer. Nonsmokers can lower their risk of acquiring cancer while also improving their all over health and well-being by following these tips. Early detection and treatment are key in improving cancer outcomes, so remain cautious and seek medical assistance if any symptoms appear. To examine the relationship between non-smokers and cancer development, utilizing power AOs within the CIFSS framework. Further, we framed the **CIFSSWA, CIFSSOWA, CIFSSWG, CIFSSOWG, CIFSSHA, CIFSSHG** Operators and evaluated their resulting three properties. Next, employing approaches based on operators, we found that the final result is C_5 That is Second hand smoke. It is the main cause for the cancer.

REFERENCES

1. Zhang,L.:Approaches to multiple attribute group decision making under Intuitionistic fuzzy settings : application of Dempster–Shafer theory of evidence.Arab. J.Sci.Eng. (2018).<https://doi.org/10.1007/s13369-018-3657-5>.
2. Zadeh,L.A.:Fuzzysets.Inf.Control8,338–353(1965).
3. Atanassov, K.T.: Intuitionistic fuzzy sets.Fuzzy Sets Syst. 20,87 96(1986).
4. Xu,Z.S.: Intuitionistic fuzzy aggregation operators. IEEE Trans. Fuzzy Syst.15,1179–1187(2007).
5. Xu, Z.S.;Yager, R.R.:Some geometric aggregation operators based on intuitionistic fuzzy sets. Int. J. Gen. Syst. 35, 417–433 (2006).
6. Liao, H.; Xu, Z.: Intuitionistic fuzzy hybrid weighted aggregation operators. Int. J. Intell. Syst. 29(11), 971–993 (2014).
7. Wang, W.; Liu, X.: Intuitionistic fuzzy information aggregation using Einstein operations. IEEE Trans. Fuzzy Syst. 20(5), 923 938 (2012).
8. Garg, H.: Generalized intuitionistic fuzzy interactive geometric interaction operators using Einstein t-norm and t-conorm and their application to decision making. Comput. Ind. Eng. 101, 53–69 (2016).
9. Akila, S., & Robinson, P. J. (2019, November). Multiple Attribute Group Decision Making Methods Using Numerical Methods of Intuitionistic Triangular Fuzzy Sets. In Journal of Physics: Conference Series (Vol. 1377, No. 1, p. 012022). IOP Publishing.
10. Alkouri,A.;Salleh, A.: Complex Intuitionistic fuzzy sets. In: 2012, Ch. 2nd International Conference on Fundamental and Applied Sciences, vol. 1482, pp. 464–470 (2012).
11. Alkouri, A.U.M.; Salleh, A.R.: Complex Atanassov’s intuitionis tic fuzzy relation. Abstract Appl. Anal. 2013, Article ID 287382 (2013).
12. Rani,D.;Garg,H.:Complex Intuitionistic fuzzy power aggregation operators and their applications in multi-criteria decision-making. Expert Syst. 35(6), e12325 (2018).<https://doi.org/10.1111/exsy.12325>.
13. Garg, H.; Rani, D.: Some generalized complex intuitionistic fuzzy aggregation operators and their application to multicrite ria decision-making process. Arab. J. Sci. Eng. 44(3), 2679–2698 (2019).
14. Garg, H.; Rani, D.: Complex interval-valued intuitionistic fuzzy sets and their aggregation operators. Fundam. Inf. 164(1), 61–101 (2019).
15. Alkouri,A.;Salleh, A.: Complexintuitionistic fuzzy sets. In: 2012, Ch. 2nd International Conference on Fundamental and Applied Sciences, vol. 1482, pp. 464–470 (2012).
16. Garg, H.; Rani, D.: Complex interval-valued intuitionistic fuzzy sets and their aggregation operators. Fundam. Inf. 164(1), 61–101 (2019).





Shahirunnisa and Akila

17. Kavitha.P. Akila.S. (2024). Integrating IVIFS and Butcher's RK Method for Multiple Attribute Group Decision Making: Mobile Brand Selection. Nanotechnology Perceptions Vol 20, S15 (2024) <https://doi.org/10.62441/nanontp.vi.3523>.
18. Garg, H.; Nancy, : Algorithms for possibility linguistic single valued neutrosophic decision-making based on COPRAS and aggregation operators with new information measures. Measure ment 138, 278–290 (2019).
19. T. Mahmood, U. U. Rehman, J. Ahmmad, and G. Santos-García, "Bipolar complex fuzzy Hamacher aggregation operators and their applications in multi-attribute decision making," Mathematics, vol. 10, no. 1, p. 23, Dec. 2021.
20. T. Mahmood, Zeeshan Ali, " complex Intuitionistic fuzzy Aczel-Alsina Aggregation operators and their applications in multi-attribute decision making,'Symmetry2022,14,225.
21. T. Mahmood,Ubaid UR Rehman,"A Knowledge based system for the classification of cancer diseases in human body using hybrid approaches based on bipolar complex fuzzy information",IEEE,digital identifier 10.1109/ACCESS2023.3310568.
22. Garg, H.; Kumar, K.: Linguistic interval-valued atanassov intuitionistic fuzzy sets and their applications to group decision-making problems. IEEE Trans. Fuzzy Syst. (2019). <https://doi.org/10.1109/TFUZZ.2019.2897961>.
23. Kavitha.P. Akila.S. (2024). Sixth Order Butcher 'S RK Methods in MAGDM Using Intuitionistic Triangular Fuzzy Sets. Journal of Electrical Systems 20-11s :575-581.

Table 1: Represented the CIFS information

	$\mathcal{E}_1'$	$\mathcal{E}_2'$	$\mathcal{E}_3'$	$\mathcal{E}_4'$	$\mathcal{E}_5'$
$\mathcal{E}_1$	$\begin{pmatrix} 0.3e^{i2\pi(0.4)} \\ 0.7e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.1e^{i2\pi(0.5)} \\ 0.9e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.3)} \\ 0.4e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.6)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$
$\mathcal{E}_2$	$\begin{pmatrix} 0.6e^{i2\pi(0.1)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.3)} \\ 0.2e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.2e^{i2\pi(0.4)} \\ 0.8e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.7e^{i2\pi(0.6)} \\ 0.3e^{i2\pi(0.1)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.8)} \\ 0.6e^{i2\pi(0.7)} \end{pmatrix}$
$\mathcal{E}_3$	$\begin{pmatrix} 0.3e^{i2\pi(0.2)} \\ 0.7e^{i2\pi(0.6)} \end{pmatrix}$	$\begin{pmatrix} 0.5e^{i2\pi(0.2)} \\ 0.6e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.7e^{i2\pi(0.4)} \\ 0.3e^{i2\pi(0.9)} \end{pmatrix}$	$\begin{pmatrix} 0.2e^{i2\pi(0.5)} \\ 0.8e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.9)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$
$\mathcal{E}_4$	$\begin{pmatrix} 0.4e^{i2\pi(0.1)} \\ 0.6e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.8)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.1)} \\ 0.2e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.6)} \\ 0.6e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.9e^{i2\pi(0.2)} \\ 0.1e^{i2\pi(0.2)} \end{pmatrix}$
$\mathcal{E}_5$	$\begin{pmatrix} 0.2e^{i2\pi(0.2)} \\ 0.1e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.7)} \end{pmatrix}$	$\begin{pmatrix} 0.1e^{i2\pi(0.9)} \\ 0.6e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.3)} \\ 0.4e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.5)} \\ 0.3e^{i2\pi(0.1)} \end{pmatrix}$

Table 2: Represented the collected values

OPERATOR	C1'	C2'	C3'	C4'	C5'
CIFSSWA	$\begin{pmatrix} 0.4137e^{i2\pi(0.4210)} \\ 0.5630e^{i2\pi(0.3393)} \end{pmatrix}$	$\begin{pmatrix} 0.6224e^{i2\pi(0.3894)} \\ 0.3776e^{i2\pi(0.4198)} \end{pmatrix}$	$\begin{pmatrix} 0.4881e^{i2\pi(0.4147)} \\ 0.5406e^{i2\pi(0.4288)} \end{pmatrix}$	$\begin{pmatrix} 0.6435e^{i2\pi(0.2083)} \\ 0.2896e^{i2\pi(0.4991)} \end{pmatrix}$	$\begin{pmatrix} 0.5101e^{i2\pi(0.5031)} \\ 0.2259e^{i2\pi(0.3879)} \end{pmatrix}$
CIFSSOWA	$\begin{pmatrix} 0.3988e^{i2\pi(0.4743)} \\ 0.5324e^{i2\pi(0.3719)} \end{pmatrix}$	$\begin{pmatrix} 0.5905e^{i2\pi(0.5480)} \\ 0.4095e^{i2\pi(0.4330)} \end{pmatrix}$	$\begin{pmatrix} 0.4732e^{i2\pi(0.5107)} \\ 0.5564e^{i2\pi(0.4043)} \end{pmatrix}$	$\begin{pmatrix} 0.6674e^{i2\pi(0.2176)} \\ 0.2702e^{i2\pi(0.4554)} \end{pmatrix}$	$\begin{pmatrix} 0.4467e^{i2\pi(0.6251)} \\ 0.3464e^{i2\pi(0.2443)} \end{pmatrix}$
CIFSSWG	$\begin{pmatrix} 0.5293e^{i2\pi(0.3850)} \\ 0.4707e^{i2\pi(0.3534)} \end{pmatrix}$	$\begin{pmatrix} 0.6435e^{i2\pi(0.4456)} \\ 0.3565e^{i2\pi(0.3331)} \end{pmatrix}$	$\begin{pmatrix} 0.4082e^{i2\pi(0.5226)} \\ 0.5918e^{i2\pi(0.4000)} \end{pmatrix}$	$\begin{pmatrix} 0.5856e^{i2\pi(0.3569)} \\ 0.3912e^{i2\pi(0.4300)} \end{pmatrix}$	$\begin{pmatrix} 0.5083e^{i2\pi(0.4044)} \\ 0.3994e^{i2\pi(0.3456)} \end{pmatrix}$





Shahirunnisa and Akila

CIFSSOWG	$(\frac{0.2781e^{i2\pi(0.4379)}}{0.6860e^{i2\pi(0.4004)}})$	$(\frac{0.4721e^{i2\pi(0.4095)}}{0.5279e^{i2\pi(0.5241)}})$	$(\frac{0.4198e^{i2\pi(0.3174)}}{0.6074e^{i2\pi(0.5259)}})$	$(\frac{0.5694e^{i2\pi(0.1692)}}{0.3793e^{i2\pi(0.5685)}})$	$(\frac{0.2980e^{i2\pi(0.4260)}}{0.4128e^{i2\pi(0.319)}})$
CIFSSHA	$(\frac{0.4536e^{i2\pi(0.4329)}}{0.4041e^{i2\pi(0.3534)}})$	$(\frac{0.5905e^{i2\pi(0.5480)}}{0.4095e^{i2\pi(0.4330)}})$	$(\frac{0.4213e^{i2\pi(0.5546)}}{0.5894e^{i2\pi(0.4384)}})$	$(\frac{0.6674e^{i2\pi(0.2176)}}{0.2702e^{i2\pi(0.4554)}})$	$(\frac{0.4467e^{i2\pi(0.6251)}}{0.3464e^{i2\pi(0.2443)}})$
CIFSSHG	$(\frac{0.3776e^{i2\pi(0.3728)}}{0.5735e^{i2\pi(0.3799)}})$	$(\frac{0.4721e^{i2\pi(0.3728)}}{0.5279e^{i2\pi(0.5241)}})$	$(\frac{0.3495e^{i2\pi(0.3812)}}{0.6582e^{i2\pi(0.5384)}})$	$(\frac{0.5694e^{i2\pi(0.1692)}}{0.3793e^{i2\pi(0.5685)}})$	$(\frac{0.2980e^{i2\pi(0.4260)}}{0.4128e^{i2\pi(0.319)}})$

Table 3: Score values

OPERATOR	$m_{SV}(C_1)$	$m_{SV}(C_2)$	$m_{SV}(C_3)$	$m_{SV}(C_4)$	$m_{SV}(C_5)$
CIFSSWA	-0.0677	0.2143	-0.0666	0.0630	0.3994
CIFSSOWA	-0.0312	0.2960	0.0232	0.1593	0.4811
CIFSSWG	-0.4049	-0.2017	-0.4787	-0.2547	0.1742
CIFSSOWG	-0.3704	-0.1703	-0.3961	-0.2091	-0.0081
CIFSSHA	0.2190	0.296	-0.0519	0.1593	0.4811
CIFSSHG	-0.2030	-0.1703	-0.4659	-0.2091	-0.0081

Table 4: Ranking Values

OPERATOR	Ranking Values
CIFSSWA	$C_5' > C_2' > C_4' > C_3' > C_1'$
CIFSSOWA	$C_5' > C_2' > C_4' > C_3' > C_1'$
CIFSSWG	$C_5' > C_2' > C_4' > C_1' > C_3'$
CIFSSOWG	$C_5' > C_2' > C_4' > C_1' > C_3'$
CIFSSHA	$C_5' > C_2' > C_1' > C_4' > C_3'$
CIFSSHG	$C_5' > C_2' > C_1' > C_4' > C_3'$





Shahirunnisa and Akila

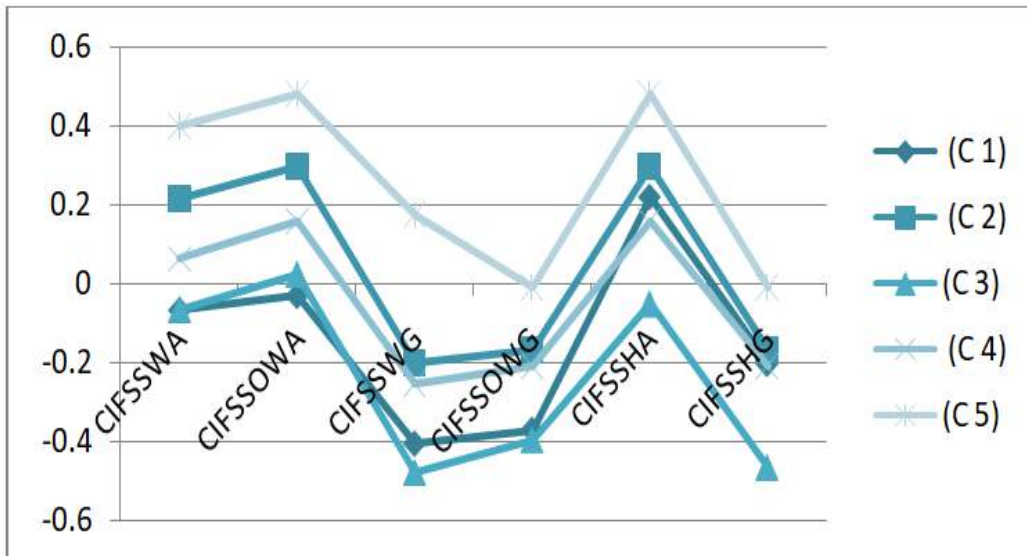


Figure 1: Graphical Expression of The Information In Table 3

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Formulation and Evaluation of Polyherbal Tablets with Antimicrobial Activity

Snigdha Chatterjee¹, Koushik Kuila², Ranadwip Kar², Anupam Bhunia² and Piyali Khamkat^{3*}

¹Assistant Professor, Department of Pharmaceutical Technology, Brainware University, Barasat, Kolkata, West Bengal, India

²Student, Department of Pharmaceutical Technology, Brainware University, Barasat, Kolkata, West Bengal, India

³Associate Professor, Department of Pharmaceutical Technology, Brainware University, Barasat, Kolkata, West Bengal, India.

Received: 19 Mar 2026

Revised: 16 Apr 2026

Accepted: 10 May 2026

*Address for Correspondence

Piyali Khamkat

Associate Professor,

Department of Pharmaceutical Technology,

Brainware University, Barasat,

Kolkata, West Bengal, India

E.Mail: piyalikhamkat95@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The study aimed to formulate and test polyherbal tablets containing neem (*Azadirachta indica*), tulsi (*Ocimum sanctum*), turmeric (*Curcuma longa*), and ginger (*Zingiber officinale*) with the actions against microbes. Tablet preparation was done through wet granulation and evaluated in terms of physicochemical parameters, FTIR, and antimicrobial characteristics. The results of the formulation were satisfactory with respect to weight (0.395 ± 0.010 g), thickness (5.00 ± 0.25 mm), compactness (5.0 ± 0.2 kg/cm²), and friability ($0.1 \pm 0.01\%$). FTIR analysis showed that all ingredients are compatible without any significant chemical interactions. Antimicrobial activity showed better results for the combination formulation, where inhibition zones were 1.57 ± 0.057 mm (*Bacillus subtilis*) and 3.93 ± 0.665 mm (*Escherichia coli*), as compared to individual powder and a marketed tablet. The results indicated that phytoconstituents are synergistic, and together they can increase therapeutic efficacy. Also, the polyherbal tablets showed potential drug stability and treatment benefits as a safe alternative in the treatment of microbial infections.

Keywords: Polyherbal tablets, granulation, physicochemical, antimicrobial, alternative.



Snigdha Chatterjee *et al.*,

INTRODUCTION

Global health is at risk from infectious diseases, which are treated with antibiotics and antiviral drugs. However, microbial resistance persists, leading to problems and recurring infections (1). The present trends for living a long and healthy life are fully reliant on the blend of multiple herbs in a specific proportion, which provides an appealing therapeutic outcome. This is because the strong phytochemical components of single plants are insufficient to attain the advantageous outcome (2,3). The polyherbal formulations are widely used due to their extensive therapeutic range, effectiveness at minimal doses, safety at elevated doses, and fewer side effects (4, 5). Ayurveda is recognized as one of the most beneficial systems in conventional medicinal practices because it incorporates various inherent components that address the key factors of illness by restoring balance and preventing future occurrences (6). This research study considered the preparation and assessment of polyherbal tablets using neem, tulsi, ginger, and turmeric. The combination of multiple herbs, which includes two or more herbs with various phytoconstituents having comparable or different therapeutic potentials. Neem (*Azadirachta indica*) is well known in traditional medicine due to its antimicrobial effects. Tulsi (*Ocimum sanctum*) has been found to have an adaptogenic effect and helps to reduce stress. Tulsi contains bioactive compounds like eugenol, ursolic acid, and carvacrol, which give it strong antimicrobial properties. Turmeric (*Curcuma longa*) has potential antimicrobial properties. Ginger (*Zingiber officinale*) has gingerol, shogaol, and zingerone compounds, which are the ones that make it have an antimicrobial effect (7, 8).

MATERIALS AND METHODS

Materials

Neem leaf powder, Tulsi leaf powder, Ginger stem powder, Turmeric stem powder, Water soluble starch (Sisco Research Laboratories Pvt Ltd, Maharashtra), Magnesium stearate (Sisco Research Laboratories Pvt Ltd, Maharashtra), Talc (Sisco Research Laboratories Pvt Ltd, Maharashtra), Microcrystalline Cellulose (Loba Chemie Pvt Ltd, Mumbai), Sodium Starch Glycolate (Loba Chemie Pvt Ltd, Mumbai), Amoxil (Zydus Corporate Park, Ahmedabad, Gujarat, India) were utilized for the research. The plants were identified and authenticated by Acharya Jagadish Chandra Bose Indian Botanical Garden, Shibpur, Howrah- 711103.

Microorganisms

Escherichia coli, a gram-negative bacterium, and *Bacillus subtilis*, a gram-positive bacterium, were collected from the microbiology lab of the department of Pharmaceutical Technology, Brainware University, Barasat, 700125.

Instruments

Electronic Weighing Balance (Vinayak Enterprise, Surat, Gujarat, India), Sieve of 12, 20 and 60 mesh (Sheetal Sales Corporation, Maharashtra, India), Hot Air Oven (Lab Care Equipments, New Delhi, India), Tablet Compression Machine (Kambert Machinery Co. Pvt Ltd, Gujarat, India), Friability Tester (Globe Scientific Instruments, Haryana, India), Monsanto Type Tablet Hardness Tester (M D Traders, Kolkata, India), Stainless Steel Digital Vernier Caliper (M D Traders, Kolkata, India), Laminar Air Flow Cabinet (Glowmax Engineers, Mumbai, India), Autoclave (Labgo, Baddi, India), Incubator (Vinayak Enterprise, Gujarat, India), Agar Well Diffusion Setup (Himedia Laboratories Pvt Ltd, India), FTIR (Bruker Germany Alpha II, Rudolf-Plank-Straße 27, 76275 Ettlingen, Germany) were employed in the study.

Formulations

Here, the significance of every component used in the development of a polyherbal tablet is emphasized. Rich in curcumin, turmeric possesses antibacterial qualities. The tablet's antimicrobial spectrum is strengthened with neem, which has antibacterial, antiviral, and antifungal properties and promotes skin with immunological health. Tulsi



**Snigdha Chatterjee et al.,**

reduces microbial infections. Gingerol", which is present in ginger, acts as an antimicrobial agent. Microcrystalline Cellulose acts as a diluent, and water-soluble starch acts as a binder. By keeping materials from adhering to punches and dies, magnesium stearate, used as a lubricant, enhances surface finish and manufacturing efficiency. Talc works as a glidant that helps improve powder flow. Sodium Starch Glycolate facilitates the quick dissolution of tablets used as a disintegrant (9,10). The polyherbal tablet formula is shown in Table 1.

Preparation of Turmeric root powder

The process involved peeling, cleaning, grating, straining, drying, and sifting turmeric roots and storing them in a container.

Preparation of Neem leaf powder

The neem leaves were cleaned and dried over a period of two days to remove moisture content, and then they were crushed into a fine powder form and stored.

Preparation of Tulsi powder

The tulsi leaves were cleaned and dried for two days, ground into powder, and kept in a well-closed container.

Preparation of Ginger powder

The process involved peeling, cleaning, grating, straining, drying, and sifting ginger roots and storing them in a container.

Preparation method of polyherbal Tablet

To guarantee consistent particle size, herbal powders such as ginger, tulsi, neem, and turmeric powders were passed through a sieve with a size 60 during the herbal medication production process. After that, the binder (starch) solution was made with warm water, and microcrystalline cellulose with sodium starch glycolate was added to it. Then the wet mass was passed through a sieve with a size 12 to formulate granules and dried at 40–50°C, which were the steps in the wet granulation process. For even dispersion, the dry granules were subsequently sized by using sieve size 20 and combined with magnesium stearate and talc. To maintain consistent weight, hardness, and thickness, the granules were then compressed into tablets using a tablet punching machine (8 mm punch size). Figure 1 represents the preparation process of polyherbal tablets against bacterial infections (11).

Evaluation of Herbal Tablets**Organoleptic Characterization**

Physical features, including nature, colour, and odour, were meticulously assessed to determine the product's organoleptic characteristics (12).

Rheological properties determination

Physical characteristics, including untapped density (D'), tapped density (D), and angle of repose (θ), were used to assess the rheological characteristics of herbal powders before compression (13).

Bulk Density & Tapped Density

A pre-weighed quantity of powder was transferred into a 100 mL graduated cylinder without tapping or compacting. The volume occupied was noted, and the bulk density was calculated using the formula. By mechanically tapping a container, the rheological quality of a powder sample was ascertained, producing an improved bulk density called "tapped density." Until only slight alterations were observed, this procedure was repeated (14,15). Bulk Density (D') = Bulk volume/Mass, Tapped Density (D) = Tapped volume/Mass Hausner's ratio = D/D' , Carr's Index = $(D-D')/D \times 100$





Snigdha Chatterjee et al.,

Angle of Repose

Its main role is to assess the flowability of powders by measuring the angle formed when piled. It was determined using the fixed funnel method. A funnel was fixed at a specific height, and the powder was allowed to flow freely through the funnel to form a cone on a flat surface. The height (h) and radius (r) of the resulting pile were measured, and the angle of repose (θ) was calculated using the formula (16).

$$\theta = \tan^{-1} \left(\frac{h}{r} \right)$$

FTIR Test

The FTIR (Fourier Transform Infrared Spectroscopy) analysis was performed on the formulated polyherbal tablets to confirm the compatibility of the herbal ingredients and to ensure that no significant chemical interaction occurred between the components during the compression process.

Thickness test

The thickness of the tablets was measured using a Vernier Caliper. 10 tablets were randomly selected, and their thickness was measured individually. It was calculated using the formula

$$\text{Mean Thickness} = \frac{\sum T_i}{n}$$

Where,

T_i = Thickness of each tablet.

n = Total number of tablets measured.

$\sum T_i$ = Sum of the thickness of all tablets.

Weight variation test

Twenty tablets were randomly selected and weighed individually. The individual weights were compared with the average weight to assess weight variation. The percentage deviation was calculated and evaluated in accordance with the Indian Pharmacopoeia (IP) specifications. It was calculated using the formula

$$\% \text{ Weight variation} = \left(\frac{\text{Individual Weight} - \text{Average Weight}}{\text{Average Weight}} \right) \times 100$$

Hardness test

10 tablets were selected randomly. Tablet hardness was determined using a Monsanto hardness tester, and the results were expressed in kg/cm^2 . The hardness can be expressed using the following formula

$$\text{Hardness (kg/cm}^2\text{)} = \frac{\text{Breaking Force (kg)}}{\text{Surface Area of Contact (cm}^2\text{)}}$$

Friability test

Tablet friability was assessed using a Roche Friabilator. Twenty tablets were initially weighed and placed in the friabilator, which was operated at 25 rpm for 4 minutes, completing a total of 100 rotations. After the test, the tablets were reweighed to calculate the percentage weight loss. The weight loss should not be more than 1.0%. It was calculated using the formula

$$\text{Friability (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \text{ Where,}$$

W_1 = Initial weight of the tablets before the test (usually in grams).

W_2 = Final weight of the tablets after the test (after dedusting).

Disintegration Test

Disintegration time is the period required for a tablet to break down into small particles and pieces by using a disintegration test apparatus. There is 900 mL of medium that is maintained at 37 °C in the basket. These were measured in time per tube, as there were six tablets per tube (5, 16).

Antimicrobial test

The antimicrobial activity of the formulated polyherbal tablets was evaluated using the agar well diffusion method. The test was conducted against selected microbial strains, including Gram-positive bacteria (e.g., *Bacillus subtilis*) and Gram-negative bacteria (e.g., *Escherichia coli*), and the marketed tablet was Amoxicillin. Mueller-Hinton agar and



**Snigdha Chatterjee et al.,**

agar agar bacto were prepared and inoculated with the respective microorganisms using a sterile swab. Fresh microbial cultures were prepared in nutrient broth and incubated at 37 °C for 24 hours. After incubation, the zones of inhibition around the wells were measured in millimetres (15, 17).

Stability studies

The stability of the formulation was tested over a course of 6 months of storage at different temperatures. The formulation was filled in an air-tight foil bag, and the physical characteristics, such as colour, odour, hardness, etc., were inspected. They were also stored at different temperatures of $25 \pm 2^\circ\text{C}$ and relative humidity (RH) of $60 \pm 5\%$ or at $40 \pm 2^\circ\text{C}$ and $75 \pm 5\%$. After six months, the parameters of the samples were assessed, such as thickness, hardness, and friability (18).

RESULTS

Organoleptic Characterization

The colour of the tablets was green, the texture was smooth, and the shape was round.

Thickness test

Ten tablets were randomly selected, and their thickness was calculated using the formula. The average thickness was found to be 4.75mm to 5.25mm, and the result is shown in Table 2.

Weight variation test

Twenty tablets were individually weighed, with an average weight of 0.395g, which was found to be within the acceptable limits. The result is shown in Table 2.

Hardness test

Five tablets were tested, and the average hardness was found to be 5.0 kg/cm². The result is shown in Table 2.

Friability test

The friability test was conducted for 4 minutes, using a Roche friabilator to assess their ability to withstand mechanical stress during handling and transportation, and the percentage weight loss was 0.1%. The result is shown in Table 2.

Disintegration test

The disintegration test data is mentioned in Table 2 by using the disintegration apparatus.

FTIR test

The results of the FTIR analysis indicate that all the key functional groups of neem, tulsi, turmeric, and ginger remained the same in the tablet formulation. The presence of broad O-H stretching bands indicates phenolic groups, whereas the presence of the overlapping C-H, C=O, C = C, and C-O signals indicates that the aliphatic, carbonyl, aromatic, and ether functions are stable. Excellent overlap was also observed in the fingerprint region ($<900\text{ cm}^{-1}$), indicating no new bond formation and compatibility of ingredients in the formulation (Figure 2). Table 3 represents the peak assignment of individual herbal components and polyherbal formulation.

Antimicrobial test

The antimicrobial activity of the individual herbal extracts, the marketed tablet, and the combined polyherbal formulation was evaluated against *Bacillus subtilis* (Gram-positive) and *Escherichia coli* (Gram-negative). For *B. subtilis*, the combined formulation exhibited the highest zone of inhibition ($1.57 \pm 0.057\text{ mm}$), which was greater than any single extract or the marketed tablet, indicating superior efficacy. Among the individual extracts, neem ($1.20 \pm 0.173\text{ mm}$) and turmeric ($1.17 \pm 0.152\text{ mm}$) showed moderate activity, while Tulsi demonstrated the lowest inhibition



**Snigdha Chatterjee et al.,**

(0.97 ± 0.057 mm). A similar trend was observed against *E. coli*, where the combined formulation displayed a significantly larger zone of inhibition (3.93 ± 0.665 mm) compared to all other samples. The marketed tablet (1.17 ± 0.057 mm) and Tulsi (1.17 ± 0.152 mm) showed the least activity, whereas neem (1.33 ± 0.057 mm) exhibited slightly higher inhibition among the individual extracts. The markedly enhanced activity of the combined formulation against both bacterial strains reflects a synergistic effect, suggesting that the multiple phytoconstituents from different herbs may interact positively to potentiate antimicrobial efficacy beyond the activity of individual components (Figure 3 & Table 4).

Stability Study

The polyherbal tablets showed smooth, uniform appearance with characteristic odour, no discoloration after accelerated study, acceptable weight variation, and hardness with proper disintegration. Stability studies results are shown in Table 5.

DISCUSSION

The objective of the current research was to develop and evaluate a polyherbal tablet that has action against bacterial infections. The parameters of post-compression evaluation, such as weight change (0.395 ± 0.010 g), thickness (5.00 ± 0.25 mm), hardness (5.0 ± 0.2 kg/cm²), disintegration (12 ± 2 min), and friability ($0.1 \pm 0.01\%$), were within the acceptable pharmacopoeia's range, which supported the mechanical strength and reproducibility of the formulation. The continuous green colour, smoothness, and roundness also showed that the prepared tablets were well organoleptically acceptable. The FTIR analysis revealed that there was no substantial chemical activity of the herbal constituents, indicating that the polyherbal blend was stable and compatible. The antimicrobial analysis indicated that the polyherbal formulation was more inhibitory, as evidenced by the results of Gram-positive (*Bacillus subtilis*, 1.57 ± 0.057 mm) and Gram-negative (*Escherichia coli*, 3.93 ± 0.665 mm) microorganisms than the individual and a commercially available tablet. The increased activity implies that there is synergy between the phytochemicals, especially flavonoids, terpenoids, alkaloids, and phenolic compounds present in the herbs that were chosen. Karole et al., (2019) and Paul et al., (2023) found that polyherbal formulations are more effective against microbes in comparison to single-herb preparations because they are multitargeted and interact synergistically (19,20). Curcumin and gingerol, obtained by hydrolyzing turmeric and ginger, have already been documented to have potent antimicrobial effects, and neem and tulsi provide immunomodulatory and antioxidant applicability (21). The accelerated stability analysis revealed no alterations in the colour, odour, hardness, and friability of the tablets in half a year, which proved that the tablets were robust and had a long shelf-life. This profile of stability is essential to large-scale development and clinical use. In general, the results of this study confirmed the design approach of using a single dosage of a neem, tulsi, turmeric, and ginger mixture to obtain anti-microbial activity.

CONCLUSION

The physical appearance, thickness, weight variation, hardness, friability, and disintegration time of a polyherbal tablet containing tulsi, ginger, turmeric, and neem extracts were all assessed. The tablet was successfully shown to be safer than chemical treatments. These results substantiated the existence of a synergistic effect of the phytoconstituents resulting in an optimistic antimicrobial activity. To improve quality and safety, more research is required.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Brainware University, Barasat, for providing us with all the equipment and chemicals we needed to conduct the research.





Snigdha Chatterjee et al.,

CONFLICT OF INTEREST

No conflicting interests are disclosed by the authors.

REFERENCES

1. Sowmya KV, Darsika C, Grace XF, Shanmuganathan S. Formulation and evaluation of a polyherbal face wash gel. *World J Pharm Pharm Sci.* 2015; 4(6): 585–588.
2. Bhowmik D, Chiranjib C, Pawan Dubey P, Margret Chandira M, Kumar KPS. Herbal drug toxicity and safety evaluation of traditional medicines. *Pharmacogn Rev.* 2009; 3(6): 17.
3. Prusty A, Jena BR, Barik V, Khamkat P, Barik BB. Liquisolid technique for solubility enhancement of poorly soluble drug - A brief review. *Curr Drug Discov Technol.* 2024.
4. Karole S, Shrivastava S, Thomas S, Soni B, Khan S, Dubey J, et al. Polyherbal formulation concept for synergic action: A review. *J Drug Deliv Ther.* 2019.
5. Paul S, Dey T, Koirala P, Tamang S, Bhattacharya S, Das R. Formulation and evaluation of polyherbal tablet by using Neem, Tulsi, Turmeric and Ginger extract. *J Drug Deliv Ther.* 2023; 13(7): 46-51.
6. Harikrishnan R, Balasundaram C. In vitro and in vivo studies of the use of some medicinal herbals against the pathogen *Aeromonas hydrophila* in goldfish. *J Aquat Anim Health.* 2008; 20(3): 165-176.
7. Mahapatra SK, Verma S. Formulation and evaluation of polyherbal tablet for better therapeutic efficacy. *Res J Pharm Technol.* 2023; 16(2): 835-838.
8. Sawanny R, Sharma A, Jain S, Mukherjee S, Khamkat P. Gastro retentive drug delivery system: latest approach towards novel drug delivery. *Res J Pharm Technol.* 2023; 16(1): 453-458.
9. Kumar KS. Novel approaches for sophistication of fingerprinting methods of polyherbal formulations. *J Ayurvedic Herb Med.* 2015; 1(2): 27-28.
10. Majumder P, Paridhavi M. Physicochemical standardization and formulation development of poly-herbal tablet for diabetes. *Br J Pharm Res.* 2016; 12(3): 1-17.
11. Khamkat P, Barik V, Barik BB, Chakraborty A, Patra D, Mondal P, Chatterjee S. Formulation and evaluation of Propranolol Hydrochloride sustained release matrix tablets using different grades of HPMC and MCC. *Int J Pharm Invest.* 2023; 13(4).
12. Ch S, Kalliyath MD, Mohammed NP, Shabeeb M, Mufeedha KP, Muhammed SKT, et al. Formulation and evaluation of anti-inflammatory gutika. *World J Pharm Res.* 2024; 13(2): 112–118.
13. Inavally AT, D'Souza D, Sadananda M. Formulation, phytochemical characterization, antioxidant, and antimicrobial activities of the Ayurvedic polyherbal formulation Mentone. *Int J Ayurveda Res.* 2024; 5(2): 85-93.
14. Kolhe RC, Chaudhari RY. Development and evaluation of antidiabetic polyherbal tablet using medicinal plants of traditional use. *Int J Curr Pharm Sci.* 2023; 15: 17-
15. Khamkat P, Chatterjee B, Barik V, Patra D, Chakraborty A. Extraction, characterization and antibacterial potential assessment of polar phytoconstituents of *Caesalpinia bonducella* seeds extract. *Yuzuncu Yil Univ J Agric Sci.* 2023; 34(1): 115-127.
16. Awasthi H, Mani D, Nath R, Nischal A, Usman K, Khattri S. Standardization, preparation and evaluation of an Ayurvedic polyherbal formulation in capsule dosage form suitable for use in clinical trials. *Indo Am J Pharm Res.* 2014; 4(10): 4093-4099.
17. Patra KC, Kumar KJ, Suresh P. Standardization of a polyherbal Siddha formulation, Amukkara Choornam. *Indian J Tradit Knowl.* 2009; 8(3): 449-452.
18. Govindarajan N, Chinnapillai A, Balasundaram M, Narasimhaji CV, Ganji K, Raju I. Pharmacognostical and phytochemical evaluation of a polyherbal ayurvedic formulation Trikatu churna. *J Ayurveda Med Sci.* 2016; 1(1).
19. Karole S, Shrivastava S, Thomas S, Soni B, Khan S, Dubey J, Dubey SP, Khan N, Jain DK. Polyherbal Formulation Concept for Synergic Action: A Review. *J Drug Deliv Ther.* 2019; 9(1-s): 453-466.





Snigdha Chatterjee et al.,

20. Paul S, Dey T, Koirala P, Tamang S, Bhattacharya S, Das R. Formulation and evaluation of polyherbal tablet by using neem, tulsi, turmeric and ginger extract. *J Drug Deliv Ther.* 2023; 13(7): 46–51.
21. Harikrishnan R, Balasundaram C. In vitro and in vivo studies of the use of some medicinal herbals against the pathogen *Aeromonas hydrophila* in goldfish. *J Aquat Anim Health.* 2008; 20(3): 165–176.

Table 1. Formulation of Polyherbal Tablets

Ingredients	Quantity (gm)
Turmeric stem powder	7.5
Neem leaf powder	10
Tulsi leaf powder	5
Ginger stem powder	7.5
Starch (water Soluble)	5
Magnesium Stearate	1
Talc	1
Microcrystalline Cellulose	10
Sodium Starch Glycolate	3
Total	50

Table 2. Post-compression evaluation of Polyherbal Tablets

Test	Method Used	Observation (Mean ± SD)
Organoleptic Characterization	Visual inspection	Green colour, smooth texture, round shape
Thickness (n=10)	Vernier Calliper	5.00±0.25 mm
Weight Variation (n=20)	Electronic balance	0.395±0.010 g
Hardness (n=5)	Monsanto hardness tester	5.0±0.2 kg/cm ²
Friability	Roche friabilator, 4 min	0.1±0.01 %
Disintegration Test	Disintegration apparatus	12±2 min

Table 3. FTIR Peak Assignment of Individual Herbal Components and Polyherbal Tablet Formulation

Functional group / Assignment	Neem (cm ⁻¹)	Tulsi (cm ⁻¹)	Turmeric (cm ⁻¹)	Ginger (cm ⁻¹)	Tablet (cm ⁻¹)	Interpretation
O–H stretching (phenolic/alcohol)	~3320	~3340	~3305	~3315	~3330	Broad peak retained in all spectra → confirms phenolic groups present in formulation
C–H stretching (aliphatic –CH ₂ /–CH ₃)	2922, 2850	2920, 2852	2924, 2851	2921, 2850	2923, 2851	Aliphatic C–H bands overlap → no change in formulation
C=O stretching (carbonyl, ester)	1735	1718	1705	1720	1722	Neem/turmeric/ginger peaks appear in formulation → intact carbonyl groups
C=C stretching (aromatic, conjugated)	1605	1608	1625, 1605	1607	1620, 1608	Strong overlapping confirms stability of aromatic phytochemicals
Aromatic skeletal vibrations	1515	1518	1512	1517	1515	All spectra show retention of aromatic ring modes
C–O stretching (phenols, ethers)	1260–1025	1245–1050	1270–1210	1220–1105	1250–1050	Overlap across all → ether and phenolic C–O groups stable
Fingerprint region (C–H bending, mixed)	<900	<900	<900	<900	<900	Complex region overlaps well, showing no new bonds formed



**Table 4. Zone of inhibition (mm) of different herbal components and combined formulation against *B. subtilis* (Gram-positive) and *E. coli* (Gram-negative)**

Sample	<i>B. subtilis</i> (Gram-positive)		<i>E. coli</i> (Gram-negative)	
	Mean Value (mm)	± SD (mm)	Mean Value(mm)	± SD(mm)
Marketed Tablets	1.07	0.115	1.17	0.057
Turmeric	1.17	0.152	1.30	0.264
Ginger	1.13	0.057	1.27	0.057
Tulsi	0.97	0.057	1.17	0.152
Neem	1.20	0.173	1.33	0.057
Polyherbal Formulation	1.57	0.057	3.93	0.665

Values are expressed as mean ± standard deviation (n=3). Against *B. subtilis*, the combined polyherbal formulation showed the highest inhibition (1.57 ± 0.057 mm)

Table 5. Stability Study for Polyherbal Tablets

Test	Observation (Mean ± SD)	Observation (Mean ± SD) after 6 months
Organoleptic Characterization	Green colour, smooth texture, round shape	Green colour, smooth texture, round shape
Thickness (n = 10)	5.00±0.25 mm	5.00±0.25 mm
Weight Variation (n = 20)	0.395±0.010 g	0.395±0.010 g
Hardness (n = 5)	5.0±0.2 kg/cm ²	5.0±0.2 kg/cm ²
Friability	0.1±0.01 %	0.1±0.01 %
Disintegration test	12±2 min	11±1.5 min





Snigdha Chatterjee et al.,

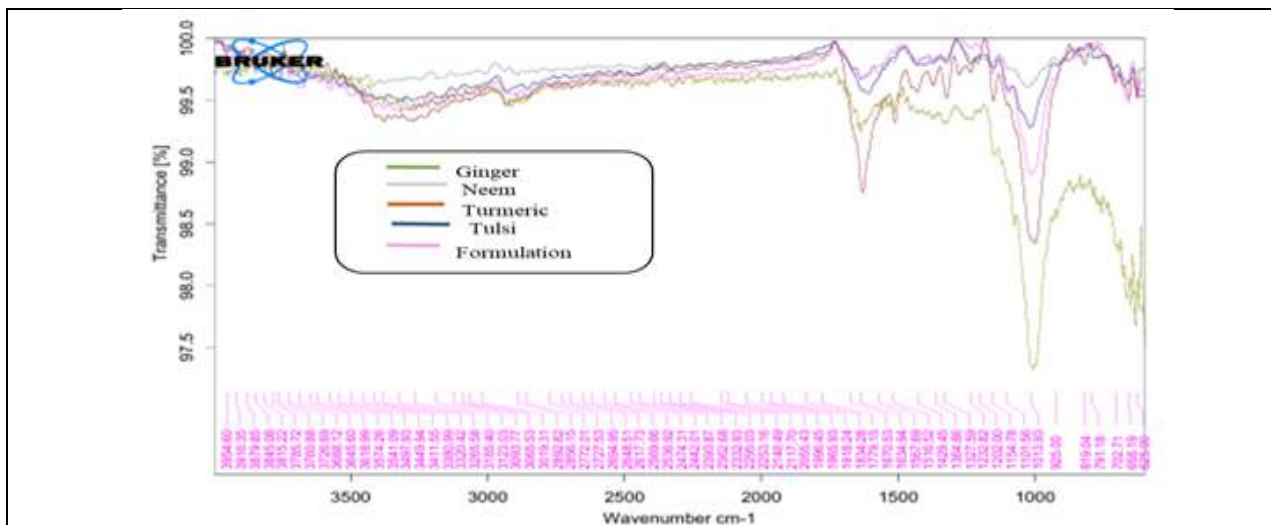


Figure 2. Observation of the FTIR analysis of herbal formulation

Figure 3. Antimicrobial activity of the combined polyherbal formulation compared with the marketed tablet: (A) Zone of inhibition against Gram-positive bacteria (*Bacillus subtilis*), (B) Zone of inhibition against Gram-negative bacteria (*Escherichia coli*)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Importance of Rasa of Ahara According to Various Seasons : An Answer to Dietary Disorders

Sarita Yadav^{1*}, Sangeeta Gupta² and Alka³

¹Ph.D Scholar, Department of Shalakya Tantra, Faculty of Indian Medical System (Ayurveda) SGT Univeristy, Gurugram, Haryana, India

²Professor, Department of Rog Nidan Evum Vikriti Vigyan, Faculty of Indian Medical System (Ayurveda), SGT Univeristy, Gurugram, Haryana, India

³Assistant Professor, Department of Panchakarma, Faculty of Indian Medical System (Ayurveda) , SGT Univeristy, Gurugram, Haryana, India

Received: 20 Mar 2026

Revised: 18 Apr 2026

Accepted: 11 May 2026

*Address for Correspondence

Sarita Yadav

Ph.D Scholar,

Department of Shalakya Tantra,

Faculty of Indian Medical System (Ayurveda)

SGT Univeristy, Gurugram, Haryana, India

E.Mail: dryadav98@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Enough solid evidences exist now a days to offer several fundamental strategies for healthy eating. They include emphasizing healthful unsaturated fats, whole grains, good protein foods and vegetables and multivitamins etc. as nutritional safety net while limiting the consumption of trans fats and saturated fats, highly refined grains and sugary beverages. Proper nutrition offers one of the most effective and least costly ways to decrease the burden of many diseases and their associated risk factors. Researches related to nutrition hold the keys in increasing our understanding of the cause of diet related disorders and its related comorbidities. Besides all these advancements, Ayurveda, a traditional system of medicine that originated thousands of years old, offers an insight about food and health based on certain unique conceptual as well as theoretical positions. In this article, we are discussing about intake of *Ahara* (food) depending on their taste (*Rasa*) and also according to various *Ritus* (seasons) according to Ayurveda. It states the importance of six tastes (*Shadrasas*) in *Ahara* and their judicial application according to various body types as well as seasons.

Keywords: *Rasa, Aahar, Ritu*, Season, Taste





Sarita Yadav et al.,

INTRODUCTION

According to Ayurveda, the best preventive medicine and support of the natural healing process is a diet and lifestyle specific to the constitutional needs of the individual and in line with the seasons and cycles of nature. Nutrition according to *Ayurveda* is different from conventional nutrition in a way that it is not caloric count only. Also, it states that one man's medicine can be another man's poison, Ayurveda validates this statement by enlightening about the diversity and *Doshik* influence of the six different tastes or the *ShadRasas* [1] in *Ahara*. In *Ayurveda*, diet forms the important component of life as it is included in the *Tri-Upastambha* [2] (three pillars of life) along with *Nidra* and *Brahmcharya*. It is also mentioned in *Ayurveda* that any material in the universe, is composed of five basic elements, the *PanchaMahabhootas* [3], namely *Prithvi* (Earth), *Apa* (Water), *Teja* (Fire), *Vayu* (Air) and *Akasha* (Ether). The *Tridoshas* (Biological Humors) i.e., *Vata*, *Pitta* & *Kapha* which constitutes the body are also made up of these five elements. So according to the above statement, each food article has either *Dosha* aggravating or pacifying or balancing action on human body [4]. To maintain the homeostasis of *Doshas* (health), *Ayurveda* has described specific diet according to various *Ritus* (seasons) also. The first step to learn Ayurvedic nutrition is to learn about tastes and *Rasas*. *Rasa* is that subtle component of the food which is perceived mainly in dry and fresh stages of the substance and in the beginning and end of the gustatory processes. *Madhur* (sweet), *Amla* (sour), *lavana* (salt), *Tikta* (bitter), *Katu* (pungent) and *Kasaya* (astringent) are the six *Rasas* (tastes) present in the different food substances, the daily intake of which regulates the elements and *doshas* of our body through their specific effects on the various body tissues [5]. According to *Ayurveda*, these various tastes result into nurturing and regulating various actions in the body system [6]. It is therefore recommended to take a wholesome diet means *Shadrasahara* according to Ayurveda to stay healthy.

Different type of Rasas (taste)

Sweet taste (*MadhuraRasa*)

The sweet taste as in wheat, rice, potatoes is believed to increase the general body resistance against diseases. All the carbohydrates and pulses are the examples of *Madhur Rasa*. This specific taste helps to nourish all the body tissues and as a consequence is the vital energy reserve of the body and mind. This taste aids in increasing not only immunity, but also the general health of an individual and keeps aging at a distance. *MadhuraRasa* is conducive of life span, pleasing to six sense organs, promotes strength and lusture, pacifies thirst and heat, beneficial for skin, hair, throat and enhances strength in the body. It promotes healing of wounds and acts as stabilizer and vitalizer [7]. Though the major portion of our food must be *Madhura Rasa* in the form of *Chapati*, rice *Dal* etc, it should not be consumed in excess. In excess it can produce obesity, laxity, lassitude, over sleep, heaviness, loss of desire for food, decreased appetite, dyspnoea, cough, coryza, fever with shivering, hardness in bowels, sweetness in mouth, nausea, vomiting [8] and thyroid disorder like goitre etc.

Sour Taste (*Amla Rasa*)

Sour taste increases the digestive power. The example of it is *Amla*, lemon, vinegar, tomatoes and citrus fruits like oranges, *Mausami*, kiwi etc. According to modern science, they are rich in vitamin C and hence enhance immunity. According to *Ayurveda*, *AmlaRasa* makes the food *Hridya* (palatable) and stimulates the excretion of enzymes well enough to aid the digestion process. All pickles, chutneys and condiments are actually having sour tastes and hence makes the food tasty and produces a feeling of satiety. It exhibits a sharp taste, which stimulates salivation and increases the appetite. It promotes strength and stability of tissues. It regulates peristalsis and downward movement of *Vata* and helps in the digestion of food. It awakes mind, makes the sense organs alert, promotes strength, moisten and digest food, gives satisfaction, and is light, hot and unctuous [9]. Though endowed with so many qualities, if used in excess it sensitises teeth, causes vertigo, thirst, liquefies *Kapha*, aggravates *Pitta*, produces inflammation and itching in emaciated and debilitated person, leads to suppuration of wounds, skin diseases like pustules, and cause burning sensation in throat, chest and cardiac region [10]. So, it must be used in restricted quantity only.





Sarita Yadav et al.,

Salty Taste (*Lavana Rasa*)

The salty taste imparts a relish for the food and provides softness to the body parts. Like the sour taste, it enhances the enzyme secretions in the digestive tract and helps in digestion. It is digestive, lubricating, appetizer, enhances salivation, expectorant, laxative, removes stiffness, cleanses channels and softens all the body parts[11]. Though having so many qualities, excessive intake of the salty taste leads to increase in the body heat, burning sensation in the body, untimely greying and loss of hair, wrinkles, excessive thirst, impotency and various skin and gastric disorders. Therefore, must be taken in limited amount only[12].

Pungent Taste (*KatuRasa*)

It is very hot taste as in Chilli, green pepper, black pepper, mustard, ginger, garlic and onion. Pungent taste improves digestion and stimulates the digestive fire (*Agni*) in the body. It improves circulations and clears the channels. It has an anti-spasmodic action. It causes instant watering of eyes and nose if consumed directly. It increases absorption of digested food, helps in healing of wounds, checks the coagulation of blood and opens the channels. Though having so many properties if used singly and excessively damages sexual potency, causes mental confusion, malaise, depression, fainting, feeling of giddiness, burning in throat, loss of strength, thirst, tremors etc[13].

Bitter Taste (*TiktaRasa*)

It is the taste present in bitter gourd, *Methi* etc. and produces a very unpleasant taste in mouth. In spite of its unpleasant taste, it is important to incorporate this taste in our meal as it is anti-infectious and also detoxifies the body^[14]. It is also, anthelmintic, alleviates burning sensation and itching, provides firmness to skin and muscles, antipyretic, appetiser etc., it helps in toning of tissue and also cleanse the blood and therefore helps to alleviate any kind of skin disorder. Bitter food consumed in excess can produce adverse effects on the body like loss of strength and energy and produces emaciation by tissue depletion, malaise, mental confusion, giddiness, dryness of mouth etc.

Astringent Taste (*KashayaRasa*)

It is like the taste as present in salads and unripe fruits like bananas and guavas. Nutmeg is another example of this taste. It gives an immediate drying sensation in mouth on consumption. It purifies blood by its anti-inflammatory effects and tones the tissues due to astringent effect. It also helps in healing. Excess use of astringent food causes choking sensation and difficulty in speaking. It causes constipation along with distension of abdomen^[15]. It can produce flatulence, choking in voice, slowing of movement of fluids in channels, blackish hue (due to loss of complexion), impotency, gas formation during digestion and malaise etc. Prolonged consumption may lead to emaciation of the body, so must be consumed in limited quantity only.

Regimen According to Different Season

Of the six rasas, *Madura Rasa* is produced by the predominance of *water element*, *Amla* by the earth and fire. *Lavana* that of water and fire, *Katu* that of air and fire element, *Tikta* that of air and ether, and *Kashaya* by that of air and earth^[16]. Thus, the six forms of manifestations of *Rasa* takes place according to the quantum of *Mahabhutas* like various complexion and shapes in plants and animals. The dominance and depletion of *Mahabhutas* is possible due to time factor having six seasons. So, *Rasa* intake should be according to different seasons. According to Ayurveda a year consists of six seasons i.e. *Shishir* (winter), *Basant* (spring), *Grishama* (summer), *Varsha* (rainy), *Sharad* (autumn), *Hemant* (late autumn).

Shishir Ritu (Winter Season)

In the month of December and January, when the cold winds are blowing and the sun rays are also not too hot, *Agni* inside the body is high so as to overcome the cold. Body needs good amount of caloric food so as to keep the body warm and *Agni* up. So, *Madhura* and *Amla Rasa* are indicated so as to keep the *Doshas* in order^[17]. That's why the season is called healthy season as what we eat is digested immediately and thus most of the tissue nourishing food can





Sarita Yadav et al.,

be taken at this time. Nuts, jaggery, panjiri, laddoos and other sweets are recommended in addition to the normal diet so as to keep the metabolism up. Also, enough ghee must be taken to nullify the drying effect of cold winds. *AmlaRasa* in the form of *Amla* in *Chyavanprash* is beneficial. *Kanji* is another *amla rasa* preparation to keep the *Agni* up and to nourish the tissues.

Basant Ritu(Spring Season)

During Basant Ritu, the accumulated *Kapha* in mid-January to mid-march in winters irritated by the strong rays of the sun, flows into body channels and disturbs the body heat and thus causes many diseases[18]. Excess of accumulated *Kapha* in channels is mobilised and cold, cough, chest congestion, post nasal discharge and other *Kapha* related problems starts. Moreover, due to blossoming of different kinds of flowers allergic reactions in the form of allergic rhinitis, bronchitis, sinusitis etc. are commonly seen. So, the main aim is to cleanse the channels of accumulated *Kapha* and also to keep the *Agni* up so as to fight against superimposed infections etc. So, the advised *Rasa* are *Katu*, *Tikta* and *Kashaya*. *Madhura* and *lavanaRasa* must be avoided as these favours the accumulation of *Kapha*. *KatuRasa* food like ginger, black pepper is highly beneficial to cleanse the channels. *TiktaRasa* like *Methi* is also good to dry up the excess *Kapha*. Turmeric is also effective. Hence, during spring evacuative measures like vomiting etc. should be followed and heavy, sour, fatty and sweet diet as well as day sleep should be avoided.

Grisham Ritu(Summer Season)

During summer one has to consume foods which are sweet in taste, oily, warm and light to digest in the form of liquids. *Rasala*[19] (a drink prepared with milk and curd), sugars, milk, lassi and other dairy products, rice, vegetables soup etc. are recommended. Addition of sugar to all varieties of food is advised. Pungent, alkaline and sour foods should be avoided.

Varsha Ritu(Rainy Season)

During rainy season, *agni* is vitiated and *Vata* is in surge[20] and to pacify it, *Madhura*(sweet), *Amla*(sour) and *lavana*(salt) foods are to be consumed. In this season, curds, hot foods, meat from animals, wheat, rice, black gram should be consumed. Rice gruel or *Kheer* is effective in pacifying *Vata* and therefore is a tradition to consume *Kheer* during all the fasts in *VarshaRitu*. Eating dry foods should be prohibited. *Amla* and *lavanRasas* must be used in restricted quantity in this season.

Sharad Ritu(Autumn Season)

During post monsoon period, it is advised to consume ghee, food substances having sweet, bitter and astringent taste, easily digestive foods, milk, sugarcane juice, salts, less quantity of flesh from wild animals, wheat, barley, green gram, rice etc. [21] Curds, sour, pungent and spicy food should be prohibited during this season. Sugarcane juice, green gram and boiled milk are the things one must adopt for his better health during post monsoon period.

Hemant Ritu(Late Autumn Season)

In this season person should consume food in early hours of the day[22]. Food items during this season should include sour, sweet and saltish taste like wheat, sugarcane products, rice, black gram, freshly cultivated cereal food, sesame seeds, musk, saffron, oily and fatty foods etc.

DISCUSSION

According to *Ayurveda* a person can be healthy if all the *Doshai*. *Vata*, *Pitta* and *Kapha* remains in *Samyavastha* (homeostatic condition) and disharmony in the doshas may result in *Roga*(disease). Because *Dosha* keeps changing according to the various seasons, so accordingly person should follow a diet and lifestyle according to the different seasons to keep the *Doshas* in equilibrium. Depending on this analytical reasoning, ancient sages set up regimen according to the various seasons to remain healthy by preventing the disease to occur. In modern medicine doctors advise a strict diet and regular exercises along with other disease controlling drugs. But with the knowledge of





Sarita Yadav et al.,

Shadras as and their judicious use according to various seasons one can surely avoid various diseases and maintain the harmony of *Tridoshas* so as to stay healthy ever.

CONCLUSION

Different *Rasas* or tastes in the food have their individual importance in terms of health and nutrition and thereby nurturing all the body tissues in an optimum way so as to attain the longevity is the aim. All the *Rasas* i.e. sweet, sour, salty, bitter, pungent and astringent have specific effect on different doshas and also on different body functions. One must learn about their body type according to *Ayurveda* means the *Doshik* dominance in their body and then must follow dietary recommendations according to *Shadras* so as to maintain the optimum balance of doshas in the body. A *Vata* body type person needs more of the tissue forming *Rasa* like sweet, sour, salty to combat dryness in their body. A *Pitta* person must avoid sour, salty and pungent taste as these *Rasa* can provoke *Pitta* and cause inflammation in the body. Sweet, bitter and astringent taste are good for them to keep the *Pitta* in balance. *Kapha* type people have tendency to put on the weight due to slow metabolism and hence bitter, pungent and astringent are good for them to keep the metabolism up. Similarly, the dominance of *Doshas* changes with seasons as discussed, and thus diet must be changed accordingly. In summer and rainy season there is more of *Vata* in the system and hence the *Vata* pacifying *Rasas* like sweet, sour and salty are beneficial. In winter and spring season the *Kapha* is more in the system and thus bitter, pungent and astringent works well. Autumn season favours the increase of *Pitta* in the system and thus *Pitta* pacifying *Rasas* sweet, bitter and astringent are suggested. So, one must follow the principle of *Shadras* in day to day life as mentioned in *Ayurveda* according to various *Ritus* (season) as well as according to one's own body type to stay healthy.

REFERENCES

1. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthansutra sthan 26/8
2. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 11/35
3. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthansharirasthan 5/3
4. Sushruta, Sushruta Samhita with Ayurveda Tatvasandeeepika, Hindi Commentary by Kaviraj Ambika Dutt Shastri Chaukhabha Sanskrit Sansthan Edition 2015, Sutrasthan 46/5, page no. 290
5. Astanghridyam, Astanghridyam Vidhotani Bhasha Teeka by Kaviraj Atridev Gupta, Published by Chaukhabha Prakashan sutrasthan 3/57
6. Kashyap, Kashyapsamhita Vridhjeevkeeyam Tantra Va with Vidhyotani Hindi Commentary by Nepal Rajguru, Pandit Hemraj Sharma Published by Chaukhabha Sanskrit Sansthan, Khilasthan 5/40
7. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 26/42-2
8. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Chaukhabha Orientalia Varanasi, Part-1, Poorvakhand, 6/176
9. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi published by Chaukhabha Sanskrit Pratisthan sutra sthan 26/42
10. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Chaukhabha Orientalia Varanasi, Part-1, Poorvakhand, 6/171
11. Ahara -Ancient Secret of Diet in Ayurveda and Yoga by Pradip Kumar R. Suryawanshi, Published by Chaukhabha Sanskrit Pratisthan, 1st Edition Chapter -9, Page-170
12. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Chaukhabha Orientalia Varanasi, Part-1, Poorvakhand, 6/173



**Sarita Yadav et al.,**

13. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 26/42-3
14. Sushruta, Sushruta Samhita with Ayurveda Tatvasandeeepika, Hindi Commentary by Kaviraj Ambika Dutt Shastri Chaukhabha Sanskrit Sansthan Edition 2015, Sutrasthan 42/16
15. Ahara -Ancient Secret of Diet in Ayurveda and Yoga by Pradip Kumar R. Suryawanshi, Published by Chaukhambha Sanskrit Pratisthan, 1st Edition Chapter -9, Page-173-174
16. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 26/40
17. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Haukhabha Orientalia Varanasi, Part-1, Poorvakhanda, 5/337
18. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 5/22-26
19. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Haukhabha Orientalia Varanasi, Part-1, Poorvakhanda, 5/340-341
20. Charaka, Charak Samhita of Agnivesh Charak Chandrika Hindi Teeka by Brahmanand Tripathi by Chaukhabha Sanskrit Pratisthan sutra sthan 6/34
21. Ahara -Ancient Secret of Diet in Ayurveda and Yoga by Pradip Kumar R. Suryawanshi, Published by Chaukhambha Sanskrit Pratisthan, 1st Edition Chapter -9, Page-173-174
22. Bhavprakasa of Bhavmisra, Original Text Along with Commentary and Translation, Commentary by Bulusu Sitaram, Published by Chaukhabha Orientalia Varanasi, Part-1, Poorvakhanda, 5/33

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

gb - Chromatic Number of Some Standard Product Graphs

Shila. D^{1*} and Arokialancy. A²

¹Assistant Professor, Department of Mathematics, SNS College of Technology (Affiliated to Anna University, Chennai) Coimbatore, Tamil Nadu, India

²Assistant Professor, Department of Mathematics, Nirmala College for Women (Affiliated to Bharathiyar University), Coimbatore, Tamil Nadu, India.

Received: 11 Mar 2026

Revised: 10 Apr 2026

Accepted: 13 May 2026

***Address for Correspondence**

Shila. D

Assistant Professor,
Department of Mathematics,
SNS College of Technology
(Affiliated to Anna University, Chennai)
Coimbatore, Tamil Nadu, India
E.Mail: kishoreshila@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The gb -chromatic number for a graph is defined as a proper colouring of a graph G , which combines the smallest cardinality of geodetic set and b -chromatic set of graph G whereas the combination of this is defined as gb -chromatic number and it is denoted as $\varphi_{gb}(G)$. In this paper, the gb -chromatic number of product graphs are obtained and we extend few results of gb -chromatic number for product graph of certain existing graphs as path graph and cycle graph.

Keywords: Geodetic, gb -Chromatic, Cartesian product, Corona product, Tensor product, Co-normal product, Lexicographic product

INTRODUCTION

All the graphs used in this study are undirected, simple, and finite. The order and size of G are n and m for any graph G with edge set $E(G)$ and vertex set $V(G)$ [2, 3]. The shortest distance between two vertices in $V(G)$, x_1 , and x_2 , determines the minimum size of $x_1 - x_2$ pathways in G . The term "geodesic of G " refers to an $x_1 - x_2$ path of size $d_G(x_1, x_2)$. We define $I_G(x_1 - x_2)$ as the collection of geodesics of G 's $x_1 - x_2$ vertices. The vertex is said to reside on the $x_1 - x_2$ geodesic if c is an inner vertex of $\mathcal{P}$. The vertices of the limited interval $I(x_1, x_2)$ are all situated on a geodesic of G between x_1 and x_2 . Consider a non - empty set $I(S) = \bigcup_{x_1 x_2 \in S} I(x_1 x_2)$. If G is connected graph, thus S is a geodetic set $g(S)$ such that $I(S) = V(G)$ [1,7]. The geodetic number $g(G)$ defines the least cardinality S of G [4,5,6]. A k - coloring of a G is a division of V into independent sets of G with $\mathcal{P} = \{v_1, v_2, v_3, \dots, v_k\}$. The chromatic number $\chi(G)$ of G is the minimum cardinality of k for which G has a k - coloring. The largest positive integer k such that G allows a proper k -





Shila and Arokialancy

coloring in which every color class has a representation adjacent to at least one vertex in each of the other color classes is the graph's b – chromatic number $\phi_b(G)$ of G [8]. In general, gb-chromatic number is both geodetic set and b-chromatic set. Here the gb-chromatic number for some standard product graphs such as Cartesian product, Corona product, Tensor product, Co-normal product, Lexicographic product as path graph and cycle graph has been covered [9,10].

gb Chromatic Number on Cartesian product graph on path graph with path graph

Let us consider $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_3 = \{u_1, u_2, u_3\}$. The Cartesian product of $\mathcal{P}_2 \otimes \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$ which is 2 chromatic of b-colourable . (i.e.) We colour the vertices as C_1 for $\{(v_1u_1), (v_1u_3), (v_2u_2)\}$ and colour C_2 for $\{(v_1u_2), (v_2u_1), (v_2u_3)\}$.

The geodetic set of the Cartesian product of $\mathcal{P}_2 \otimes \mathcal{P}_3$ is $g(S) = \{(v_1u_1), (v_2u_3)\}$ which is the minimum gb chromatic number. (i.e.) The set $g(S)$ satisfies both geodetic set and b-chromatic set.

Hence $\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_3) = 2$.

Theorem

For the Cartesian product of path graph $\mathcal{P}_2$ with the path graph $\mathcal{P}_n$ when $n > 2$ the gb- chromatic number is given by

$$\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_n) = \begin{cases} 2, & \text{for } n = 3 \\ 3, & \text{for } n > 3 \end{cases}$$

Proof

Let G be the path graph of $\mathcal{P}_2 \otimes \mathcal{P}_n$, $n > 3$ where $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_n = \{u_1, u_2, u_3, \dots, u_n\}$.

The Cartesian product $\mathcal{P}_2 \otimes \mathcal{P}_n$ is given by

$$\mathcal{P}_2 \otimes \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n)\}$$

Now, $g(S) = \{(v_1u_1), (v_2u_n)\}$ is the minimum geodetic set of $\mathcal{P}_2 \otimes \mathcal{P}_n$ and also $\mathcal{P}_2 \otimes \mathcal{P}_n$ is 3 chromatic of b-colouring.

That is we colour the vertices in such way that if n is even (v_1u_1) receive colour C_1 , (v_1u_n) receive colour C_2 and the neighbourhood vertex (v_1u_2) is coloured by C_3 and the remaining vertices are coloured by using proper colouring.

Similarly, when n is odd (v_1u_1) receive colour C_2 , (v_1u_n) receive colour C_1 and the neighbourhood vertex (v_1u_2) is coloured by C_3 and the remaining vertices are coloured by using proper colouring.

The b-colouring is given by $\phi_b = \{(v_1u_1), (v_1u_2), (v_1u_n)\}$.

Therefore, $g(S) \cup \phi_b = \{(v_1u_1), (v_1u_2), (v_1u_n)\}$ be the minimum colour gb-colouring of the graph $\mathcal{P}_2 \otimes \mathcal{P}_n$

Therefore $\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_n) = 3$.

gb- Chromatic Number on Lexicographic Product on path graph with path graph

Let us consider $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_3 = \{u_1, u_2, u_3\}$. Then the Lexicographic product of $\mathcal{P}_2 \bullet \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$, which is 6 chromatic of b-colouring.

We colour the vertex (v_1u_1) by C_1 , (v_1u_2) by C_2 , (v_1u_3) by C_3 , (v_2u_1) by C_4 , (v_2u_2) by C_5 , (v_2u_3) by C_6 .

The geodetic set of the Lexicographic product is $\mathcal{P}_2 \bullet \mathcal{P}_n$ is given by

$g(S) = \{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$, which is minimum gb-chromatic.

Hence $\phi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = 6$.

Theorem

For the Lexicographic product of two paths graphs $\mathcal{P}_2$ and $\mathcal{P}_n$, the gb chromatic number is given by

$$\phi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \begin{cases} \frac{n}{2} + 3, & \text{if } n \text{ is odd} \\ \frac{(n+1)}{2} + 2, & \text{if } n \text{ is even} \end{cases}$$

Proof

Let us consider the vertices of $\mathcal{P}_2 = \{v_1, v_2\}$ and the vertices of $\mathcal{P}_n = \{u_1, u_2, u_3, \dots, u_n\}$.

Let G be Lexicographic product path graph for $\mathcal{P}_2$ and $\mathcal{P}_n$ denoted by $\mathcal{P}_2 \bullet \mathcal{P}_n$, for $n > 3$.

The lexicographic product is given by

$\mathcal{P}_2 \bullet \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n)\}$.





Shila and Arokialancy

The graph $\mathcal{P}_2 \bullet \mathcal{P}_n$ is 4 chromatic of b-colouring.

Now $g(S) = \{(v_1u_1), (v_1u_3), (v_1u_n)\}$

When n is even the geodetic set S is given by $S = \{(v_1u_1), (v_1u_3), (v_1u_n)\}$ which is minimum. i.e. The set S receives only 2 colours C_1 and C_2 .

By adding 2 vertices of different colours C_3 and C_4 to the set S , it becomes a geo chromatic set.

That is $S_c = S \cup \{2 \text{ vertices with different colours}\}$ will be a minimum gb -chromatic set, which is given by

$$\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \frac{(n+1)}{2} + 2.$$

When n is odd the geodetic set S receives same colour C_1 , so adding the remaining colours C_2, C_3, C_4 to $g(S)$. Therefore

$$\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \{S \cup (v_1u_2), (v_2u_1), (v_2u_{n-1})\}.$$

That is vertex v_1u_2 is coloured by C_2 , v_2u_1 by C_3 and v_2u_{n-1} by C_4 .

Therefore it becomes a gb -chromatic set given by $\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \frac{n}{2} + 3$

gb-Chromatic Number on Tensor Product graph on path graph with path graph

The gb -chromatic number for the Tensor product graph $\mathcal{P}_2 \times \mathcal{P}_n$ does not exist.

In the graph $\mathcal{P}_2 \times \mathcal{P}_n$ we find the Tensor product for the given $G_1 = \mathcal{P}_2$ and $G_2 = \mathcal{P}_n$ for $G_2 \times G_n$. Whereas the graph $G_2 \times G_n$ form a disconnected graph

Thereby we cannot find a u - v path in the graph $G_2 \times G_n$. Therefore the graph $G_2 \times G_n$ does not exist for Tensor product

Let us consider the cycle graph C_3 where $V(C_3) = \{v_1, v_2, v_3\}$ and the path graph $V(\mathcal{P}_2) = \{u_1, u_2\}$. The Corona product of $C_3 \circ \mathcal{P}_2$ defined as

$$V(C_3 \circ \mathcal{P}_2) = \{v_1, v_2, v_3\} \cup \{u_1, u_2\} \cup \{u'_1, u'_2\} \cup \{u''_1, u''_2\} \text{ which is 3 chromatic of b-colourable.}$$

The geodetic set of the Corona product of $C_3 \circ \mathcal{P}_2$ is

$$g(S) = \{u_1, u_2, u'_1, u'_2, u''_1, u''_2\} \text{ which is the minimum } gb \text{ chromatic number.}$$

(i.e.) The set $g(S)$ satisfies both geodetic set and b-chromatic set.

Hence $\varphi_{gb}(C_3 \circ \mathcal{P}) = 6$.

Theorem:

For the corona product of gb -chromatic number for path graph $\mathcal{P}_n$ and cycle graph C_3 is given by

$$\varphi_{gb}(C_3 \circ \mathcal{P}_n) = \begin{cases} \frac{3n+6}{2}, & \text{if } n \text{ is even} \\ \frac{3n+3}{2}, & \text{if } n \text{ is odd} \end{cases}.$$

Proof

Consider the cycle graph C_3 where $V(C_3) = \{v_1, v_2, v_3\}$ and the path graph $\mathcal{P}_n$ where $V(\mathcal{P}_n) = \{u_1, u_2, u_3, \dots, u_n\}$.

$$\text{Let } V(C_3 \circ \mathcal{P}_n) = \{v_1, v_2, v_3\} \cup \{u_1, u_2, u_3, \dots, u_n\} \cup \{u'_1, u'_2, u'_3, \dots, u'_n\} \cup \{u''_1, u''_2, u''_3, \dots, u''_n\}.$$

By definition of corona graph every vertex of C_3 is adjacent to every vertex of path $\mathcal{P}_n$, i.e. every vertex of u_i is adjacent with v_1 , u'_i is adjacent to v_2 and u''_i is adjacent with v_3 for $i=1, 2, 3, \dots, n$.

Let us assign the 4 colouring for $C_3 \circ \mathcal{P}_n$ as b-chromatic, i.e. for u_1 the colour is C_3 , for u_3 color C_2 , for u_2 colour C_4 and u'_1 colour C_1 . The remaining vertices are coloured by proper colouring.

Thus the geodetic set $g(S)$ of $C_3 \circ \mathcal{P}_n$ is $\{u_{2i-1}, u'_{2i-1}, u''_{2i-1}\}$ for odd and $\{u_{2i-1}, u_n, u'_{2i-1}, u'_n, u''_{2i-1}, u''_n\}$ for even which is the minimum geodetic set and b-chromatic set.

Therefore, when n is even the gb -chromatic number of $\varphi_{gb}(C_3 \circ \mathcal{P}_n)$ is $\frac{3n+6}{2}$ and for odd is given by $\frac{3n+3}{2}$.

gb Chromatic Number on Co-normal product graph on path graph with path graph

Let us consider $\mathcal{P}_4 = \{v_1, v_2, v_3, v_4\}$ and $\mathcal{P}_2 = \{u_1, u_2\}$. The Co-normal product of $\mathcal{P}_2 * \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_2u_1), (v_2u_2), (v_3u_1), (v_3u_2), (v_4u_1), (v_4u_2)\}$

$$\text{Now } g(S) = \{(v_1u_1), (v_3u_1), (v_4u_1)\}.$$

Now, $g(S)$ is the minimum geodetic set of $\mathcal{P}_4 * \mathcal{P}_2$ and also $\mathcal{P}_4 * \mathcal{P}_2$ is 4 chromatic of b-colouring.

(i.e.) We colour the vertices as C_1 for (v_1u_1) , (v_3u_1) and colour C_3 for (v_4u_1) . The set S receives only 2 colours C_1 and C_3





Shila and Arokialancy

The geodetic set of the Cartesian product of $\mathcal{P}_4 * \mathcal{P}_2$ is $g(S) = \{(v_1u_1), (v_2u_3)\}$ which is the minimum gb chromatic number. The b-chromatic is given by

$$\phi_b(\mathcal{P}_4 * \mathcal{P}_2) = \{(v_1u_1), (v_3u_1), (v_4u_1), (v_1u_2), (v_4u_2)\}.$$

By adding 2 vertices of different colours C_2 and C_4 to the set S , it becomes a geo chromatic set.

$$\text{Therefore } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_2) = S \cup \phi_b = \{(v_1u_1), (v_3u_1), (v_4u_1), (v_1u_2), (v_4u_2)\}.$$

$$\text{Hence } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_2) = 5$$

Theorem:

For the Co-normal product of two paths graphs $\mathcal{P}_4$ and $\mathcal{P}_n$, the gb chromatic number is given by $\phi_{gb}(\mathcal{P}_4 * \mathcal{P}_n) = 7$ for $n > 2$.

Proof

Consider the cycle graph $\mathcal{P}_4$ where $\mathcal{P}_4 = \{v_1, v_2, v_3, v_4\}$ and the path graph $\mathcal{P}_n$ where

$$V(\mathcal{P}_n) = \{u_1, u_2, u_3, \dots, u_n\}.$$

Let G be Co-normal product path graph for $\mathcal{P}_4$ and $\mathcal{P}_n$ denoted by $\mathcal{P}_4 * \mathcal{P}_n$, for $n > 2$.

The co-normal product is given by

$$\mathcal{P}_4 * \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n), \\ (v_3u_1), (v_3u_2), (v_3u_3), \dots, (v_3u_n), (v_4u_1), (v_4u_2), (v_4u_3), \dots, (v_4u_n)\}$$

The graph $\mathcal{P}_4 * \mathcal{P}_n$ is 5 chromatic of b-colouring.

$$\text{Now } g(S) = \{(v_1u_1), (v_3u_1), (v_1u_n), (v_3u_n)\}.$$

Now, $g(S)$ is the minimum geodetic set of $\mathcal{P}_4 * \mathcal{P}_n$ and also $\mathcal{P}_4 * \mathcal{P}_n$ is 5 chromatic of b-colouring. That is we colour the vertices in such way that,

If n is odd $(v_1u_3), (v_3u_1)$ receive colour C_1 , $(v_1u_n), (v_3u_n)$ receive colour C_3 and the neighbourhood vertex (v_1u_2) is coloured by C_2 , (v_2u_2) by C_4 , (v_3u_2) by C_5 and the remaining vertices are coloured by proper colouring.

Similarly, when n is even $(v_1u_3), (v_3u_1)$ receive colour C_1 , $(v_1u_n), (v_3u_n)$ receive colour C_2 and the neighbourhood vertex (v_1u_2) is coloured by C_2 , (v_2u_2) by C_4 , (v_3u_2) by C_5 and the remaining vertices are coloured by proper colouring.

The b-colouring is given by $\phi_b = \{(v_1u_1), (v_3u_1), (v_1u_2), (v_2u_2), (v_3u_2), (v_1u_n), (v_3u_n)\}$.

Therefore, $g(S) \cup \phi_b = \{(v_1u_1), (v_3u_1), (v_1u_2), (v_2u_2), (v_3u_2), (v_1u_n), (v_3u_n)\}$ be the minimum gb-colouring of the graph $\mathcal{P}_4 * \mathcal{P}_n$

$$\text{Therefore } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_n) = 7.$$

CONCLUSION

In this work, we have found few results about the gb-chromatic number for some standard product graphs like Cartesian product, Corona product, Tensor product, Co-normal product, and Lexicographic product for path graph with path and cycle graphs with path. This concept can further be extended to other product graphs and general graph classes.

REFERENCES

1. Beulah, S. S., & Robinson Chellathurai, S. Geo chromatic number of a graph. International Journal of Scientific Research in Mathematical and Statistical Sciences (2018), 5, 259-264.
2. Bondy, J. Á., & Murthy, U. S. R., Graph theory with application. Macmillan London and Elsevier, New York (1976)..
3. Buckley, F., & Harary, F. Distance in Graphs. Addition – Wesley, Red – wood city, CA (1990).
4. Buckley, F., Harary, F., & Quintas, L. V. Extremal results on the geodetic number of a graph. Scientia (1988). A2, 17-26.
5. Chartrand, G., Harary, F., & Zhang, P. On the geodetic number of a graph. Networks(2002), 39, 1-6.





Shila and Arokialancy

6. Chartrand, G., Harary, F., & Zhang, P.. Geodetic sets in graphs. *Discussiones Mathematicae Graph Theory* (2000). 20, 129-138.
7. Joseph Paul, R., & Mary, U..Geo Chromatic number of Certain Graphs *Journal of Interdisciplinary Mathematics* Volume 26: Issue 1: 11-16, 2023.
8. Irving R.W and Manlove D.F, "The b – chromatic number of a graph," *Discrete Applied Mathematics*, 91, pp.127–141, 1999.
9. Joseph Paul, R., & Mary, U..gb – Chromatic Number of Graph. *Journal of Xidian University* 16 (10), 401 – 410, 2022.
10. Joseph Paul, R., & Chitra Ramaprasanth, Geo Chromatic Number of Certain Product graphs. *Journals of Dynamic and Control*, Volume 9 Issue5 : 201-207.

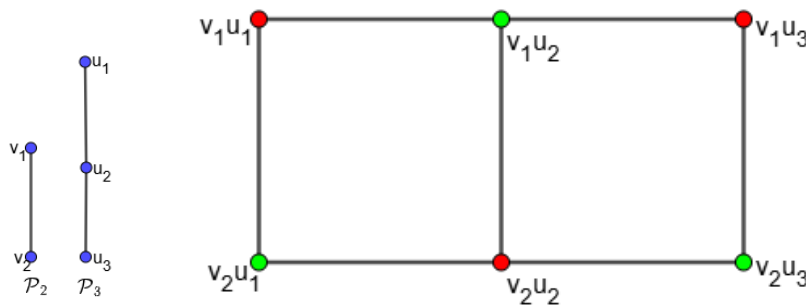


Fig $\phi_{gb}(P_2 \otimes P_3) = 2$

Cartesian Product for $P_2 \otimes P_3$

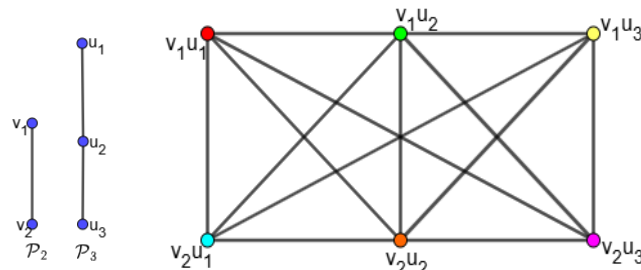


Fig $\phi_{gb}(P_2 \bullet P_n) = 6$.

Lexicographic Product for $P_2 \bullet P_n$

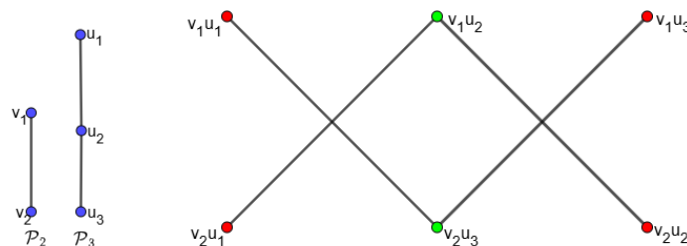


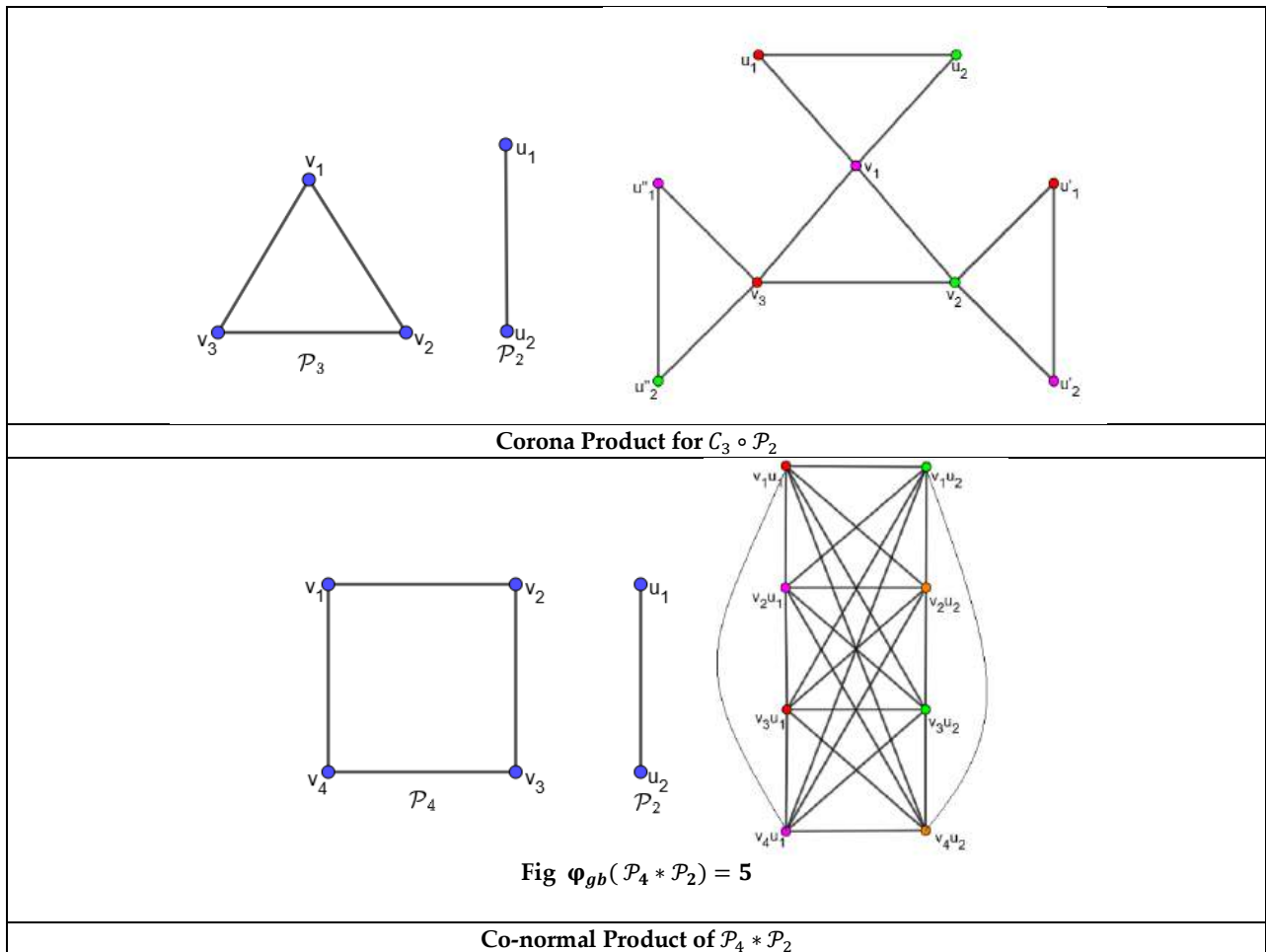
Fig $P_2 \times P_n$

Corollary





Shila and Arokialancy



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Exploring Near Difference Cordial Labeling In Cycle-Related Graph

S. Jackson¹, M. Abirami^{2*} and G.K. Mathan Kumar³

¹Assistant Professor, Department of Mathematics, V.O. Chidambaram College (Affiliated to Manonmaniam Sundaranar University (Tirunelveli)) Thoothukudi, Tamil Nadu, India

²Research Scholar, (Reg.No.23212232092001), Department of Mathematics, V.O. Chidambaram College (Affiliated to Manonmaniam Sundaranar University (Tirunelveli)) Thoothukudi, Tamil Nadu, India

³Assistant Professor, Department of Mathematics, Kamaraj College (Autonomous) (Affiliated to Manonmaniam Sundaranar University (Tirunelveli)) Thoothukudi, Tamil Nadu, India

Received: 10 Mar 2026

Revised: 07 Apr 2026

Accepted: 11 May 2026

*Address for Correspondence

M. Abirami

Research Scholar (Reg.No.23212232092001),

Department of Mathematics,

V.O. Chidambaram College

(Affiliated to Manonmaniam Sundaranar University (Tirunelveli))

Thoothukudi, Tamil Nadu, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Graphs are widely used in computer science, engineering, and social sciences to model complex systems and networks. This paper discusses the NDCL (near difference cordial labeling) of a few cycle-related graphs. We explore the concept in detail, examining several types of graphs. Specifically, we demonstrate that the snail graph(S_n), tortoise graph(T_n), Herschel graph, and fish graph are examples of NDCL (near difference cordial graph). Overall, this paper provides a comprehensive discussion of the NDCL of cycle-related graphs, with specific examples and theorems to illustrate the concept.

AMS Subject Classification: 05C78, 05C15, 05C38, and 05C75.

Keywords: Near Difference Cordial Labeling, Graph Labeling, Cycle related Graph and Cordial graphs.

INTRODUCTION

A variety of both graceful and harmonious labels were introduced in 1987 by I. Cahit [1]. An interactive summary of graph labeling was provided by Gallian, J.A. (2013) [2]. R. Ponraj, S. Sathis Narayanan, and R. Kala presented graphs with DCL (difference cordial labeling) [4]. Many kinds of graphs are examined. First introduced in 2017, the NDCL of various graphs was done by M. Abirami and S. Shanbaga Devi [5]. In 2019, M. Abirami and S. Shinbaga Devi [6]





presented NDCL for graphs connected to paths. This work aims to show that the Tortoise graph T_n , Snail graph S_n , Herschal graph, and fish graph are NDCG.

Preliminaries

Definition 2.1. Assume that the function f maps G 's vertices to $\{0, 1\}$. then, f can be thought of as a **Cordial labeling** of G , since the difference modulus between the number of nodes with the label "zero" and the number of nodes with the label "one" has at least one, as does the difference modulus between the number of lines with the label "zero" and the number of lines with the label "one." thus, we might write the modulus of the difference between two nodes on each line xy . [1]

Definition 2.2. Assume that $f: V(G) \rightarrow \{1, 2, \dots, P\}$ and that G is a (V, E) graph. Assign the label modulus of the difference between the two nodes that are assigned to each bridge uv . f is referred to as a **Difference Cordial labeling (DCL)**. If f is into and the difference modulus between bridges not labeled with one and those with a label of one is at least one, then should it be into. [4]

Definition 2.3. By joining two parallel edges between v_j and v_{n-j+1} for $j = 1, 2, \dots, \left\lfloor \frac{n}{2} \right\rfloor$, one can create a **snail** S_n ($n \geq 4$) from the path $P_n = v_1, v_2, \dots, v_n$. [7]

Definition 2.4. When one edge is attached between v_i and v_{n-i+1} for $i = 1, 2, \dots, \left\lfloor \frac{n-1}{2} \right\rfloor$, one obtains a **tortoise** T_n ($n \geq 4$) from route $P_n = v_1, v_2, \dots, v_n$. [7]

Definition 2.5. Slightly smaller than a Hamiltonian polyhedral graph, the **Herschel graph** is a bipartite graph with eleven nodes and eighteen bridges. [8]

Definition 2.6. A unique kind of graph is the **fish graph**. It consists of seven lines and six nodes. [9]

MAIN RESULTS

Definition 3.1. Assume with $f: v(g) \rightarrow \{1, 2, \dots, p-1, p+1\}$ and that G is a (p, q) graph. Each line must have the label modulus of the difference between two nodes assigned to it. When f is into, and the modulus of the difference between lines that are not labeled with a value of one and those that have a label of one is at least one, we refer to it as near difference cordial labeling (NDCL). A graph is referred to as a Near difference cordial labeling graph (NDCG) if it has a Near difference cordial labeling (NDCL). [5]

Theorem 3.2. Snail graph (S_n) admits NDCG.

Proof.

Suppose $V(S_n) = \{u_t: 1 \leq t \leq n\}$ &

$E(S_n) = \{(u_t u_{t+1}): 1 \leq t \leq n-1\} \cup \{2(u_t u_{t+1}): 1 \leq t \leq \frac{n}{2}\}$

Assume that $\omega: V(S_n) \rightarrow \{1, 2, \dots, p-1, p+1\}$.

The labels assigned to the vertices are,

$$\omega(u_t) = t, \quad 1 \leq t \leq n-2$$

$$\omega(u_{n-1}) = n+1$$

$$\omega(u_n) = n-1$$

These are the induced edge labelings:

$$\omega^*(u_t u_{t+1}) = 1, \quad 1 \leq t \leq n-3$$

$$\omega^*(u_t u_{n-t+1}) = n-2 \text{ if } t = 1$$

$$\omega^*(u_t u_{n-t+1}) = n-1 \text{ if } t = 2$$

$$\omega^*(u_t u_{n-t+1}) = n-2t+1 \text{ if } 3 \leq t \leq n$$

Consequently, the conditions that $|e_\omega(0) - e_\omega(1)| \leq 1$ are also satisfied by $e_\omega(0) = n$ and





$$e_{\omega}(1) = n - 1.$$

Hence, S_n admits NDCG.

Example: NDCL of S_6 is shown in Fig.3.2.1.

Theorem 3.3. The Tortoise graph or T_n admits NDCG.

Proof:

Let $V(T_n) = \{u_z : 1 \leq z \leq n\}$ &

$$E(T_n) = \{(u_z u_{z+1}) : 1 \leq z \leq n-1\} \cup \left\{2(u_z u_{z+1}) : 1 \leq z \leq \frac{n-1}{2}\right\}$$

Establish $\phi: V(T_n) \rightarrow \{1, 2, \dots, p-1, p+1\}$ by

$$\phi(u_z) = z, \quad 1 \leq z \leq n-1$$

$$\phi(u_n) = n+1$$

The labelings at the induced edges are,

$$\phi^*(u_z u_{z+1}) = 1, \quad 1 \leq z \leq n-2$$

$$\phi^*(u_z u_{n-z+1}) = n \quad \text{if } z = 1$$

$$\phi^*(u_z u_{n-z+1}) = n - 2z + 1 \quad \text{if } 2 \leq z \leq \frac{n-1}{2}$$

As shown here, $e_{\phi}(1) = n - 2$ and $e_{\phi}(0) = n - 3$. Because it ensures the requirement

$|e_{\phi}(0) - e_{\phi}(1)| \leq 1$ In every case, T_n is a NDCG.

Example: Fig 3.3.1 displays the accurate labeling of T_7 with NDCG

Theorem 3.4. The Herschel graph (with eleven vertices and eighteen edges) is a NDCG.

Proof:

Assume G to be a Herschel graph.

$$V = \{u_r : 1 \leq r \leq 5, v_s : 1 \leq s \leq 6\} \&$$

$$E = \{v_s u_r, v_s u_{r+2}, u_r v_{s+3} : 1 \leq r, s \leq 3\} \cup \{u_r v_{s+1} : 3 \leq r, s \leq 5\} \cup$$

$$\{u_1 u_2, u_4 u_5, v_4 v_5, v_5 v_6\} \cup \{v_s v_{s+1} : 1 \leq s \leq 2\}.$$

Consider, $\eta: V(G) \rightarrow \{1, 2, \dots, p-1, p+1\}$ by

Because of this, $e_{\eta}(0) = e_{\eta}(1) = n - 2$ and it is also satisfied by $|e_{\eta}(0) - e_{\eta}(1)| \leq 1$.

As such, an NDCG is a Herschel graph.

Example: As seen in fig.3.4.1, the Herschel graph is an NDCG

Theorem 3.5. Fish graph admits NDCG (it has six vertices and seven edges).

Proof:

Consider G be a fish graph

$$\text{Suppose } V(G) = \{u_w : 1 \leq w \leq 6\} \text{ and } E(G) = \{u_w u_{w+1} : 1 \leq w \leq 5\} \cup \{u_6 u_3\} \cup \{u_3 u_1\}$$

$$\text{Define } \psi: V(G) \rightarrow \{1, 2, 3, 4, 5, 7\}$$

The vertex labels are,

Thus, it fulfills the requirement $|e_{\psi}(0) - e_{\psi}(1)| \leq 1$.

Fish graph is an NDCG as a result.

Example: The NDCL of fish graph is shown in fig.3.5.1.

CONCLUSION

In the field of graph theory, we believe that this work will be a helpful resource for scholars and practitioners. Our goal is to stimulate more study and innovation in this field by providing a thorough analysis of the NDCL of graphs connected to cycles.





REFERENCES

1. I.Cahit, *Ars combinatoria* 23 (1987), 201-207.
2. J.A. Gallian, *The electronic journal of combinatorics*, 18 (2013)# Ds6.
3. F. Harary, *Addition Wesley*, New Delhi(1969).
4. R.Ponraj, S.Sathis Narayanan, and R.Kala, *Global Journal of Mathematical Sciences: Theory and Practice*, 3(2013), 192-201.
5. S.Shenbaga Devi and M.Abirami, *International Journal of Science and Advance Research in Technology*, Volume 3, Issue 5 – May 2017.
6. S.Shenbaga Devi and M.Abirami, *International Journal of Mathematics Trends and Technology*, Special issue NCPAM Sep 2019.
7. L. Pandiselvi and K. Palani, *Turkish Online Journal of Qualitative Inquiry*, Volume 12, Issue 7, July 2021: 6470- 6474.
8. J. Rashmi Kumar and K. Manimekala, *Turkish Journal of Computer and Mathematics Education*, Vol. 12, No. 10 (2021), 1482-1486.
9. H. Aswathy and S. S. Sandhiya, *AIP Conference Proceedings*, AIP Publishing, 2277, 100013 (2020), <https://doi.org/10.1063/5.0025279>

Table 1:

$\eta(v_1) = 12$	$\eta(v_2) = 3$	$\eta(v_3) = 10$
$\eta(v_4) = 8$	$\eta(v_5) = 7$	$\eta(v_6) = 6$
$\eta(u_1) = 1$	$\eta(u_2) = 2$	$\eta(u_3) = 9$
$\eta(u_4) = 4$	$\eta(u_5) = 5$	

The edge labels that are generalized are,

$\eta^*(u_1u_2) = 1$	$\eta^*(u_4u_5) = 1$	$\eta^*(u_2v_2) = 1$
$\eta^*(u_5v_6) = 1$	$\eta^*(v_2v_4) = 1$	$\eta^*(v_6v_5) = 1$
$\eta^*(v_4v_5) = 1$	$\eta^*(v_4u_3) = 1$	$\eta^*(u_3v_3) = 1$
$\eta^*(v_1v_2) = 9$	$\eta^*(v_2v_3) = 7$	$\eta^*(v_1u_1) = 11$
$\eta^*(v_1u_3) = 3$	$\eta^*(v_3u_5) = 5$	$\eta^*(u_1v_4) = 7$
$\eta^*(u_2v_5) = 5$	$\eta^*(u_3v_6) = 3$	$\eta^*(u_4v_5) = 3$

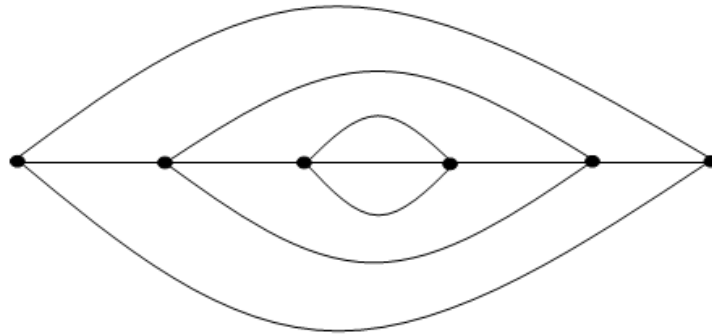
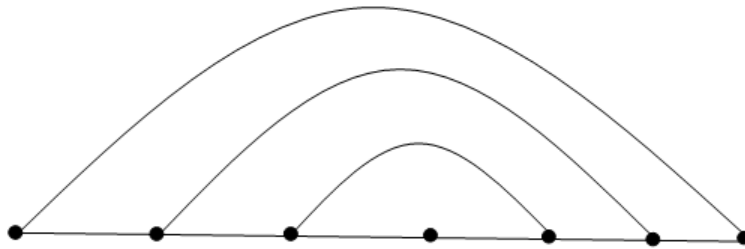
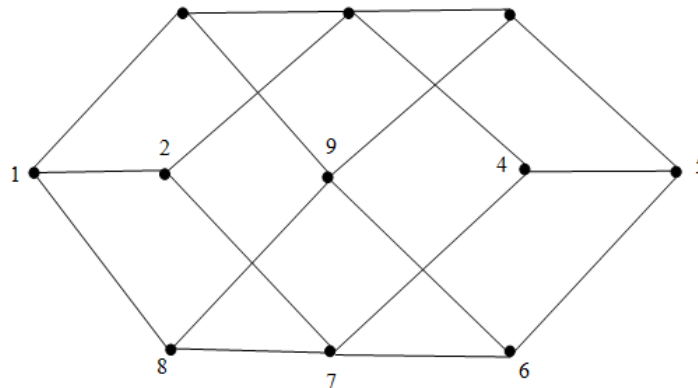
Table 2:

$\psi(u_1) = 1$	$\psi(u_2) = 2$	$\psi(u_3) = 3$
$\psi(u_4) = 4$	$\psi(u_5) = 5$	$\psi(u_6) = 7$

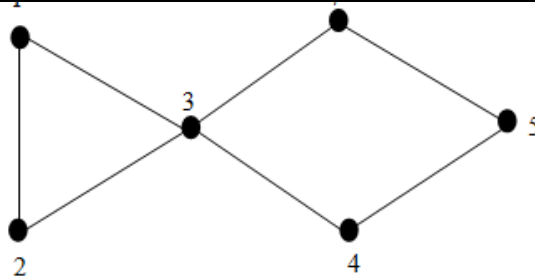
The induced edge labels are,

$\psi^*(u_1u_2) = 1$	$\psi^*(u_2u_3) = 1$	$\psi^*(u_3u_4) = 1$	$\psi^*(u_4u_5) = 1$
$\psi^*(u_5u_6) = 2$	$\psi^*(u_6u_3) = 4$	$\psi^*(u_3u_1) = 2$	



Jackson *et al.*,Example: NDCL of S_6 is shown in Fig.3.2.1.Example: Fig 3.3.1 displays the accurate labeling of T_7 with NDCG.

Example: As seen in fig.3.4.1, the Herschel graph is an NDCG



Example: The NDCL of fish graph is shown in fig.3.5.1.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Geometric Mean and Root Mean Square Based Fuzzy Delay Fourth Order Runge - Kutta Methods for Solving Fuzzy Delay Differential Equations

S.Devigayathri^{1*} and R.Gethsi Sharmila²

¹Research Scholar (Reg. No.: BDU2110182779264), Department of Mathematics, Bishop Heber College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India.

²Associate Professor, Department of Mathematics, Bishop Heber College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 06 Mar 2026

Revised: 18 Apr 2026

Accepted: 09 May 2026

*Address for Correspondence

S.Devigayathri

Research Scholar

(Reg. No.: BDU2110182779264),

Department of Mathematics,

Bishop Heber College (Autonomous),

(Affiliated to Bharathidasan University),

Tiruchirappalli, Tamil Nadu, India

E.Mail: gayathripadmavathy@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

In this paper, a numerical algorithm for solving fuzzy delay differential equations using the fuzzy delay fourth order Runge-Kutta methods based on Geometric Mean and the fuzzy delay fourth order Runge-Kutta method based on Root mean square are proposed in detail. The convergence of the methods are presented. Numerical examples are given to validate the effectiveness of the proposed numerical algorithm

Keywords: Triangular fuzzy number, Fuzzy Delay Differential Equations, Fuzzy Delay fourth order Runge-Kutta method, Fuzzy Delay fourth order Runge-Kutta method based on Geometric Mean, Fuzzy Delay fourth order Runge-Kutta method based on Root Mean Square.

INTRODUCTION

Fuzzy Delay Differential Equations (FDDEs) arise in many real world problems where the rate of change of variable depends not only on its present value but also on its past state and incorporates fuzziness. The fuzzy set theory was first introduced by Zadeh[1]. Gethsi Sharmila[21] proposed fourth order Runge-Kutta method based on Geometric





Devigayathri and Gethsi Sharmila

mean to solve hybrid fuzzy initial value problems. Jansirani et.al [3] given Intuitionistic fuzzy differential equations using composite Runge-Kutta method using variety of means. Indrakumar et.al [4] given FDDE using Euler's method under generalised differentiability. A.F. Jameel et.al [5] presented paper to find an approximate analytical solution for first order fuzzy delay differential equations. Yookesh et.al [6] applied the variational iteration method which provides approximate solution for time delay differential equations under uncertainty conditions. Hamza et.al [7] presented an approximation technique for solving linear fuzzy delay differential equation. Muthukumar et.al [8] presented paper on solving fuzzy neutral delay differential equation using RK method of order five. Prasantha Bharathi et.al [9,10] presented approximate solution using Runge-Kutta method for fuzzy neutral and fuzzy mixed delay differential equation. Nguyen [11] studied fuzzy delay differential equations under granular differentiability, which provides both theoretical and practical applications. In this work, The Fuzzy Delay fourth order Runge-Kutta method based on Geometric Mean (FDRK4GM) and the Fuzzy Delay fourth order Runge-Kutta method based on Root Mean Square (FDRK4RMS) are developed and using the numerical algorithm, numerical examples are given. The comparison of solutions are done with Fuzzy Delay fourth order Runge-Kutta method (FDRK4).

The structure of the paper is organized as follows: Section 2 gives preliminaries. Section 3 explains the numerical algorithm to solve a fuzzy delay differential equations using the fuzzy delay fourth order Runge-Kutta method based on Geometric Mean and the convergence of the method. Section 4 explains the numerical algorithm to solve a fuzzy delay differential equations using the fourth order Runge-Kutta method based on Root Mean Square and the convergence of the method. In Section 5 numerical examples are given using the proposed algorithms and section 6 gives the conclusion.

Preliminaries

Triangular Fuzzy Number

The triangular fuzzy number is fuzzy interval represented as $A = (a_1, a_2, a_3)$ where a_1 and a_2 are two endpoints and a_2 is a peak point. The α cut interval for a fuzzy number A as A_α , the obtained interval A_α is defined as then

$$\mu_A(x) = \begin{cases} 0, & x < a_1 \\ \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2 \\ \frac{a_3 - x}{a_3 - a_2}, & a_2 \leq x \leq a_3 \\ 0, & x > a_3 \end{cases}$$

The crisp interval is obtained as follows, $\forall \alpha \in [0, 1]$ by α cut operations. Then

$$A_\alpha = [(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3]$$

Fuzzy Delay Differential Equation

A delay differential equation is of the form,

$$\begin{aligned} y'(\mathcal{X}) &= f(\mathcal{X}, y(\mathcal{X}), y(\mathcal{X} - \tau_1), y(\mathcal{X} - \tau_2), \dots, y(\mathcal{X} - \tau_i)), \mathcal{X} \geq \mathcal{X}_0 \\ y(\mathcal{X}) &= \phi(\mathcal{X}), \mathcal{X} \leq \mathcal{X}_0 \end{aligned} \quad (1)$$

where τ_i is a constant for each $i = 1, 2, 3, \dots, n$. In a Delay Differential Equation, a fuzzy parameter could be a coefficient, an initial condition, or both. It is known as a fuzzy delay differential equation (FDDE). The function $y(\mathcal{X})$ is a fuzzy derivative of $y(\mathcal{X})$ at $\mathcal{X} \in [-\tau, T]$ and $\phi(\mathcal{X})$ is a fuzzy number corresponding to the given initial function when $\mathcal{X} < 0$. It is represented in the following form





Devigayathri and Gethsi Sharmila

$$\begin{aligned} \underline{y}'(\kappa) &= f(\kappa, \underline{y}(\kappa), \underline{y}(\kappa - \tau_1), \dots, \underline{y}(\kappa - \tau_i)), \kappa \geq \kappa_0 \\ \underline{y}(\kappa) &= \underline{\phi}(\kappa) \\ \overline{y}'(\kappa) &= f(\kappa, \overline{y}(\kappa), \overline{y}(\kappa - \tau_1), \dots, \overline{y}(\kappa - \tau_i)), \kappa \geq \kappa_0, \\ \overline{y}(\kappa) &= \overline{\phi}(\kappa) \end{aligned} \quad (2)$$

where τ_i is constant for each

The Fuzzy Delay Fuzzy delay fourth order Runge-Kutta method based on Geometric Mean(FDRK4GM)

Considering the fuzzy delay fourth order Runge-Kutta method based on Geometric Mean proposed by Gethsi Sharmila[1] for fuzzy differential equation, and it is further developed for FDEs as follows:

$$k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa) = h_{n+1}$$

$$k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa) = h_{n+1} f((\kappa_n + c_i h_{n+1}, y(\kappa_n) + \sum_{j=1}^r a_{ij} k_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa), y(\kappa_{n+1})) = y(\kappa_n) + i=1r \text{ wi } k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa). \quad (3)$$

where $y_\kappa = y(\kappa_n + c_i h - \tau)$ is a delay term. Let $\delta = \{\kappa_0, \kappa_1, \dots, \kappa_N = X\}$ be the given grid points and Here $h_{n+1} = \kappa_{n+1} - \kappa_n, n = 0, 1, 2, 3, \dots, N$ denote the corresponding stepsizes at which the exact solution $[Y]^r = [\underline{Y}(\kappa; r), \overline{Y}(\kappa; r)]$ is approximated by some $[Y]^r = [\underline{Y}(\kappa; r), \overline{Y}(\kappa; r)]$.

$$\underline{k}_i(\kappa_{n+1}, y(\kappa), y_\kappa; r) = h_{n+1} F\{(\kappa_n + c_i h_{n+1}), y + \sum_{j=1}^r a_{ij} \underline{k}_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa; r\}, \quad y_\kappa \in [y(\kappa_n; r), \overline{y}(\kappa_n; r)],$$

$$y_\kappa \in [\underline{y}(\kappa_n + c_i h - \tau; r), (\kappa_n + c_i h - \tau; r)]$$

$$\begin{aligned} \overline{k}_i(\kappa_{n+1}, y(\kappa), y_\kappa; r) &= h_{n+1} G\{(\kappa_n + c_i h_{n+1}), y \\ &+ \sum_{j=1}^r a_{ij} \overline{k}_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa; r\}, y \in [\overline{y}(\kappa_n; r), \overline{y}(\kappa_n; r)], \\ y_\kappa &\in [\underline{y}(\kappa_n + c_i h - \tau; r), \overline{y}(\kappa_n + c_i h - \tau; r)] \end{aligned}$$

$$\underline{k}_1(\kappa; y(\kappa; r)) = \min \{h f(\kappa, y(\kappa), y_\kappa) \mid y(\kappa) \in [\underline{y}(\kappa; r), \overline{y}(\kappa; r)], y(\kappa - \tau) \in [\underline{y}(\kappa - \tau; r), \overline{y}(\kappa - \tau; r)]\}$$

$$\overline{k}_1(\kappa; y(\kappa; r)) = \max \{h f(\kappa, y(\kappa), y_\kappa) \mid y(\kappa) \in [\underline{y}(\kappa; r), \overline{y}(\kappa; r)], y(\kappa - \tau) \in [\underline{y}(\kappa - \tau; r), \overline{y}(\kappa - \tau; r)]\}$$

$$\underline{k}_2(\kappa; y(\kappa; r)) = \min \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau), y(\kappa) \in [\underline{z}_1(\kappa, \underline{y}(\kappa; r)), \overline{z}_1(\kappa, \overline{y}(\kappa; r))], y(\kappa - \tau) \in [\underline{z}_1(\kappa - \tau) \underline{y}(\kappa - \tau; r)), \overline{z}_1(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\}$$

$$\overline{k}_2(\kappa; y(\kappa; r)) = \max \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_1(\kappa, \underline{y}(\kappa; r)), \overline{z}_1(\kappa, \overline{y}(\kappa; r))], y(\kappa - \tau) \in [\underline{z}_1(\kappa - \tau) \underline{y}(\kappa - \tau; r)), \overline{z}_1(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\}$$

$$\underline{k}_3(\kappa; y(\kappa; r)) = \min \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_2(\kappa, \underline{y}(\kappa; r)), \overline{z}_2(\kappa, \overline{y}(\kappa; r))], y(\kappa - \tau) \in [\underline{z}_2(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_2(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\}$$

$$\overline{k}_3(\kappa; y(\kappa; r)) = \max \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_2(\kappa, \underline{y}(\kappa; r)), \overline{z}_2(\kappa, \overline{y}(\kappa; r))], y(\kappa - \tau) \in [\underline{z}_2(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_2(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\}$$

$$\underline{k}_4(\kappa; y(\kappa; r)) = \min \{h f(\kappa + h, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))], y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\}$$





Devigayathri and Gethsi Sharmila

$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau_1, \underline{y}(\kappa - \tau_1; r)), \overline{z}_3(\kappa - \tau_1, \overline{y}(\kappa - \tau_1; r))]$$

$$\underline{k}_4(\kappa; y(\kappa; r)) = \max \{h f(\kappa + h, y(\kappa), y(\kappa - \tau_1)),$$

$$y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))]$$

$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau, \underline{y}(\kappa - \tau_1; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau_1; r))]$$

where,

$$\underline{z}_1(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{h}{2} \underline{k}_1(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_1(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{h}{2} \overline{k}_1(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_2(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{-1}{16} h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{9}{16} \underline{k}_2(\kappa, \underline{y}(\kappa; r))$$

$$\overline{z}_2(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{-1}{16} h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{9}{16} \overline{k}_2(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_3(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \left(\frac{-1}{8}\right) h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{5}{24} \underline{k}_2(\kappa, \underline{y}(\kappa; r)) + \frac{11}{12} \underline{k}_3(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_3(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \left(\frac{-1}{8}\right) h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{5}{24} \overline{k}_2(\kappa, \overline{y}(\kappa; r)) + \frac{11}{12} \overline{k}_3(\kappa, \overline{y}(\kappa; r)),$$

$$S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{|\underline{k}_1(\kappa; y(\kappa; r)) \underline{k}_2(\kappa; y(\kappa; r))|} + \sqrt{|\underline{k}_2(\kappa; y(\kappa; r)) \underline{k}_3(\kappa; y(\kappa; r))|} \\ + \sqrt{|\underline{k}_3(\kappa; y(\kappa; r)) \underline{k}_4(\kappa; y(\kappa; r))|}$$

$$T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{|\overline{k}_1(\kappa; y(\kappa; r)) \overline{k}_2(\kappa; y(\kappa; r))|} + \sqrt{|\overline{k}_2(\kappa; y(\kappa; r)) \overline{k}_3(\kappa; y(\kappa; r))|} \\ + \sqrt{|\overline{k}_3(\kappa; y(\kappa; r)) \overline{k}_4(\kappa; y(\kappa; r))|}$$

Then the approximate solution is given by

$$\begin{cases} \underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_{n+1}; r) + \underline{y}(\kappa_n - \tau; r) \\ \overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_{n+1}; r) + \overline{y}(\kappa_n - \tau; r) \end{cases} \quad (4)$$

Where,

$$\underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_n; r) + \frac{1}{3} h S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$\overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_n; r) + \frac{1}{3} h T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

The Convergence result for Fourth order Runge-Kutta based on Geometric Mean

The following lemmas will be applied to show convergence of these approximates in Theorem 2.1. and Theorem 3.1

Lemma:3.1

Let the sequence of numbers $\{W_n\}_{n=0}^{\{N\}}$ satisfy

$$|W_{n+1}| \leq (1 + A h) |W_n| + B h^2, \quad n = 0, 1, \dots, N-1$$

for some given positive constants A and B. Then

$$|W_n| \leq e^{\{A t_n\} \left(|W_0| + \frac{B h}{A} \right)}, \quad 0 \leq n \leq N.$$





Devigayathri and Gethsi Sharmila

Lemma:3.2

Let the sequences of numbers $\{W_n\}_{n=0}^{\{N\}}$ and $\{V_n\}_{n=0}^{\{N\}}$ satisfy

$$|W_{n+1} - V_{n+1}| \leq (1 + Ah)|W_n - V_n| + Bh^2, \quad n = 0, 1, \dots, N-1$$

for some given positive constants A and B. Then, denoting

$$En = |W_n - V_n|,$$

we have

$$E_n \leq e^{\{A t_n\}} \left(E_0 + \frac{Bh}{A} \right),$$

Where $B = 2B$.

Let $S(\kappa, \beta, \alpha)$ and $T(\kappa, \beta, \alpha)$ be obtained by substituting $[y(t)]_r = [u, v]$

$$I = \{(\kappa, \beta, \alpha) | 0 \leq \kappa \leq X - \infty < \alpha < \infty, -\infty < \beta \leq \alpha\}.$$

The domain where S and T are defined and is given by

$$I = \{(\kappa, \beta, \alpha) | \kappa_0 \leq \kappa \leq X, -\infty < \beta \leq \gamma\}$$

Theorem: 3.1

Let S and T belong to $C^4(I)$ and let the partial derivatives of S and T be bounded over I. Then for arbitrary fixed $r : r \in [0, 1]$, the numerical approximate of Equation(4) converge uniformly to the exact solutions $\underline{Y}(\kappa; r), \bar{Y}(\kappa; r)$ uniformly in κ .

Proof

$$\underline{Y}(\kappa_{n+1}; r) = \underline{Y}(\kappa_n; r) + \frac{1}{3} S[\kappa_n, y(\kappa_n; r)] + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\bar{Y}(\kappa; r) = \bar{Y}(\kappa_n; r) + \frac{1}{3} T[\kappa_n, \{y\}(\kappa_n; r)] + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

where M, L are positive constants. Then if

$$W_n = \underline{Y}(\kappa_n; r) - \underline{y}(\kappa_n; r)$$

$$V_n = \bar{Y}(\kappa_n; r) - \bar{y}(\kappa_n; r)$$

$$W_{n+1} = W_n + \frac{1}{3} \left\{ S[\kappa_n, \underline{Y}(\kappa_n; r), \bar{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \bar{Y}(\kappa_n - \tau; r)] \right. \\ \left. - S[\kappa_n, \underline{y}(\kappa_n; r), \bar{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \bar{y}(\kappa_n - \tau; r)] \right\} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$V_{n+1} = V_n + \frac{1}{3} \left\{ T[\kappa_n, \underline{Y}(\kappa_n; r), \bar{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \bar{Y}(\kappa_n - \tau; r)] \right. \\ \left. - T[\kappa_n, \underline{y}(\kappa_n; r), \bar{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \bar{y}(\kappa_n - \tau; r)] \right\} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\|W_{n+1}\| \leq \|W_n\| + \frac{2}{3} Ph \max \|W_{n+1}\|_{[\tau, \kappa_n]}, \|W_n\|_{[\tau, \kappa_n]} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\|V_{n+1}\| \leq \|V_n\| + \frac{2}{3} Ph \max \|V_{n+1}\|_{[\tau, \kappa_n]}, \|V_n\|_{[\tau, \kappa_n]} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

for $\kappa \in [0, X]$ and $P > 0$ is a bound for the partial derivatives of S and T. Then

$$\|W_n\| \leq \left(1 + \frac{2}{3} Ph\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{2429}{92160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} Ph\right)^n - 1}{\frac{4}{3} Ph} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} Ph\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{2429}{92160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} Ph\right)^n - 1}{\frac{4}{3} Ph} \right)$$

where $\|\zeta_0\| = \|W_0\| + \|V_0\|$.





Devigayathri and Gethsi Sharmila

In particular

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \mathcal{X}_n]} + \frac{2429}{122880} h^5 M L^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \mathcal{X}_n]} + \frac{2429}{122880} h^5 M L^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

since $W_0 = V_0 = 0$,

$$\|W_n\| \leq \frac{2429}{122880} h^4 M L^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

$$\|V_n\| \leq \frac{2429}{122880} h^4 M L^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

and if

$$h \rightarrow 0 \quad \|W_n\| \rightarrow 0, \|V_n\| \rightarrow 0$$

which completes the proof.

The Fourth Order Runge-Kutta method based on Root Mean Square(FDRK4RMS)

Considering the fuzzy delay fourth order Runge-Kutta method based on Root Mean Square to solve fuzzy delay differential equation,

$$\underline{k}_i(\mathcal{X}_{n+1}, y(\mathcal{X}), y_{\mathcal{X}}; r) = h_{n+1} F \mathcal{X}_n + c_i h_{n+1}, y + \sum_{j=1}^r a_{ij} k_j(\mathcal{X}_{n+1}, y(\mathcal{X}_n), y_{\mathcal{X}}, y_{\mathcal{X}}; r), \quad y_{\mathcal{X}} | y[\underline{y}(\mathcal{X}_n; r), \bar{y}(\mathcal{X}_n; r)],$$

$$y_{\mathcal{X}} \in [\underline{y}(\mathcal{X}_n + c_i h - \tau; r), (\mathcal{X}_n + c_i h - \tau; r)]$$

$$\bar{k}_i(\mathcal{X}_{n+1}, y(\mathcal{X}), y_{\mathcal{X}}; r) = h_{n+1} G[\mathcal{X}_n + c_i h_{n+1}, y + \sum_{j=1}^r a_{ij} k_j(\mathcal{X}_{n+1}, y(\mathcal{X}_n), y_{\mathcal{X}}, y_{\mathcal{X}}; r), y_{\mathcal{X}} | y \in [\bar{y}(\mathcal{X}_n; r), \bar{y}(\mathcal{X}_n; r)],$$

$$y_{\mathcal{X}} \in [\underline{y}(\mathcal{X}_n + c_i h - \tau; r), \bar{y}(\mathcal{X}_n + c_i h - \tau; r)]$$

$$\underline{k}_1(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f(\mathcal{X}, y(\mathcal{X}), y_{\mathcal{X}}) | y(\mathcal{X}) \in [\underline{y}(\mathcal{X}; r), \bar{y}(\mathcal{X}; r)],$$

$$y(\mathcal{X} - \tau) \in [\underline{y}(\mathcal{X} - \tau; r), \bar{y}(\mathcal{X} - \tau; r)]\}$$

$$\bar{k}_1(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f(\mathcal{X}, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{y}(\mathcal{X}; r), \bar{y}(\mathcal{X}; r)],$$

$$y(\mathcal{X} - \tau) \in [\underline{y}(\mathcal{X} - \tau; r), \bar{y}(\mathcal{X} - \tau; r)]\}$$

$$\underline{k}_2(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{z}_1(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_1(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_1(\mathcal{X} - \tau), \underline{y}(\mathcal{X} - \tau; r)], \bar{z}_1(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))\}$$

$$\bar{k}_2(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{z}_1(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_1(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_1(\mathcal{X} - \tau), \underline{y}(\mathcal{X} - \tau; r)], \bar{z}_1(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))\}$$

$$\underline{k}_3(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f\left(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)\right) | y(\mathcal{X}) \in [\underline{z}_2(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_2(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_2(\mathcal{X} - \tau), \underline{y}(\mathcal{X} - \tau; r)], \bar{z}_2(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))\}$$

$$\bar{k}_3(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f\left(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)\right) | y(\mathcal{X}) \in [\underline{z}_2(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_2(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_2(\mathcal{X} - \tau), \underline{y}(\mathcal{X} - \tau; r)], \bar{z}_2(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))\}$$

$$\underline{k}_4(\mathcal{X}; y(\mathcal{X}; r)) = h \{f(\mathcal{X} + h, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{z}_3(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_3(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_3(\mathcal{X} - \tau), \underline{y}(\mathcal{X} - \tau; r)], \bar{z}_3(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))\}$$

$$\bar{k}_4(\mathcal{X}; y(\mathcal{X}; r)) = h \{f(\mathcal{X} + h, y(\mathcal{X}), y(\mathcal{X} - \tau)) |$$





Devigayathri and Gethsi Sharmila

$$y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))],$$

$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau, \underline{y}(\kappa - \tau; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau; r))] \}$$

where,

$$\underline{z}_1(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{h}{2} \underline{k}_1(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_1(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{h}{2} \overline{k}_1(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_2(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{1}{16} h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{7}{16} \underline{k}_2(\kappa, \underline{y}(\kappa; r))$$

$$\overline{z}_2(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{1}{16} h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{7}{16} \overline{k}_2(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_3(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \left(\frac{1}{8}\right) h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{-17}{56} \underline{k}_2(\kappa, \underline{y}(\kappa; r)) + \frac{33}{28} \underline{k}_3(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_3(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \left(\frac{1}{8}\right) h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{-17}{56} \overline{k}_2(\kappa, \overline{y}(\kappa; r)) + \frac{33}{28} \overline{k}_3(\kappa, \overline{y}(\kappa; r))$$

$$S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{\frac{|\underline{k}_1^2(\kappa; \underline{y}(\kappa; r)) \underline{k}_2^2(\kappa; \underline{y}(\kappa; r))|}{2}} + \sqrt{\frac{|\underline{k}_2^2(\kappa; \underline{y}(\kappa; r)) + \underline{k}_3^2(\kappa; \underline{y}(\kappa; r))|}{2}}$$

$$+ \sqrt{\frac{|\underline{k}_3^2(\kappa; \underline{y}(\kappa; r)) \underline{k}_4^2(\kappa; \underline{y}(\kappa; r))|}{2}}$$

$$T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{\frac{|\overline{k}_1^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_2^2(\kappa; \overline{y}(\kappa; r))|}{2}} + \sqrt{\frac{|\overline{k}_2^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_3^2(\kappa; \overline{y}(\kappa; r))|}{2}}$$

$$+ \sqrt{\frac{|\overline{k}_3^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_4^2(\kappa; \overline{y}(\kappa; r))|}{2}}$$

Then the approximate solution is given by

$$\begin{cases} \underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_{n+1}; r) + \underline{y}(\kappa_n - \tau; r) \\ \overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_{n+1}; r) + \overline{y}(\kappa_n - \tau; r) \end{cases} \quad (5)$$

Where

$$\underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_n; r) + \frac{1}{3} h S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$\overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_n; r) + \frac{1}{3} h T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

Convergence for Fourth Order Runge-Kutta based on Root Mean Square(FDRK4RMS)

Let $S(\kappa, \beta, \alpha)$ and $T(\kappa, \beta, \alpha)$ be obtained by substituting $ytr = [u, v]$.

The domain where S and T are defined is therefore

$$I = \{(\kappa, \beta, \alpha) \mid 0 \leq \kappa \leq X, -\infty < \alpha < \infty, -\infty < \beta \leq \alpha\}.$$

The domain where S and T are defined and is given by

$$I = \{(\kappa, \beta, \alpha) \mid \kappa_0 \leq \kappa \leq X, -\infty < \beta \leq \gamma\}$$

Theorem:4.1

Let S and T belong to $C^4(I)$ and let the partial derivatives of S and T be bounded over I . Then for arbitrary fixed $r : r \in [0, 1]$, (the numerical approximate of equation(5) converge uniformly to the exact solutions $\underline{Y}(\kappa; r), \overline{Y}(\kappa; r)$ uniformly in κ





Devigayathri and Gethsi Sharmila

Proof:

$$\underline{Y}(\kappa_{n+1}; r) = \underline{Y}(\kappa_n; r) + \frac{1}{3} S [\kappa_n, \underline{y}(\kappa_n; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\overline{Y}(\kappa; r) = \overline{Y}(\kappa_n; r) + \frac{1}{3} T [\kappa_n, \overline{y}(\kappa_n; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

where M, L are positive constants. Then if

$$W_n = \underline{Y}(\kappa_n; r) - \underline{y}(\kappa_n; r)$$

$$V_n = \overline{Y}(\kappa_n; r) - \overline{y}(\kappa_n; r)$$

$$W_{n+1} = W_n + \frac{1}{3} \left\{ S [\kappa_n, \underline{Y}(\kappa_n; r), \overline{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \overline{Y}(\kappa_n - \tau; r)] \right. \\ \left. - S [\kappa_n, \underline{y}(\kappa_n; r), \overline{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \overline{y}(\kappa_n - \tau; r)] \right\} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$V_{n+1} = V_n + \frac{1}{3} T [\kappa_n, \underline{Y}(\kappa_n; r), \overline{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \overline{Y}(\kappa_n - \tau; r)] - T [\kappa_n, \underline{y}(\kappa_n; r), \overline{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \overline{y}(\kappa_n - \tau; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\|W_{n+1}\| \leq \|W_n\| + \frac{2}{3} P h \max \|W_{n+1}\|_{[\tau, \kappa_n]}, \|W_n\|_{[\tau, \kappa_n]} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\|V_{n+1}\| \leq \|V_n\| + \frac{2}{3} P h \max \|V_{n+1}\|_{[\tau, \kappa_n]}, \|V_n\|_{[\tau, \kappa_n]} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

for $\kappa \in [0, X]$ and $P > 0$ is a bound for the partial derivatives of S and T. Then

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{645120} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^n - 1}{\frac{4}{3} P h} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{645120} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^n - 1}{\frac{4}{3} P h} \right)$$

where $\|\zeta_0\| = \|W_0\| + \|V_0\|$.

In particular

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{860160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{860160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

since $W_0 = V_0 = 0$,

$$\|W_n\| \leq \frac{15363}{860160} h^4 ML^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

$$\|V_n\| \leq \frac{15363}{860160} h^4 ML^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

and if $h \rightarrow 0$ $\|W_n\| \rightarrow 0$, $\|V_n\| \rightarrow 0$

which completes the proof.





Numerical Example

Example:5.1

Consider the FDDE

$$y'(\kappa) = y(\kappa) + y(\kappa - 1), \quad \kappa \geq 0,$$

$$y(\kappa) = \phi(\kappa), -1 \leq \kappa \leq 0$$

The initial value is given by

$$[y_0]^r(\kappa) = [(0.75 + 0.25r), (1.125 - 0.125r)] \quad r \in [0,1]$$

The approximate solutions obtained using the methods FDRK4GM and FDRK4RMS are presented graphically in the figure 5.1 and the numerical solutions obtained by FDRK4GM and FDRK4RMS are compared with FDRK4 in table 5.1. The table and figure show the numerical result for $h=0.1$ and $h=0.01$ respectively. The numerical result of the proposed methods FDRK4GM and FDRK4RMS coincide with numerical result obtained by FDRK4

Example:5.2

Consider the FDDE

$$y'(\kappa) = \lambda y(\kappa - 1) \quad \kappa \geq 0,$$

$$y(\kappa) = \phi(\kappa), \quad -1 \leq \kappa \leq 0$$

The initial value is given by $[y_0]^r(\kappa) = [(0.75 + 0.25r), (1.125 - 0.125r)] \quad r \in [0,1]$

The approximate solution for the values of $\lambda=0.5$ and $r \in [0,1]$. Figure 5.2 illustrates the comparison of numerical solutions obtained using FDRK4GM and FDRK4RMS when $\kappa=2$ and $h=0.01$. Table 5.2 presents the numerical values of solution obtained by FDRK4RMS and FDRK4GM when $\kappa=2$ and $h=0.1$. The numerical result of the proposed methods FDRK4GM and FDRK4RMS coincide with numerical result obtained by FDRK4.

CONCLUSION

In this chapter, the Fourth Order Runge Kutta method based on Geometric Mean and Root Mean Square are proposed to solve FDDE. The numerical algorithm are developed and the Convergence of the methods proposed. From the comparative study of the numerical solutions obtained using FDRK4, FDRK4GM, and FDRK4RMS methods, it is observed that all three schemes successfully approximate the solution of the given problems. The FDRK4GM produces numerical results that are very close to those obtained by the FDRK4, indicating higher accuracy and better stability when compared to the FDRK4 and FDRK4RMS approaches. This closeness suggests that FDRK4GM effectively captures the dynamics of the system with reduced truncation error. Hence FDRK4GM can be an efficient alternative FDRK4 for solving fuzzy delay differential equations.

REFERENCES

1. Zadeh, L. A Fuzzy sets. *Information and control*, 8(3), 338-353. . (1965).
2. R Gethsi Sharmila, "Fuzzy delay fourth order Runge-Kutta method Based On Geometric Mean for Hybrid Fuzzy Initial Value Problems", *IOSR Journal of Mathematics(IOSR-JM)*, Volume 13, Issue 2 Ver. II(Mar-Apr. 2017), PP 43-51
3. Mary Jansirani.M, Jamshida.K, "Composite Runge-Kutta Method Fourth Order based on a variety of Means by using Intuitionistic Fuzzy Differential Equations ", *PalArch's Journal of Archaeology of Egypt/ Egyptology*17(6), ISSN 1567-214x, (2020). <https://archives.palarch.nl/index.php/jae/article/view/2475/2420>
4. S Indrakumar and K Kanagarajan, "Numerical solution of fuzzy delay differential equations under generalized differentiability by Euler's method", *Journal of Advances in Mathematics*,10(7), 2015.





Devigayathri and Gethsi Sharmila

5. Jameel.A.F, Anakira N.R, Alomari.A.K, Al-Mamameed.M, Saaban.A, "A new approximate solution of the fuzzy delay differential equations", Int J.Mathematical Modelling and Numerical optimisation, vol.9, No.3,(2019). DOI:10.1504/IJMMNO.2019.100476
6. Yookesh, T.L., Boobalan, E.D., and Latchoumi, T.P. (2020) Variational Iteration Method to Deal with Time Delay Differential Equations under Uncertainty Conditions. International Conference on Emerging Smart Computing and Informatics (ESCI), pp 252-256, IEEE, 2020/3/12. <https://10.1109/ESCI48226.2020.9167629>
7. Hamza A.R. Al-Abedi, Abdul Khaleq O. AL-Jubory (2023), "Approximated solution for solving the linear Fuzzy Delay Differential Equations", *AIP Conf. Proc.* <https://doi.org/10.1063/5.0176399>
8. Muthukumar.T, Jayakumar.T, Prasantha Bharathi.D, (2021)," Numerical Solution of Fuzzy Delay Differential Equations by Fifth Order Runge-Kutta Method", Journal of University of Shanghai for Science and Technology, Volume 23, Issue 11, ISSN:1007-6735. <https://jusst.org/wp-content/uploads/2021/11>
9. Prasantha Bharathi.D, Jayakumar.T, Vinoth.S,(2019), "Numerical Solution of Fuzzy Mixed Delay Differential Equation using Runge-Kutta Method of Order Four", Journal of Emerging Technologies and Innovative eResearch, Volume 6, Issue 2. https://www.ripublication.com/ijaerspl2019/ijaerv14n3spl_14.pdf
10. Prasantha Bharathi.D, Jayakumar.T, Vinoth.S,(2019), "Numerical Solution of Fuzzy neutral Delay Differential Equation using Runge-Kutta Method of Order Four", International Journal of Applied Engineering Research ISSN:0973-4562 Volume 14. <https://www.researchgate.net/publication/331491663>
11. Nguyen Thi Kim Son, Hoang Viet Long, Nguyen Phuong Dong (2019), "Fuzzy delay differential equations under granular differentiability with applications", Computational and Applied Mathematics. <https://10.1007/s40314-019-0881-x>

Table 1 Comparison between the solutions of example 1 obtained by FDRK4RMS and FDRK4GM with FDRK4 when $x=2$ and $h=0.1$

r	FDRK4GM		FDRK4RMS		FDRK4	
	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$
0.0	11.8379958	17.7569937	11.8359101	17.7538652	11.8369598	17.7554398
0.1	12.23259568	17.5596938	12.2304405	17.5566001	12.2315251	17.5581571
0.2	12.6271955	17.3623938	12.6249708	17.3593349	12.6260905	17.3608744
0.3	13.0217954	17.165093	13.019501	17.1620697	13.0206558	17.1635918
0.4	13.4163952	16.96779402	13.4140315	16.9648045	13.4152211	16.9663091
0.5	13.81099513	16.77049408	13.80856187	16.7675394	13.8097865	16.7690264
0.6	14.20559499	16.57319415	14.20309221	16.5702742	14.2043518	16.5717438
0.7	14.60019485	16.37589422	14.59762255	16.3730090	14.5989171	16.3744611
0.8	14.99479471	16.17859429	14.99215289	16.1757439	14.9934825	16.1771784
0.9	15.38939457	15.98129436	15.3866832	15.9784787	15.3880478	15.9798958
1.0	15.78399443	15.78399443	15.7812135	15.7812135	15.7826131	15.7826131

Table 2 Comparison between the solutions of example 2 obtained by FDRK4RMS and FDRK4GM with FDRK4 when $x=2$ and $h=0.1$

r	FDRK4GM		FDRK4RMS		FDRK4	
	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$
0.0	1.59373416	2.39060124	1.59376583	2.39064875	1.59375000	2.39062499
0.1	1.64685863	2.36403900	1.64689136	2.36408599	1.64687500	2.36406250
0.2	1.69998310	2.33747677	1.70001689	2.33752322	1.69999999	2.33749999
0.3	1.75310757	2.31091453	1.75314242	2.31096046	1.75312500	2.31093750
0.4	1.80623204	2.28435229	1.80626794	2.28439770	1.80624999	2.28437499
0.5	1.85935659	2.25779006	1.85939347	2.25783490	1.85937499	2.25781250





Devigayathri and Gethsi Sharmila

0.6	1.91248099	2.23122782	1.91251900	2.23127217	1.91249999	2.23125000
0.7	1.96560546	2.20466559	1.96564453	.204709408	1.96562499	2.20468749
0.8	2.01872993	2.17810335	2.01877006	2.178146644	2.01875000	2.17812500
0.9	2.07185441	2.15154111	2.07189558	2.151583880	2.07187500	2.15156249
1.0	2.12497888	2.12497888	2.12502111	2.125021116	2.12500000	2.12500000

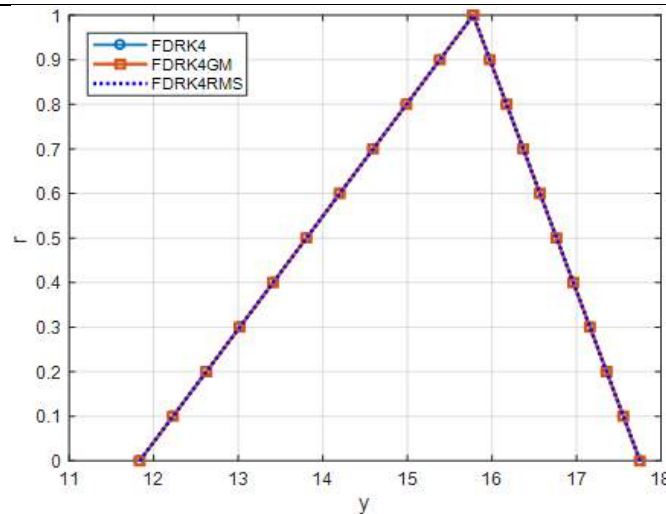


Fig.1 Comparison between the solutions of example 1 obtained by FDRK4RMS and FDRK4GM when $x=2$ and $h=0.01$

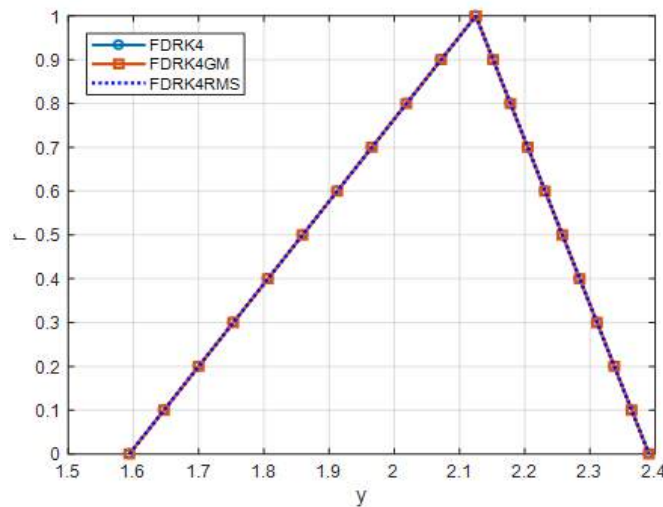


Fig. :2 Comparison between the solutions of example 2 obtained by FDRK4RMS and FDRK4GM when $x=2$ and $h=0.01$

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Controversial Analysis of *Bauhinia Variegata* L.[*Kanchanar*]: A Solution

Vaishnavi Acharya^{1*}, Suwarna Meshram², and Kruti Patel³

¹Second Year PG Scholar, Department of Dravyaguna Vigyana, Parul Institute of Ayurved and Research (Affiliated to Parul University), Vadodara, Gujarat, India

²Professor and HOD, Department of Dravyaguna Vigyana, Parul Institute of Ayurved and Research (Affiliated to Parul University), Vadodara, Gujarat, India

³Assistant Professor, Department of Dravyaguna Vigyana, Parul Institute of Ayurved and Research (Affiliated to Parul University), Vadodara, Gujarat, India

Received: 17 Mar 2026

Revised: 15 Apr 2026

Accepted: 11 May 2026

*Address for Correspondence

Vaishnavi Acharya
Second Year PG Scholar,
Department of Dravyaguna Vigyana,
Parul Institute of Ayurved and Research
(Affiliated to Parul University)
Vadodara, Gujarat, India
E.Mail: drvaishnaviacharya@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This article sets one's sight on the masked controversy of a medicine *Bauhinia variegata* [*Kanchanar*]. In ayurveda literature, disputes and differences are usually in identification, names and synonyms, species variations of certain substances. This medicinal plant is also part of that controversial theory with different names in different traditional texts. This difference might create a trouble in research, academics, medicinal use and identifying the drug. Therefore, the purpose of this study is to conduct and explore the controversy of *Bauhinia variegata* based on classical texts, traditional lexicons, and to clarify its actual form. Present study will help in authentication of *Bauhinia variegata* for identification and uniformity in clinical use as medicine.

Keywords: *Kanchanar*, Kovidara, Controversial Drug, *Bauhinia Variegata*, Medicinal Plants

INTRODUCTION

The identity of medicinal plants in ayurveda has historically been influenced by variations in nomenclature, synonymy and morphological interpretation. Such variations often lead to difference in understanding and using of drug, especially when one plant is described by multiple names in different texts. *Bauhinia variegata* (*Kanchanar*),





Vaishnavi Acharya and Suwarna Meshram *et al.*,

commonly identified Ayurvedic drug uncertainly has confusion about its synonyms and correct identifications. In classical literature, the mentioned names are Kovidara, *Karbudara* or *Kanchanar* but with the same name for a single drug is questionable. In earlier classical medical compendia, the term Kovidara is mainly used, suggesting that it was the commonly accepted name during that early phase of Ayurvedic documentation. In later traditional Lexicons and Materia medica texts, the term *Kanchanar* becomes more prominently accepted and the plant is described in greater detail based on the observational features such as flower colour and structural characterization. The term *Karbudara* is uncommon and in specific contexts, which says it may not be a complete independent species but might be a condition-based choice of the same plant. These descriptive interpretations, the difference in naming and observational features, regional variations or practicing documentation among research scholars lead to inconsistency. This can affect pharmacological standardization, botanical identity and clinical applicability of the substance in modern era.

Additionally, complexity has been raised from the classification of *Bauhinia variegata* into different forms like red, white and yellow and the difference in there flowering patterns according to the observations and described in traditional sources. although present studies have scientifically validated *Bauhinia variegata* action potential with its identification points but the description couldn't be that successful in resolving the controversy of substance. Therefore, the present study aims to critically analyse traditional literature related to *Bauhinia variegata* L. Considering the names *Kanchanar*, *Karbudara*, and Kovidara to bring out the solution.

MATERIALS AND METHODOLOGY

The present work was carried out as a critical analysis of review of literature to solve the controversy of *Bauhinia variegata* as explained in traditional compendia sources. To fulfil this purpose, the information was collected from the range of classical medical texts along with later complications and modern scientific publications. The work was not only to gather the data but also to understand the interpretation for using the drug which is on focus because of its medicinal utility indication. Primarily references were taken from earlier compendia as well as later lexicons and texts, so that both the original as well as evolved developments could be considered together. In addition, the help was taken from commentarial works wherever required to justify the difference in naming and explaining multiple sources. Modern literature, which includes Review articles, related to *Bauhinia variegata* and its allied species, was also addressed to support correlation and botanical understanding. During analysis, emphasis was placed mainly on three aspects mainly related to synonyms of drug in different texts, the description in terms of features and therapeutic uses. Rather than treating these descriptions separately, they were together examined to understand whether they point towards multiple entities or a single plant.

A comparative approach was followed throughout the study. Descriptive tables were prepared and data was placed side by side from different sources to observe overlaps, similarities and differences in view. Special attention was given to features such as flower colour, types, plant form, flowering patterns as these appeared repeatedly in classics seems to play important role in differentiation. Interpretations provided by later scholars and commentators were taken in account, where context dependency occurred. This helped in identifying possible reasons behind variation in naming and classification. The collected data were then examined to see that different variations as mentioned in literature indicates distinct botanical species or simply variations within the same plant group. For botanical validation, available modern literature on *Bauhinia variegata* and related species was reviewed and classical descriptions were compared with contemporary scientific observations. The step taken was to understand the practical botanical basis of traditional classification. Since the study is based entirely on literature, the analysis remained qualitative in nature. No statistical methods were applied, as the study is about interpretation rather than experiment. Overall, the study approach to develop a more logical explanation for identity related confusion associated with *Bauhinia variegata* L. (*Kanchanar*) synonyms and integration of text for trials.



Vaishnavi Acharya and Suwarna Meshram *et al.*,

RESULTS AND DISCUSSION

The observations obtained from classical and modern sources are summarized in Figure 1.1 and Figure 1.2.A Comparison of these sources reveals a clear understanding in a way *Kanchanar* and terms related to this have been described over time. One of the most noticeable findings is the difference in terminology across different periods of ayurvedic literature. Earlier texts consistently use the term *Kovidara*, suggesting that this was the commonly accepted name during the initial phase of documentation. In contrast, later works show a gradual shift toward the use of the term *Kanchanar* with detailed descriptions. This change reflects an evolution in classification practices from function-based identification process to morphology-based classification. A clear distinction is visible when classical textual interpretation is done with pharmacological and botanical study. Modern pharmacognostic studies provide further clarity on this variation. Comparative analysis has interpreted measurable differences between *Kanchanar* and *Kovidara* in terms of microscopic structure, physicochemical and phytochemical parameters. However, despite these differences, their therapeutic properties show considerable overlap, which explains why classical texts often treat them as functional equivalent.

The interpretation of *Karbudara* is significantly different from the above two terms. Some traditional demonstrations associated with specific morphology, particularly the white flowered variety, while the others relate it to clinical condition such as glandular swellings. This dual pattern says that the term may have been used either to denote a phenotypic variant or to emphasize therapeutic conditions. Further insight is gained when seasonal as well as environmental factors are focused. A consistent observation is that entity identified as *Kovidara* is associated with a distinct morphological feature of bilobed leaves with a deep cleft, along with the profuse purplish-pink flowering. The flowering tendency is seen in autumn season, indicating a specific phenological behaviour. In contrast, the entity correlated with *Kanchanar* including the form referred as *Karbudara*, demonstrates a different seasonal expression. This form has a flowering during spring season and is linked with *Bauhinia variegata*. The plant has broader leaves with less pronounced cleaving and show variation in flower colour, including lighter or white forms. This represents a variant expression of *Karbudara* associated with this group with same botanical entity rather than a separate species. When we observed together, a clear pattern emerges in which seasonal variation plays a defining role in differentiation. The spring Flowering form, corresponding to *Kanchanar*, includes multiple phenotypic variants, while the autumn flowering form identified as *Kovidara* shows relatively distinct morphological traits. Such differentiation contributes to assignment of different names. An additional information of cleft pattern in leaf shape, flower colour and flowering season supports modern era studies as species of *Bauhinia* show variations while their close relation explains similar medicinal use. Thus, *Bauhinia variegata* has multiple varieties and the properties are similar due to natural diversity variations and not due to incorrect identification.

CONCLUSION

The Present analysis indicated that there is variation among the terms *Kanchanar*, *Kovidara* and *Karbudara* due to morphology, seasonal expression and textual interpretation rather than true difference in identity. *Kanchanar* and *Kovidara* can be considered closely related and may be interchangeably in most contexts. In contrast, *Karbudara* shows variable usage across sources and is also synonym to different plants. Its use in relation to *Bauhinia variegata* [*Kanchanar*] appears to be context specific, therefore the careful interpretation is must on textual references rather than assumed as fixed botanical identity. *Kovidara* represents the original classical drug, *Kanchanar* denotes its later classified varieties based on morphology and flower colour, *Karbudara* is best understood as a closely related variant or subtype within the same *Bauhinia* group rather than a completely separate entity. This is the solution helps in resolving and support accurate identification, improved standardization, and consistent clinical application of the drug.





REFERENCES

1. Agnivesha. Charaka Samhita, revised by Charaka and Dridhabala, with Ayurveda Deepika commentary by Chakrapanidatta. Varanasi: Chaukhamba Prakashana; 2011.
2. Sushruta. Sushruta Samhita with NibandhaSangraha commentary of Dalhana and Nyaya Chandrika of Gayadasa. Varanasi: Chaukhamba Orientalia.
3. Vagbhata. Ashtanga Hridaya with commentaries of Arunadatta and Hemadri. Paradakara HS, editor. Varanasi: Chaukhamba Orientalia; 2002.
4. Vagbhata. Ashtanga Sangraha. Srikanthamurthy K, translator. Varanasi: Chaukhamba Orientalia; 1999.
5. Bhavamishra. Bhavaprakasha Nighantu. Chuneekar KC, commentator; Pandey GS, editor. Varanasi: Chaukhamba Bharati Academy; 2006.
6. Shodala. Shodala Nighantu. Dwivedi RR, editor. Varanasi: Chowkhambha Sanskrit Series Office; 2009.
7. Madanapala Nrupa. Madanapala Nighantu. Mumbai: Ganga Vishnu Sri Krishnadas; 1867.
8. Kaiyadeva Acharya. Kaiyadeva Nighantu (Pathyapathyavibodhaka). Sharma PV, Sharma GP, editors. Varanasi: Chaukhambha Orientalia; 1979.
9. Narahari Pandit. Raja Nighantu. Tripathi I, editor. Varanasi: Chaukhamba Krishnadas Academy; 2003.
10. Sharma PV. Priya Nighantu with Padma commentary. Varanasi: ChaukhambaSurabharati Prakashan; 1995.
11. Bhogika Mahendra. Dhanvantari Nighantu. Sharma GP, commentator; Sharma PV, editor. Varanasi: Chaukhambha Orientalia; 1998.
12. Radhakanta Deva. Shabdakalpadruma. Vol. 4. Delhi: Naga Publishers; 2006.
13. Hemachandra Suri. Nighantushesha. e-Nighantu Online; 2019. Available from: <http://www.e-nighantu.com>
14. Madhava. Madhava Dravyaguna. e-Nighantu Online; 2019. Available from: <http://www.e-nighantu.com>
15. Ravidatta. Nighantu Ratnakara. Godbole VV, editor. Lucknow: Nawal Kishore Press; 1892.
16. Saraswati Nighantu. e-Nighantu Online. Available from: <http://www.e-nighantu.com>
17. Shaligrama Nighantu. e-Nighantu Online. Available from: <http://www.e-nighantu.com>
18. Shankara Nighantu. e-Nighantu Online. Available from: <http://www.e-nighantu.com>
19. Amarasimha. Amarakosha. Varanasi: Chaukhamba Sanskrit Series Office.
20. Chakrapanidatta. Shabdachandrika. e-Nighantu Online; 2019. Available from: <http://www.e-nighantu.com>
21. Sushruta Nighantu. Sharma K, Suvedi K, Tiwari N, editors. Nepal: Mahendra Sanskrit Vishvavidyalaya.
22. Bapalal Vaidya. Nighantu Adarsha. Vol. 2. Varanasi: Chaukhambha Bharati Academy; 2007.
23. Sharma A, Chandel V, Roy S. Exploring the bioactive properties and diverse uses of Bauhinia variegata: A comprehensive review. Discover Plants. 2025;2:86.
24. Verma R, Dash S, Thakur S, Kumar R, Singh G, Kaur C. Genus Bauhinia (Fabaceae): phytochemistry, traditional uses and pharmacological insights. Phytomedicine. 2024;135:156246.
25. Gudavalli D, Pandey K, Ede VG, Sable D, Ghagare AS, Kate AS. Phytochemistry and pharmacological activities of five species of Bauhinia genus: A review. Fitoterapia. 2024;174:105830.
26. More-Adate P, Lokhande KB, Swamy KV, Nagar S, Baheti A. GC–MS profiling and identification of bioactive compounds of Bauhinia variegata. ComputBiol Med. 2022;147:105679.
27. Mesquita PG, Araujo LM, Neves FAR, Borin MF. Secondary metabolites and biological activities associated with Bauhinia variegata. Front Fungal Biol. 2022;3:1049690.
28. Soundarya RJ, Lalitha BR, Akshaya B, Murthy JS. Database study of Kanchanara (Bauhinia variegata Linn.) with special reference to controversial aspects. Int Ayurveda Publication. 2020;5(5):1567–1585.
29. Kansal M, Shukla P, Shukla P. A boon to human health—Bauhinia variegata. Int J Pharmacogn. 2020;7(7):155–161.
30. Deep P, Mishra A, Verma N. Pharmacognostical evaluation and HPTLC analysis of Bauhinia variegata leaves. Res J Pharm Technol. 2020;13(6):2667–2671.
31. Khare P, Kishore K, Sharma DK. Historical aspects, medicinal uses and pharmacological review of Bauhinia variegata. Asian J Pharm Pharmacol. 2018;4(5):546–562.





32. Nariyal V, Sharma P. Kanchnar (*Bauhinia variegata*) as a medicinal herb: a systematic review. *Int J Adv Res.* 2017;5(9):587–591.
33. Shirkande AA, Shirkande AS. Kovidar—A holistic Ayurvedic approach. *Int J Ayurveda Yoga Unani Siddha Homeopathy.* 2016.
34. Chandra TR, Suresh C, Sanghamitra D, Kumar GR. Kanchnara (*Bauhinia variegata* Linn.): a critical review. *Int J Ayurveda Pharm Res.* 2015;3(7):39–46.
35. Irchhaiya R, Kumar A, Gurjar H, Gupta N, Kumar S, Kumar M. Plant profile, phytochemistry and pharmacology of *Bauhinia variegata* Linn. *Int J Pharmacol.* 2014;1(5):279–287.
36. Rivera JO, Loya AM, Ceballos R. Use of herbal medicines and implications for conventional drug therapy. *Altern Integr Med.* 2013;2(6):1–6.
37. Pani SR, Mishra S, Sahoo S, Panda PK. Nephroprotective effect of *Bauhinia variegata* against cisplatin-induced nephropathy. *Indian J Pharmacol.* 2011;43(2):200–202.
38. Dhale DA. Phytochemical screening and antimicrobial activity of *Bauhinia variegata* Linn. *J Ecobiotechnol.* 2011;3(9):4–7.
39. Rajani GP, Ashok P. In vitro antioxidant and antihyperlipidemic activities of *Bauhinia variegata* Linn. *Indian J Pharmacol.* 2009;41(5):227–229.
40. Mali RG, Dhake AS. *Bauhinia variegata* Linn.: A review on ethnobotany, phytochemistry and pharmacology. *Orient Pharm Exp Med.* 2009;9(3):207–216.
41. Filho VC. Chemical composition and biological potential of plants from the genus *Bauhinia*. *Phytother Res.* 2009;23(10):1347–1354.
42. Garodia P, Ichikawa H, Malani N, Sethi G, Aggarwal BB. From ancient medicine to modern medicine: Ayurvedic concepts in inflammation and cancer. *J Soc Integr Oncol.* 2007;5(1):25–37.
43. Gurib-Fakim A. Medicinal plants: traditions of yesterday and drugs of tomorrow. *Mol Aspects Med.* 2006;27(1):1–93.
44. Patwardhan B, Warude D, Pushpangadan P, Bhatt N. Ayurveda and traditional Chinese medicine: a comparative overview. *Evid Based Complement Alternat Med.* 2005;2(4):465–473.
45. Reddy MV, Reddy MK, Gunasekar D, Caux C, Bodo B. A flavanone from *Bauhinia variegata*. *Phytochemistry.* 2003;64(4):879–882.
46. Rajkapoor B, Jayakar B, Muruges N. Antitumour activity of *Bauhinia variegata* on Dalton's ascitic lymphoma. *J Ethnopharmacol.* 2003;89(1):107–109.
47. Gupta AK, Chauhan JS. Constituents from the stem of *Bauhinia variegata*. *Natl Acad Sci Lett India.* 1984;7(1):15–16.

Table1:Comparative Analysis of Classical and Nighantu References of *Bauhinia variegata* L. [Kanchanar/Kovidara/Karbudara] In Ayurvedic Literature

Classical Text / Sources	Term Used	Description
Charak Samhita	Kovidara / <i>Karbudara</i>	Seasonal difference [autumn / spring] , similar therapeutic use
Sushruta Samhita	Kovidara [<i>Kanchanar</i>], <i>Karbudara</i> [<i>Shelshmantak</i>]	Similar actions ; used in multiple diseases
Ashtang Hridaya	<i>Karbudara</i>	Specific use in glandular swelling
Ashtang Sangrah	Kovidara / <i>Karbudara</i>	Similar uses in different diseases
Chakrapani [commentator]	<i>Kanchanar</i> , kovidara	Different flowering time which supports distinction
Dalhana [commentator]	<i>Karbudara</i>	Considered the variety of <i>Kanchanar</i>
Bhavprakashanighantu	<i>Kanchanar</i> , kovidara	Classified by flower colour
Dhanwantari Nighantu	Kovidara , <i>Kanchanar</i>	White and reddish flowers varieties
Raj Nighantu	<i>Kanchanar</i> , kovidara	Treated as synonyms
Priya nighantu	Kanchanr, kovidara	Same properties hence synonyms



Vaishnavi Acharya and Suvarna Meshram *et al.*,

Madanpala Nighantu	Kovidara <i>Kanchanar</i>	Same therapeutical utility, confirms variants
Kaiyadeva Nighantu	<i>Kanchanar</i> , kovidara	Similar uses and respiratory , blood disorders
Saraswati Nighantu	kovidara	Focus on botanical traits not difference
Shaligram Nighantu	Kovidara , <i>Karbudara</i>	Similar use in bleeding disorders
Shankar Nighantu	<i>Kanchanar</i> , kovidara	Same use in swelling and wounds
Amarkosha	kovidara	Wound healing property
Nighantu Ratnakar	<i>Kanchanar</i>	Describes 3 varieties based on flower colour
Modern ayurvedic view	<i>Kanchanar</i>	Continuity of therapeutic use with pharmacological relevance
Modern botany	Bauhinia species	Confirms species complex rather than single entity

Table 2 –Integrated resolution of the controversy of *Bauhinia variegata* L. [*Kanchanar*/*Kovidara*/*Karbudara*]

Aspect	Observations from texts	Final interpretation
Nomenclature	Early texts used <i>Kovidara</i> & <i>Karbudara</i> ; later texts introduced <i>Kanchanar</i>	<i>Kovidara</i> is the original name ; <i>Kanchanar</i> is later term
Seasonal variation	Charak : <i>Kovidara</i> [autumn] , <i>Karbudara</i> [Spring]	Same plant group seasonal variation in flowering pattern
Morphology	Lexicons describes three varieties on flower colour ;Red , white and yellow	One plant with multiple phenotypes
Therapeutic use	All texts show similar uses [bleeding , swelling , wounds]	Same pharmacological action
<i>Karbudara</i> identity	Sometimes separate, sometimes subtype	Best considered a variant of <i>Kanchanar</i> , context dependence
synonymy	Many lexicons treated <i>Kanchanar</i> and <i>Kovidara</i> as same	Names used interchangeably
Botanical correlation	Multiple bauhinia species used	Drug is a species complex , not single plant

Figure 1. – Pink flowers of *Bauhinia variegata* observed during the autumn season [sharadritu] , representing a commonly identified variant of *Kovidara*/*Kanchanar*Figure 2. – white flowers of *Bauhinia variegata* in bloom during autumn season , showing morphological variation within the speciesFigure 3 – Yellow Flowers of *Bauhinia racemosa* during the spring season, corresponding to descriptions associated with *Kanchanar*.



Figure 4 – Flowering tree of pink *Bauhinia variegata* during the spring season , showing full plant morphology.



Figure 5 –Flowering tree of *Bauhinia variegata* during the spring season , highlighting variation in flower colour.



Figure 6– Flowering tree of *Bauhinia tomentosa* with yellow flower during the Spring Season, demonstrating seasonal flowering pattern.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Design and Development of Biodegradable Tiles for Sustainable Architecture : An Eco-Friendly Building Material Approach

Rene A. Nala^{1*} and Lope U. Codilla, Jr²

¹Program Chair, Department of Architectural Drafting Technology, College of Business and Technology, Surigao del Norte State of Technology, Surigao City, Philippines.

²OJT Coordinator, Department of Architectural Drafting Technology, College of Business and Technology, Surigao del Norte State of Technology, Surigao City, Philippines.

Received: 03 Mar 2026

Revised: 17 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

Rene A. Nala

Program Chair,

Department of Architectural Drafting Technology,

College of Business and Technology,

Surigao del Norte State of Technology,

Surigao City, Philippines.

E.Mail: renenala1969@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Today's construction industry faces a major hurdle: the heavy environmental toll of traditional materials like concrete and ceramic. These products drain natural resources, create massive pollution during manufacturing, and eventually end up as long-term waste. To tackle this, our study explores how biodegradable tiles could serve as a greener, more sustainable alternative for modern architecture. This study Conducted at Surigao del Norte State University (City Campus) between August 2024 and May 2025, we teamed up with 30 Architectural Drafting students and industry experts to put these eco-friendly tiles to the test. We looked closely at their strength, durability, and how well they stood up to water, while also making sure they break down as intended. Our results show that these tiles aren't just environmentally responsible—they're physically tough enough for everyday use and affordable enough for small-scale production. It's a practical step toward a more sustainable way of building.

Keywords: Biodegradability, Sustainability, Tiles, Construction, Materials, Durability, Cost, Environment, Waste, Impact

INTRODUCTION

Tiles are a staple of modern architecture, found in almost every home, office, and school because they are tough and reliable. For decades, we have relied on concrete and ceramic tiles for their strength and long service life. However, these traditional materials come with a heavy environmental price tag. Their production drains natural resources,



**Rene A. Nala and Lope U. Codilla**

fuels industrial pollution, and leaves behind a mountain of waste that never truly goes away. As the world pushes for more sustainable ways to build, the construction industry is searching for materials that don't just work well but also respect the planet. One of the most exciting breakthroughs in this area is the development of biodegradable tiles. Made from renewable, natural materials, these tiles are designed to eventually return to the earth without leaving a trace of harm. Recent innovations—like the seaweed-based tiles introduced in 2024—have already proven that eco-friendly materials can be just as strong and stylish as traditional ones.

Objectives of the Study

This study focuses on several key goals:

- **Developing a Greener Alternative:** We set out to design and build biodegradable tiles using sawdust as our main ingredient, turning a common byproduct into a sustainable building material.
- **Testing the Limits:** We wanted to see how these tiles actually perform, specifically testing their physical strength and how well they stand up to water and moisture.
- **Measuring Environmental Impact:** We aim to clearly show how shifting to biodegradable tiles can reduce the ecological footprint compared to traditional, high-pollution materials.
- **Proving Real-World Use:** It's important to us that these tiles aren't just a lab experiment—we are evaluating if they are truly practical and functional for real architectural and construction projects.
- **Evaluating the Bottom Line:** Finally, we are looking at the costs and production requirements to see if these tiles are an affordable and scalable option for the construction industry.

MATERIALS AND METHODS

This study used a descriptive-developmental research design. This approach allowed us to do two things: first, build the product (the developmental side), and second, carefully observe and record how it performs (the descriptive side).

- **The Developmental Phase:** This was our "hands-on" stage. We focused on the chemistry and craftsmanship of the tiles—experimenting with sawdust ratios and organic binders to create a sturdy, reliable prototype. It wasn't just about making a tile; it was about refining a process that could be repeated and scaled.
- **The Descriptive Phase:** Once the tiles were ready, we shifted our focus to evaluation. We gathered data on their physical strength and water resistance and collected feedback from students and professionals. This gave us a clear, evidence-based picture of how well the tiles met our goals for sustainability and performance.

Project Design

Design Consideration

In the development of biodegradable tiles for sustainable architectural applications, several key design factors were carefully considered to ensure functionality, environmental responsibility, and practical usability:

- **Sustainability** - The tile composition uses biodegradable and low-impact materials, primarily incorporating recycled sawdust.
- **Strength and durability** - The tiles are engineered to endure normal construction stress while maintaining a balance between structural integrity and biodegradability.
- **Water resistance** - The design includes testing for water resistance to assess the tiles' performance in different environmental conditions.
- **Eco-friendly materials** - All components, including the Polytech epoxy binder, are selected to minimize environmental damage and support resource sustainability.
- **Practical application** - The tiles are designed with standard dimensions to ensure easy use, fabrication, and compatibility in typical construction settings.



**Rene A. Nala and Lope U. Codilla****Project Development**

Below are the stages of how the biodegradable tiles are to be developed or constructed following the collection of all required materials:

Stage 1 involves the preparation of all necessary tools and equipment such as molds, mixers, measuring instruments, and safety gear essential for the tile-making process.

Stage 2 focuses on accurate measurement of ingredients—primarily sawdust and Polytech laminating epoxy clear—following the predetermined tile formula to ensure consistency in each batch.

Stage 3 includes the precise mixing of sawdust with the binder until a uniform consistency is achieved, ensuring an even distribution of materials for proper bonding and strength.

Stage 4 is the pouring of the prepared mixture into 4-inch hexagonal molds framed with 1x1-inch wood cuts, followed by smoothing and leveling the surface.

Stage 5 is the drying and curing of the tiles under controlled room temperature to prevent warping or uneven hardening, ensuring maximum strength and durability.

Stage 6 soak involves the removal of the cured tiles from the molds, followed by sanding and cleaning the edges to produce a refined and usable finish.

Stage 7 is the testing phase, where the tiles are subjected to compressive strength tests and water resistance evaluations to determine their structural integrity and environmental suitability.

Stage 8 includes a survey evaluation using printed questionnaires distributed to 30 BSIT Architectural Drafting Technology students to gather feedback on the tiles' practicality, appearance, and potential application.

Stage 9 is the documentation and review of all test results, observations, and survey feedback to finalize the analysis and prepare the biodegradable tiles for presentation and further research validation.

Material Selection and Specifications

The materials selected for the biodegradable tiles will be based on their availability, environmental sustainability, durability, affordability, and overall quality. Sawdust, a recycled and eco-friendly wood by-product, is used as the primary component for the tile body, while Polytech laminating epoxy clear is utilized as a non-toxic binder to enhance strength and water resistance. Wood is also used in creating molds for shaping and forming the tiles.

Other materials that will be used in the project include wood glue for additional bonding support, sandpaper for smoothing tile surfaces, and a gun tacker for securing molds or temporary fixtures during tile formation.

Moisture Control and Preservation Process**Drying the Sawdust**

The first step in ensuring the quality and performance of the biodegradable tiles is properly drying the sawdust before use. Fresh or damp sawdust retains moisture, which can compromise bonding with the binder and increase the risk of mold, decomposition, or warping of the final product. Dry sawdust is also more stable during the curing process and contributes to the overall durability of the tiles. To dry the sawdust effectively, it is spread thinly on clean trays or surfaces in a well-ventilated, shaded area to avoid exposure to direct sunlight or rain. Consistent airflow is crucial for uniform drying. The sawdust is regularly stirred and rotated to ensure even moisture evaporation and prevent clumping or fungal growth. This drying process typically takes several days, depending on humidity and temperature conditions.

Preservation Using Non-Toxic Binding Materials

After drying, the sawdust is mixed with Polytech laminating epoxy clear, a non-toxic, eco-friendly binder that improves strength and water resistance. Unlike conventional adhesives, this sustainable binder helps maintain the integrity of the tiles without harming the environment, ensuring they remain both functional and biodegradable.



**Rene A. Nala and Lope U. Codilla****Operation and Testing Procedure**

This section details the systematic steps undertaken in operating and testing the biodegradable tiles to evaluate their performance in real-world conditions.

Step 1. Compressive Strength Test

Apply increasing pressure to each tile using a weight or manual press to determine the point at which the tile cracks or breaks.

Step 2. Water Resistance Test

Soak a set of tiles in water for 24 hours. After soaking, dry and inspect for swelling, cracking, or weakening. Record all observations.

Step 3. Durability Test (Abrasion) Rub the tile surface with sandpaper to simulate daily wear. Note the amount of surface degradation or material loss.

Step 4. Visual Inspection

Inspect tiles after each test for physical changes such as deformation, color change, or cracks. Photograph and document the condition of each tile.

Step 5. Record Results

Log all findings in a table, noting the performance of each tile under different testing conditions for analysis in the results and discussion section.

Evaluation Procedure

The respondents will evaluate the biodegradable tiles based on their effectiveness and acceptability in terms of strength, durability, environmental impact, and practical application. Evaluation will be conducted through printed survey forms, where each respondent will place a check mark (✓) in the column that corresponds to their rating for each criterion.

The rating scale is as follows:

- Very effective
- Effective
- Fair
- Not effective

RESULTS AND DISCUSSION

This section presents the evaluation results and discussion of the biodegradable tile prototype in terms of functionality, strength, durability, manageability, standard dimension compatibility, and water resistance. Data were gathered through printed evaluation questionnaires distributed to thirty (30) Architectural Drafting students from first- to third-year levels at the College of Technology, Surigao del Norte State University, Main Campus. Results showed that the biodegradable tiles were rated Very Effective in terms of functionality and usability, with an overall weighted mean of 3.57, indicating high performance in strength, durability, handling, compatibility with standard dimensions, and water resistance. In terms of aesthetic and visual appeal, the tiles were also rated Very Effective, with respondents giving favorable ratings for surface appearance, color consistency, and texture, indicating suitability for architectural applications. Evaluation results on environmental value were likewise Very Effective, confirming that the tiles' use of biodegradable and recycled materials and their potential to reduce environmental impact make them a sustainable and eco-friendly building material.

Summary of Findings

The evaluation results revealed that the biodegradable tile prototype was rated Very Effective by the respondents in terms of functionality and usability, with an overall weighted mean of 3.57. The tiles demonstrated satisfactory





Rene A. Nala and Lope U. Codilla

performance in strength, durability, manageability, compatibility with standard tile dimensions, and water resistance. The respondents also rated the tiles Very Effective in terms of aesthetic and visual appeal, indicating that the surface appearance, color consistency, and texture are suitable for architectural applications. Furthermore, the biodegradable tiles were evaluated as Very Effective in terms of environmental value, confirming that the use of biodegradable and recycled materials contributes to reduced environmental impact and supports sustainable construction practices.

CONCLUSION

Based on the findings, it is determined that the Biodegradable Tiles for Sustainable Architecture: Exploring Eco-Friendly Building Materials yielded highly favorable results in terms of Functionality and Usability, Aesthetic and Visual Appeal, and Environmental Value. The model was consistently described as very effective and was well-received by the BSIT - Major in Architectural Drafting Technology students. This confirms that the biodegradable tile prototype is a viable alternative for sustainable construction and is highly accepted by the respondents for its practicality, design, and environmental benefits.

REFERENCES

1. Architizer. (n.d.). *Environmental impact of traditional tiles*. Architizer Journal.
2. Ayeni, D. A., Adeyemi, A. O., & Akinyemi, B. A. (2017). Utilization of sawdust in the production of eco-friendly construction materials. *Journal of Sustainable Construction Materials and Technologies*, 2(1), 23–30.
3. Cemex Ventures. (2023). *Innovative sustainable materials for construction*. <https://www.cemexventures.com>
4. Designing Buildings Wiki. (2021). *Tile materials and their properties*. <https://www.designingbuildings.co.uk>
5. Kumar, R., & Rath, A. (2021). Development of biodegradable composites using sawdust and bio-resins. *International Journal of Green Building Technology*, 5(2), 45–52.
6. Mageswari, M., & Vidivelli, B. (2010). The use of sawdust ash as a partial replacement for cement in concrete. *International Journal of Civil and Structural Engineering*, 1(3), 432–440.
7. McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. North Point Press.
8. Mohammed, B. S., Al-Mufti, R. A., & Nashwan, A. A. (2019). Lightweight bricks made of sawdust as aggregate. *Construction and Building Materials*, 204, 335–343.
9. Olutoge, F. A., Adesanya, D. A., & Quadri, A. A. (2019). The use of sawdust in construction composites. *Journal of Building Materials and Structures*, 6(4), 1–10.
10. Shopee. (n.d.). *Polytech laminating epoxy clear*. Retrieved May 23, 2025, from <https://shopee.ph/product/156299599/14794147171>
11. Shopee. (n.d.). *Sawdust for pet bedding or construction use*. Retrieved May 23, 2025, from <https://shopee.ph/product/726697373/22155429561>
12. Shopee. (n.d.). *Wooden framing strips for crafts or tiles*. Retrieved May 23, 2025, from <https://shopee.ph/product/345331890/19884617818>
13. World Commission on Environment and Development. (1987). *Our common future*.

Table1-Functionality and Usability

	BSIT - ADT Drafting Students of Surigao Del Norte State University					
Area of Concern	n=30				X	VI
	4	3	2	1		
	VE	E	LE	NE		
Strength and resistance to pressure	20	10	0	0	3.67	VE
Durability under simulated daily use	16	14	0	0	3.53	VE




Rene A. Nala and Lope U. Codilla

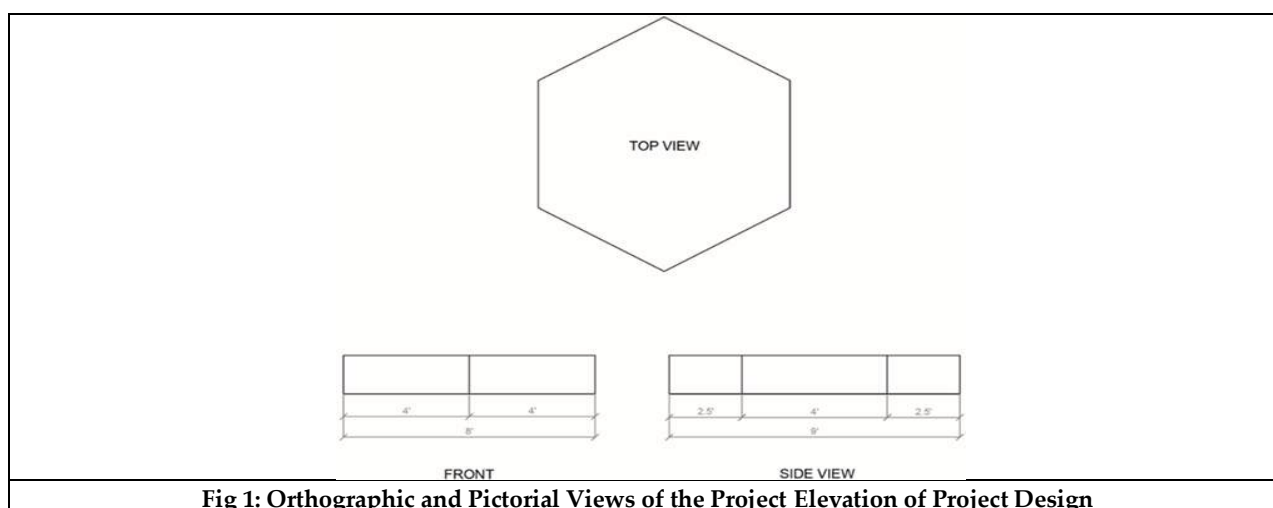
Manageability and ease of handling	17	13	0	0	3.57	VE
Compatibility with standard tile dimensions	19	11	0	0	3.63	VE
Water resistance performance	13	17	0	0	3.43	VE
Average Weighted Mean	3.57					
Interpretation	Very Effective					

Table2– Aesthetic and Visual Appeal

Area of Concern	BSIT-ADT Drafting Students of Surigao Del Norte State University n=30				X	VI
	4 VE	3 E	2 LE	1 NE		
Overall surface appearance	15	15	0	0	3.50	VE
Color consistency and texture	20	10	0	0	3.67	VE
Average Weighted Mean	3.59					
Interpretation	Very Effective					

Table3– Environmental Value

Area of Concern	BSIT-ADT Drafting Students of Surigao Del Norte State University n=30				X	VI
	4 VE	3 E	2 LE	1 NE		
Use of biodegradable and recycled materials	20	10	0	0	3.67	VE
Potential to reduce environmental impact	19	9	0	0	3.43	VE
Average Weighted Mean	3.55					
Interpretation	Very Effective					


Fig 1: Orthographic and Pictorial Views of the Project Elevation of Project Design




Rene A. Nala and Lope U. Codilla



Fig 2: Pictorial View of the Project Design

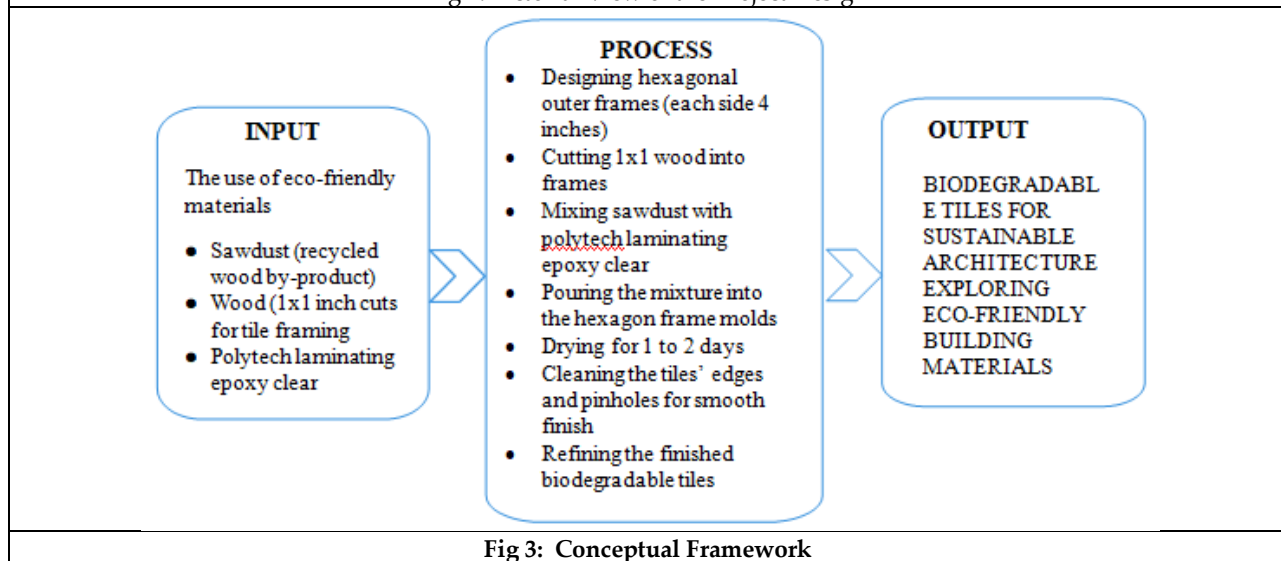


Fig 3: Conceptual Framework

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Study on Theoretical and Experimental Assessment of RC Beams using Both Geopolymer Concrete, Self-Healing Concrete Incorporating Microbial and Mineral Admixtures for Extended Service Life

Shubham Kesarwani^{1*}, Swati Keserwani² and Mohd.Aquib³

¹Resource Person, Department of Civil Engineering, University Institute of Engineering and Technology (Affiliated to Babasaheb Bhimrao Ambedkar University), Lucknow, Uttar Pradesh, India.

²Department of Botany, University of Allahabad, Uttar Pradesh, India

³Assistant Professor, Department of Civil Engineering, Babu Banarasi Das Institute of Technology and Management, Lucknow, Uttar Pradesh, India.

Received: 10 Mar 2026

Revised: 07 Apr 2026

Accepted: 08 May 2026

*Address for Correspondence

Shubham Kesarwani

Resource Person,

Department of Civil Engineering,

University Institute of Engineering and Technology

(Affiliated to Babasaheb Bhimrao Ambedkar University),

Lucknow, Uttar Pradesh, India.

E.Mail: er.shubhamkesarwani@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The progressive cementitious systems have increased with the desire of possessing durable and environmental friendly material of building. The article displays a theoretical and experimental study of reinforced concrete (R.C.) beam produced using geopolymer concrete (GPC) and self-healing concrete(SHC) using microbial and mineral admixtures. Measures of the performance in the aspects of structure, crack behaviour and service-life improvement were compared with the traditional reinforced concrete beams. Flexural loading was experimented and analytical models of beam specimens of full size developed to predict the load capacity and behaviour in serviceability. The experimental results indicate that the flexural strength and stiffness retention and crack closure and mechanical recovery of geopolymer and self- healing concrete beams are significantly improved and improved after a period of time respectively. The synergistic effect of the microbial agents and mineral admixtures is the cumulative effect, which gives strength to the structure and surpasses the obstacles of wear and tear of the structure in the long run and this justifies the use of these materials in construction of sustainable structures.

Keywords: Geopolymer concrete, self-healing concrete, reinforced concrete beam, microbial admixtures, durability, service life



**Shubham Kesarwani et al.,**

INTRODUCTION

The reinforced concrete is used in the infrastructure systems due to its popularity as a structure that is flexible and efficient. However, the formation of cracks during service loads remains unavoidable and may lead to the durability-related failures, such as the reinforcement corrosion and the structural loss [1]. Besides, the production of ordinary Portland cement is also associated with the carbon dioxide emissions, and that is why there are sustainable alternatives that could be pursued. Geopolymer concrete is the new product that is being tested as one of the potential replacement products to the traditional concrete; the industrial by-products, such as fly ash and slag, are activated by the usage of the alkaline solutions. They have stated that previously, geopolymer systems have been enhanced in terms of mechanical performance, reduced permeability, and chemical resistance (Davidovits 2015; Rangan 2014). At the same time, self-healing concrete is also a highly-researched example of an intelligent material that can self-heal cracks and, therefore, extend the life span of the concrete building (Jonkers 2011). The calcium carbonate which is biologically precipitated and subsequently self-healed is the one that seals the cracks in case they are exposed to moisture and oxygen (DeMuynck et al. 2010). These materials are impregnated with mineral admixtures and enhanced in terms of their capability to fill cracks more effectively and dependably (Wang et al. 2014). In spite of such advances, there is insufficient research on the behavior of reinforced concrete beam with the incorporation of geopolymer and self-healing infrastructures structure wise. The present study addresses this gap by performing theoretical and experimental review.

LITERATURE REVIEW

The previous research studies established that geopolymer concrete compressive and tensile strength are similar or even superior to the traditional concrete and more importantly higher service in unfavorable climatic conditions[2]. It has also been reported to boost bond behavior between geopolymer matrices and steel reinforcement since the interfacial transition zone is dense (Fernandez-Jimenez et al. 2007). The capsule-based systems have led to self-healing concrete studies to bio-mediated systems offering repeatable and sustainable systems of healing. Jonkers (2011) demonstrated the decreasing effect of bacteria-based healing on the cracks permeability, and De Muynck et al. (2010) established the significance of the microbial calcite precipitation in the promotion of the durability. Mineral admixtures such as calcium lactate and expansive agent also contribute to filling in the cracks and regaining the mechanical strength (Wang et al. 2014). However, almost all the existing studies are interested in the material level of performance, but not the whole-scale structural elements. The fact that there are no experimental findings on reinforced concrete beam when using geopolymer and self-healing system limits its application. The given study offers a level of the scale assessment to facilitate the future design and realization[3].

MATERIALS AND PROPORTIONS OF MIXES

Geopolymer Concrete

The major source of aluminosilicate used in producing the geopolymer concrete mix was the low-calcium flyash. The sodium hydroxide and sodium silicate solution (alkali activator solution) was used to initiate geopolymerization. The mix design was modified to contain structural-grade strength

self-Healing Concrete

Some types of microbial strain which can survive in alkaline conditions and precipitate calcium carbonate were used in self-healing concrete. To prevent degradation during mix, the bacteria were filled in protective carriers. They suggested that the mineral admixtures increased the crystal growth and long-term recovery efficacy and were subsequently incorporated based on the suggestions of Wang et al. (2014).



**Reinforcement**

High-yield deformed steel bars all beam specimens were made of longitudinal reinforcement and shear resistance was made by mild steel stirrups. Similar comparison assessment was done by following the same reinforcement detailing.

Experimental Program**Specimen Casting and Curing**

Reinforced concrete beams were cast using conventional concrete, geopolymer concrete and self-healing concrete. The cure of geopolymer beams was done at ambient temperature and that of self-healing beams was done at moist environment to induce bacterial healing in beams [5].

Testing Procedure

Flexural testing was conducted by using a four-point bending test set-up. The test involved load deflection, mid-span deflection, crack initiation and crack propagation that were measured in the test. The first cracking and after a rest period, self-healing beams were loaded once more to establish the regeneration of stiffness and strength.

Theoretical Analysis

The models have been developed to predict flexural capacity and serviceability behavior in an analytical manner. Adjusted stress-strain relations were embraced on geopolymer concrete basing on previous experimental outcomes (Hardjito and Rangan 2005). Self-healing concrete Self-healing had been proposed to reduce the cracks and stiffness recovery to serviceability to limit state computations, consistent with the performance models of durability [6].

RESULTS AND DISCUSSION**Structural Performance**

Geopolymer concrete beams in terms of ultimate load capacity and deflections were superior to conventional items that confirmed the improved stiffness and load resistance (Davidovits 2015). Self-healing concrete beams showed the same level of strength in the early stages, and a measurable increase in strength with the healing.

Crack Healing Behavior

Self-healing concrete beams showed large crack widths reduction after the healing period. The presence of a calcium carbonate deposit at the interfaces of the cracks was confirmed by the microscopic analysis in accordance with bio-mediated healing in the research by DeMuynek et al. (2010).

Durability Implications

The reduction in the thickness of the crack and permeability of the self-healing concrete beams suggests that it is more susceptible to the intrusion of attacks, thus increases the life service. The geopolymer concrete beams were also proved to be stronger against cracks and were not stable chemically hence they were used in hostile conditions (Fernandez-Jimenez et al. 2007).

Long Analysis and Technical Reporting.**Comparative Performance Beam Specimen Analysis.**

The comparison was done in a way that would quantify the differences in flexural behavior, crack behavior and loss of stiffness of conventional reinforced concrete (CRC), geopolymer concrete (GPC) and self-healing concrete (SHC) beam. The test was directed towards first-crack load, maximum load capacity, mid-span deflection and post-cracking behavior [7]. The geopolymer concrete beams were better in first-crack load and ultimate load compared to the traditional ones; tensile resistance and matrix stiffness was high in the traditional ones. Self-healed concrete beams





Shubham Kesarwani et al.,

had medium strength improvement where the decrease of crack width after the healing process was significant. The deflection of the loads on the beams provides an insight of the stiffness change, ductile, and energy absorbing abilities. GPC beams were also more elastic since the initial slope of load-deflection curve was steeper. SHC beam had exhibited the recovery of stiffness in reloading after healing period..

Crack Pattern and Efficiency of Healing.

Crack progress was traced visually and by the aid of crack-width gauges. Old beams contained bigger spread cracks as compared to geopolymer beams that contained small cracks with wide distance owing to improved integrity of the matrix [8]. The partial to near complete close-up of a crack after being exposed to moisture had been credited to biologically precipitation of calcium carbonate and development of mineral crystals in self-healing beams..

Analytical Flexural Capacity Test.

The flexural capacity of reinforced concrete beam was tested using the equilibrium and compatibility. In geopolymer and self-healing stiffness in reloading after healing period.. with wide distance owing to improved integrity of the matrix [8]. The partial to near complete close-up of a crack after being exposed to moisture had been credited to biologically precipitation of calcium carbonate and development of mineral crystals in self-healing beams.. concrete beam, modified material properties were adopted to suggest better tensile as well as post-cracking properties. It was established that the nominal moment capacity was:

$$M_n = (d - a) A_s f_y$$

where:

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

For geopolymer concrete, compressive strength term f'_c was replaced by an equivalent geopolymer concrete compressive strength f'_{gc} , determined experimentally. For self-healing concrete beams, an effective tensile contribution was considered through a crack-healing efficiency factor η , incorporated into serviceability calculations.

Serviceability Limit State and Crack

Width Modeling Crack width the estimated using a modified crack-width expression

$$w = \frac{\beta(1-\eta)}{E_s} \sigma_s$$

where the healing efficacy factor η takes into consideration microbial and mineral based sealing of a crack. The experimental findings attested to the fact that SHC beams reduced crack-width by up to 70 percent following the healing process [9].

Performance Indicators of Durability.

The indirect assessment of the durability performance was carried out in the axis of reduction of the width of the crack, restoration of the stiffness and the analysis of the visual inspection of the healed regions. Fewer crack widths imply a lower permeability and greater ingress/carbonation resistance of chloride.

Discussion of the Service Life Enhancement.

Complementary processes are used in the synergistic process of extending service and life of geopolymer binders and self-healing. Geopolymer concrete is less susceptible to crack propagation and initiation since it possesses a larger matrix strength, whereas, self-healing concrete can eradicate the damage of cracks because of autonomous healing. Structurally, the inclusion of healing efficiency in services based on serviceability enables the forecasting of the performance and maintenance requirements in the long-term manner more realistic [10].





Shubham Kesarwani *et al.*,

Nomenclature and Notation

This paper uses the following symbols and abbreviations. Listing of symbols according to ASCE manuscript preparation rules is in alphabetical order.

Notes on Usage

All stresses are expressed in megapascal (MPa) forces (in kilonewtons kN) moments (in kilonewton-meters kN m) and dimensions (in millimeters mm), otherwise. Values of the material properties that are used in the formulations of analysis are the values of every concrete system that are determined experimentally [11].

Appendix: Data Supplies and Analysis

Derivations. Derivation of flexural capacity of geopolymer beam of concrete is provided as below. To describe the geopolymer behavior, the flexural strength of the reinforced geopolymer concrete beam was determined using classical reinforced concrete theory with modified material property. A plane after bending plane section was assumed and perfect bonding between the concrete and reinforcement was assumed.

The force equilibrium requires at the last limit state:

$$C = T$$

where

C = compressive force in concrete

T = tensile force in steel reinforcement

The tensile force is expressed as:

$$T = A_s f_y$$

The compressive force for geopolymer concrete is defined using an equivalent rectangular stress block:

$$C = 0.85 f_{gc} b a$$

Equating compression and tension forces:

$$A_s f_y = 0.85 f_{gc} b a$$

Solving the depth of the stress block:

$$a = \frac{A_s f_y}{0.85 f_{gc} b}$$

The nominal flexural moment capacity is then obtained as:

$$M = A_s f_{sy} \left(d - \frac{a}{2} \right)$$

This formulation was found to be good in comparison to the experimental findings, which confirmed that the conventional design assumptions apply to geopolymer concrete beam using the right material property adjustments.

Analytical comment on Stiffness

Recovery of self-healing concrete beam. The stiffness recovery of the self-healing concrete beams was measured by the comparison between the effective flexural stiffness of the beams prior to the cracking, the post-cracking and the healing time. It is expressed that the effective flexural stiffness is

$$(EI)_{eff} = \frac{M}{\kappa}$$

where

M = applied bending moment

κ = curvature at mid-span





Shubham Kesarwani *et al.*,

A healing of efficiency parameter η_h was introduced to account for crack closure and matrix regeneration:

$$(EI)_{healed} = (1 - \eta_h)(EI)_{cracked} + \eta_h(EI)_{uncracked}$$

Experimental the observation indicated that values of η_h ranged between 0.55 and 0.75 depending on crack width and healing duration, confirming substantial stiffness recovery in self healing concrete beams

Supplementary Data of Load-Deflection.-

-This is supplementary data of load deflection Other load-deflection measurements realized during reloading of self-healing concrete beams are provided in Table A1. These data indicate The increase in stiffness following period. Healing The reduction deflection at corresponding load levels confirms the effectiveness of microbial and mineral-based healing mechanisms.

Crack Width Measurement and Healing Ratio

The crack-healing ratio was calculated to quantify the extent of crack closure:

$$HR = \frac{w_i - w_h}{w_i}$$

where

HR= healing ratio

w_i =initial crack width

w_h =crack width after healing

Concrete beams which were self-healing Showed higher healing rates over cracks less than 0.4 mm with a ratio of above 0.70 hence healing cracks efficiently in moist curing conditions

Characterization Data

Supplementary Material Characterization Data Analytical models were performed on standard cube and cylinder tests to get values of compressive strength and elastic modulus. The average material properties are summed up in Theoretical modeling and serviceability calculations were done using these values constantly.

Notes on Applicability

The analysis formulation in this appendix will be directed to structural-scale analysis of reinforced concrete beam using geopolymers and self-healing systems. The simplified assumptions were applied in practice implementation but due to the high levels of similarity in the experimental and analytical results, they can be applied in pre initial design and performance based evaluation[12].

CONCLUSIONS

The paper was a theoretical and experimental analysis of reinforced concrete beam constructed using geopolymers concrete and self-healing concrete using microbial and mineral additives with a perspective of assessing their structural performance and service-life enhancement potential. Basing on the received results, it is possible to make the following conclusion:

Flexural behavior of reinforced geopolymer concrete beam was established to be superior to reinforced concrete beam since the former exhibited high first-crack loads, ultimate load capacity and superior stiffness properties. These have been attributed to the high density geopolymer structure and enhanced transfer systems of stress.





Shubham Kesarwani et al.,

The self-healing concrete beams showed effective decrease of the cracks basing on the biologically influenced precipitation of calcium carbonate as well as on the mechanisms of healing basing on minerals. The post healing period showed significant positive changes in the width of the crack and led to the measurable recovery of stiffness and serviceability performance.

The experiments were observed to correlate well with the analytical forecasts of flexural capacity and serviceability conduct when the property of the material and the efficiency of factoring of the healing was given and this confirms the applicability of the traditional reinforced concrete theory to the advanced concrete systems with appropriate adjustments.

A parameter of efficiency on the healing of cracks provided a convenient means of gauging the stiffness recovery and shrinkage of crack-width in self-healing concrete beam serviceability, and permitted a more realistic performance analysis in serviceability.

Pointers of durability such as reduced crack widths, enhanced retention of stiffness, and reduced permeability threat denote that both geopolymer and self-healing concrete delivery systems can provide substantial service path to reinforced concrete components particularly in violent conditions.

Geopolymer concrete, in regards to sustainability, has a potential of being a low-carbon substitute of Portland cement concrete, and self-healing concrete will considerably reduce the maintenance and repair needs which would lead to enhanced life-cycle performance of reinforced concrete buildings. Overall, the findings confirm that the integration of geopolymer binders and selfhealing technologies is a good solution to the development of the sustainable, resilient ,and durable reinforced concrete infrastructure. It is recommended that this research should be furthered to enable the performance of these systems in the field over a long period and the manner through which these systems can be expanded to the large scale structural systems.

REFERENCES

1. K. Sahani, S. Khadka, and S. Sahani, "Influence of Corrosion on Lifespan of Reinforced Concrete Structures: A Comprehensive Review," *Kathmandu Univ. J. Sci. Eng. Technol.*, vol. 18, Jun. 2024, doi: 10.3126/kuset.v18i1.67503.
2. M. Amran et al., "Long-term durability properties of geopolymer concrete :An in-depth review," *Case Stud. Constr. Mater.*, vol. 15, p. e00661, Dec. 2021, doi: 10.1016/j.cscm.2021.e00661.
3. H. Unis Ahmed et al., "Geopolymer concrete as a cleaner construction material: An overview on materials and structural performances," *Clean. Mater.*, vol. 5, p. 100111, Sep. 2022, doi: 10.1016/j.clema.2022.100111.
4. A. Hanani Ismail, A. Kusbiantoro, Y. Tajunnisa, J. Jaya Ekaputri, and I. Laory, "A review of alumino silicate sources from inorganic waste for geopolymer production: Sustainable approach for hydrocarbon waste disposal," *Clean. Mater.*, vol. 13, p. 100259, Sep. 2024, doi:10.1016/j.clema.2024.100259.
5. S. Sowmya and R. M. R. Pannem, "Integrating bacteria and fibres for self-healing concrete: a comprehensive review of synergistic effects," *Results Eng.*, vol. 28, p. 107071, Dec. 2025, doi: 10.1016/j.rineng.2025.107071.
6. O. Kocaer and A. Aldemir, "Compressive stress-strain model for the estimation of the flexural capacity of reinforced geopolymer concrete members," *Struct. Concr.*, vol. 24, pp. 5102–5121, Dec. 2022, doi: 10.1002/suco.202200914.
7. N. Shakir and A. Dawood, "Flexural Behavior of Geopolymer RC Concrete Beams Containing Pet Waste as Sand Replacement," *Civ. Environ. Eng.*, vol. 28, Mar. 2025, doi: 10.2478/cee-2025-0015.
8. "(PDF) Crack detection and vertical deflection monitoring in concrete beams using plastic optical fibre sensors," *Research Gate*, Nov. 2025, Accessed: Jan. 21, 2026. [Online]. Available: https://www.researchgate.net/publication/230970444_Crack_detection_and_vertical_deflection_monitoring_in_concrete_beams_using_plastic_optical_fibre_sensors





Shubham Kesarwani et al.,

9. C.Qian,H.Chen,L.Ren,andM.Luo, "Self-healing of early age cracks in cementbased materials by mineralization of carbonic anhydramicroorganism,"Front.Microbiol., vol. 6, p. 1225, Nov. 2015, doi: 10.3389/fmicb.2015.01225.
10. V. S. Sujitha, S. Raja, M.A. Rusho, and S.Yishak,"Advance sand development sin high strength geopolymer concrete for sustainable construction – A review," Case Stud. Constr. Mater., vol. 22, p. e04669, Jul. 2025, doi: 10.1016/j.cscm.2025.e04669.
11. T.Rochman,E.Arifi, E.N.Cahya, and . Darmawan, " Innovative flexural performance of polymer pipes considering PE ropes radial reinforcement under patch loads: a sustainable approach," J. Umm Al-Qura Univ. Eng. Archit., vol. 16, no. 3, pp. 891–909, Sep. 2025,doi:10.1007/s43995-025-00204-2.
12. "Experimental and numerical analysis on shear capacity of steel-reinforced geopolymer concrete beams with different shear span ratios | Request PDF," Research Gate, doi: 10.1108/IJSI-02-2024-0028.

Table 1.SummaryExperimental Results for R.C. Beam Specimens

Beam Type	First-Crack Load (kN)	Ultimate Load (kN)	Mid-Span Deflection at Ultimate Load (mm)	Crack Width after Healing (mm)
CRC	18.5	52.0	14.8	0.42
GPC	22.3	61.5	12.1	0.31
SHC	20.1	55.8	13.5	0.12

Table 2. Durability in Performance Indicators

Parameter	CRC	GPC	SHC
Average Crack Width (mm)	High	Moderate	Low
Stiffness Recovery	None	Limited	Significant
Permeability Risk	High	Low	VeryLow

Table 3. Response of Self-Healing Concrete Beams Reloading

Load Level (kN)	Deflection before Healing (mm)	Deflectionafter Healing (mm)
15	3.6	2.4
30	8.9	6.1
45	13.7	9.8



Shubham Kesarwani *et al.*,

Table 4. Average Material Properties

Material Type	Compressive Strength (MPa)	Elastic Modulus (GPa)
Conventional Concrete	38.5	29.0
Geopolymer Concrete	44.8	31.5
Self-Healing Concrete	41.2	30.2

Table 5. List of Symbols

Symbol	Description
A_s	Area of tensile reinforcement (mm ²)
a	Depth of equivalent rectangular stress block (mm)
b	Width of beam section (mm)
d	Effective depth of beam (mm)
d_c	Concrete cover to reinforcement (mm)
E_s	Modulus of elasticity of steel (MPa)
f_y	Yield strength of steel reinforcement (MPa)
f'_c	Compressive strength of conventional concrete (MPa)
f_{gc}	Compressive strength of geopolymer concrete (MPa)
M_n	Nominal flexural moment capacity (kN-m)
w	Crack width (mm)
β	Bond and strain distribution factor
η_h	Crack-healing efficiency factor





Table 6. Roman Symbols

Symbol	Description	Units
A_s	Area of tensile steel reinforcement	mm ²
a	Depth of equivalent rectangular stress block	mm
b	Width of beam cross-section	mm
d	Effective depth of reinforced concrete beam	mm
d_c	Clear concrete cover to tensile reinforcement	mm
E_c	Modulus of elasticity of concrete	MPa
E_g	Modulus of elasticity of	MPa
	Geo polymer concrete	
E_s	Modulus of elasticity of steel reinforcement	MPa
f'_c	Compressive strength of conventional concrete	MPa
f_{gc}	Compressive strength of geopolymer concrete	MPa
f_t	Tensile strength of concrete	MPa
f_y	Yield strength of steel reinforcement	MPa
L	Effective span length of beam	mm
M	Applied bending moment	kN-m
M_n	Nominal flexural moment capacity	kN-m
P	Applied load	kN
w	Crack width	mm





Table 7. Greek Symbols

Symbol	Description	Units
β	Bond and strain distribution coefficient	—
ϵ_s	Steel strain	—
ϵ_c	Concrete compressive strain	—
η_h	Crack-healing efficiency factor	—
ϕ	Strength reduction factor	—

Table 8. Subscripts

Subscript	Meaning
c	Concrete
g	Geopolymer concrete
s	Steel reinforcement
u	Ultimate condition
y	Yield condition

Table 9. Abbreviations

Abbreviation	Description
CRC	Conventional reinforced concrete
GPC	Geopolymer concrete
SHC	Self-healing concrete
RC	Reinforced concrete
JMCE	Journal of Materials in Civil Engineering
OPC	Ordinary Portland cement
LVDT	Linear variable differential transformer





Shubham Kesarwani et al.,

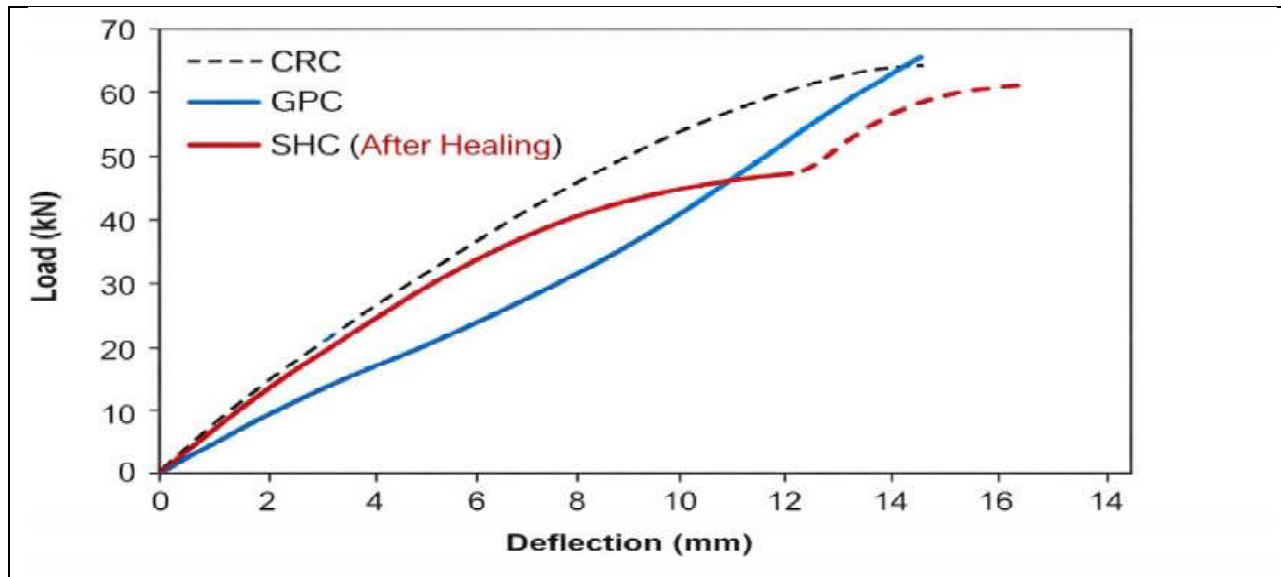


Figure 1. Load deflection characteristics of CRC, GPC and SHC beams in a four point Bending setup

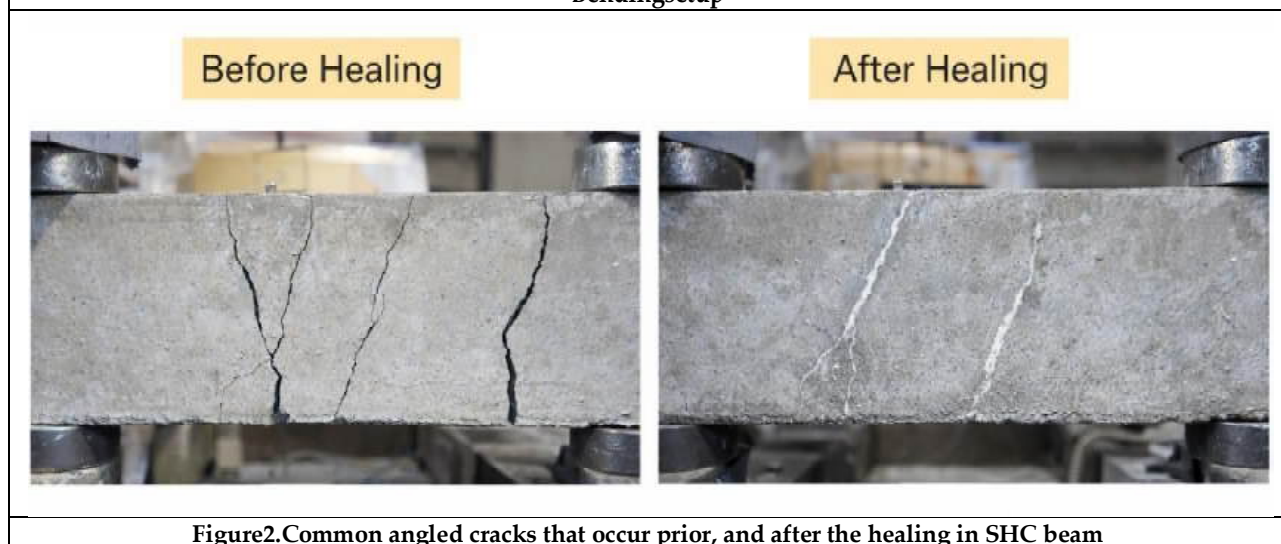


Figure 2. Common angled cracks that occur prior, and after the healing in SHC beam

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Molecular Docking - Based Bio-Screening Assay for the Evaluation of ACE Inhibitory Potential of Phytocomponents from Polyherbal Formulation Vaasathi Kashayam – A Comparative Study with Captopril

K.Preyadarsheni^{1*} and A. Manoharan²

¹Final Year PG Scholar, Department of Pothu Maruthuvam, Government Siddha Medical College, Palayamkottai, Tirunelveli, (Affiliated to The Tamil Nadu Dr MGR Medical University, Chennai) Tamil Nadu, India

²HOD, Department of Pothu Maruthuvam, Government Siddha Medical College, Palayamkottai, Tirunelveli, (Affiliated to The Tamil Nadu Dr MGR Medical University, Chennai) Tamil Nadu, India

Received: 28 Feb 2026

Revised: 22 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

K.Preyadarsheni

Final Year PG Scholar,

Department of Pothu Maruthuvam,

Government Siddha Medical College, Palayamkottai, Tirunelveli,

(Affiliated to The Tamil Nadu Dr MGR Medical University, Chennai)

Tamil Nadu, India

E.Mail: preyadarshenikrishnan@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Hypertension affects an estimated 1.4 billion adults globally (33% of population aged 30–79 years), with significant burden in low- and middle-income countries. VaasathiKashayam (VK), a Siddha herbal decoction comprising Justiciaadhatoda leaves and Vitisvinifera dried fruits, demonstrates promising anti-hypertensive potential through angiotensin-converting enzyme (ACE) inhibition pathways. To investigate the binding affinity and interaction patterns of bioactive phytochemicals from VK against the crystalline structure of human ACE (PDB ID: 1O86) through computational molecular docking analysis. Methods: Seven phytochemicals (vasicoline, adhatodine, anisotine, astragalin, kaempferol, vitexin, and rutin) retrieved from ingredients of VK were subjected to molecular docking studies using AutoDock 4. Target protein preparation involved retrieval of ACE structure from Protein Data Bank, followed by protein clean-up and hydrogen atom addition. Ligands underwent geometry optimization via MMFF94 method. Docking simulations employed Lamarckian Genetic Algorithm with 250,000 energy evaluations, population size of 150, and grid dimensions of 60×60×60 Å. Binding energy, inhibition constant (K_i), and interaction with key active site residues (GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, TYR523) were analyzed. Rutin exhibited superior binding affinity (–11.07 kcal/mol) with inhibition constant of 7.72 nM, forming **9 interactions** with active site residues comparable to captopril standard (**9 interactions**, –5.04 kcal/mol, K_i = 201.28 μM). Vitexin (–8.05 kcal/mol,

115541



**Preyadarsheni and Manoharan**

Ki = 1.25 μ M, 8 interactions), astragalin (–8.00 kcal/mol, Ki = 1.38 μ M, 11 interactions), and adhatodine (–7.80 kcal/mol, Ki = 1.92 μ M, 6 interactions) demonstrated strong binding characteristics. Vasicoline showed moderate affinity (–4.96 kcal/mol, Ki = 232.12 μ M, 3 interactions). All tested compounds, except vasicoline, exhibited binding energies exceeding or comparable to captopril, with multiple active site interactions critical for ACE inhibition. Phytochemicals from VaasathiKashayam, particularly rutin, vitexin, astragalin, and adhatodine, demonstrate significant ACE inhibitory potential through robust binding to catalytic site residues. These findings provide molecular evidence and position VK as a promising therapeutic candidate warranting clinical investigation for hypertension management.

Keywords: VaasathiKashayam, Molecular docking, Angiotensin-converting enzyme inhibition, Siddha medicine, Hypertension management

INTRODUCTION

Hypertension constitutes a major global public health concern with substantial epidemiological significance; affecting approximately 1.4 billion adults aged 30–79 years worldwide. With a disproportionate burden in low- and middle-income countries and suboptimal rates of awareness, treatment, and control, hypertension is the leading contributor to premature mortality and cardiovascular morbidity. The global status of hypertension underscores the urgent need for effective, accessible, and safe interventions, thereby drawing attention toward traditional systems of medicine such as Siddha, which possess a long history of clinical application and holistic therapeutic principles. In Siddha medicine, hypertension is described under various entities including UraththaPitham, Vaathapitham, and Raththakothippu Noi, reflecting derangements primarily of Vaatham and Pitham. From a contemporary biomedical perspective, hypertension is driven by mechanisms such as excessive sodium intake, pressure natriuresis, vascular remodeling, endothelial dysfunction, and activation of the renin–angiotensin–aldosterone system, leading to increased vascular stiffness, reduced nitric oxide bioavailability, and sodium retention.[2]

These pathological alterations closely correspond with Siddha concepts of Bootham imbalance, where reduction in vascular lumen and compliance indicates diminished Aagaya (Ether) and Mann (Earth) boothams, resulting in Vaatham aggravation and subsequent Pitham vitiation. Clinically, hypertension remains largely asymptomatic until severe stages, wherein manifestations such as headache, chest pain, dizziness, dyspnea, visual disturbances, epistaxis, and arrhythmias emerge, predominantly attributable to Vaatham and Pitham imbalance.[3] VaasathiKashayam is indicated for hypertension based on Suvai (taste) principles and elemental (Bootham) science, supporting its role in restoring humoral balance and regulating circulatory dynamics. In this context, molecular docking has emerged as a vital computational approach in contemporary drug discovery, enabling prediction of ligand–receptor interactions, virtual screening, and efficient identification of potential antihypertensive leads with reduced time and resource expenditure.[4] Importantly, within traditional systems of medicine, the integration of computational methods provides a scientifically assuring pathway to validate classical formulations, elucidate mechanisms of action, and strengthen the foundation for further pharmacological and clinical investigations of Siddha drugs.

VaasathiKashayam: Formulation and Pharmacological Evidence

VaasathiKashayam is a classical Siddha polyherbal decoction documented in Agathiyar 2000[5] and traditionally indicated for RathathaPitham (hypertension). The formulation consists of equal proportions of Justiciaadhatoda L. (Acanthaceae) leaves and Vitisvinifera L. (Vitaceae) dried fruits.[6] The drug is prepared by soaking the purified ingredients in water overnight, followed by grinding equal quantities and boiling with water to obtain a reduced decoction, characteristic of Kashayam preparations with a short shelf life. Phytochemical characterization through HR-LCMS analysis, reported in a separate study, identified approximately twenty metabolites in aqueous–



**Preyadarsheni and Manoharan**

acetonitrile extracts, including bioactive compounds such as peganine (vasicine), jatrophone, kuwanon Z, and isoacteoside. Database-based pharmacological evaluation attributes these metabolites with antihypertensive, vasorelaxant, ACE inhibitory, antioxidant, sedative, and adrenergic modulatory activities, supporting the traditional indication of the formulation.[7] Preclinical evaluation from another study using DOCA-salt-induced hypertensive Wistar albino rats demonstrated significant reductions in systolic and diastolic blood pressure at both low and high doses of VaasathiKashayam, comparable to standard antihypertensive drugs. Additional findings revealed notable diuretic and antioxidant activities, with acute and subacute toxicity studies confirming the safety profile of the formulation.[8]

MATERIALS AND METHODS

The primary objective of the study is to evaluate the binding efficacy of selected phytochemicals toward key catalytic amino acid residues of angiotensin-converting enzyme (ACE), namely GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, and TYR523, which are critical for enzymatic conversion of angiotensin I to the potent vasoconstrictor angiotensin II. Inhibition of these residues suppresses ACE activity and thereby reduces blood pressure, highlighting ACE as a validated therapeutic target in hypertension management.

Target Protein Selection and Preparation

The crystalline structure of human ACE (PDB ID: 1O86) was retrieved from the Protein Data Bank. Protein preparation involved removal of water molecules, heteroatoms, and co-crystallized ligands, followed by addition of missing hydrogen atoms using AutoDock Tools to ensure structural readiness for docking analysis. The selected structure provides high-resolution atomic details suitable for accurate interaction studies.[9-14]

Ligand Selection and Preparation

Seven phytochemicals reported in VaasathiKashayam were selected based on literature evidence. From *Justicia adhatoda*, vasicoline, adhatodine, anisotine, astragalin, kaempferol, and vitexin were chosen, while rutin was selected from *Vitis vinifera*. Three-dimensional ligand structures were generated using ChemDraw Professional 12.0 and optimized with MMFF94 force field. Captopril was employed as the standard ACE inhibitor. All ligands were converted to PDBQT format for docking.[15-20] Figure 1 Shows the 2D and 3D images of the phytocompounds along with captopril.

Molecular Docking Methodology

Molecular docking was performed using AutoDock 4 with AutoGrid. Grid maps of 60×60×60 Å and 0.375 Å spacing were generated around the active site. Docking employed the Lamarckian Genetic Algorithm with two independent runs, 250,000 energy evaluations, and a population size of 150.

Data Analysis

Docking outcomes were analyzed based on binding free energy (ΔG), inhibition constant (K_i), intermolecular and electrostatic energies, and hydrogen bond interactions, with results compared against captopril to assess relative binding affinity.

RESULTS**Molecular Properties and Docking Parameters**

Table 1 presents comprehensive ligand properties and docking results for all tested compounds against human ACE (PDB ID: 1O86). Molecular characteristics including molar weight, molecular formula, hydrogen bond donors/acceptors, and rotatable bonds were analyzed alongside binding parameters.



**Preyadarsheni and Manoharan****Binding Energy and Inhibition Constants**

Rutin demonstrated superior binding affinity with binding free energy of -11.07 kcal/mol and remarkably low inhibition constant of 7.72 nM, indicating high-affinity interaction with ACE. (Table 2) This substantially exceeded captopril standard performance (-5.04 kcal/mol, $K_i = 201.28$ μ M), suggesting approximately 26,000-fold stronger binding affinity. Vitexin (-8.05 kcal/mol, $K_i = 1.25$ μ M), astragalin (-8.00 kcal/mol, $K_i = 1.38$ μ M), and adhatodine (-7.80 kcal/mol, $K_i = 1.92$ μ M) exhibited strong binding characteristics with submicromolar inhibition constants, demonstrating 160-fold to 1,450-fold enhanced binding compared to captopril. Anisotine (-7.07 kcal/mol, $K_i = 6.59$ μ M) and kaempferol (-5.34 kcal/mol, $K_i = 120.91$ μ M) demonstrated moderate binding affinities, with kaempferol approaching captopril binding strength. Vasicoline exhibited the weakest interaction (-4.96 kcal/mol, $K_i = 232.12$ μ M), marginally weaker than captopril, suggesting limited ACE inhibitory potential as an isolated compound. Electrostatic and intermolecular energies correlated with binding affinity trends. Rutin demonstrated highest intermolecular energy (-9.30 kcal/mol) and electrostatic contribution (-0.74 kcal/mol), reflecting extensive hydrogen bonding network and favorable electrostatic interactions with active site residues.

Active Site Interaction Analysis

Table 3 presents amino acid residue interaction profiles for lead phytochemicals and captopril standard. Critical active site residues mediating ACE catalytic function include GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, and TYR523. Rutin formed 9 interactions with active site residues, matching captopril interaction count despite vastly superior binding energy. Detailed amino acid residue interaction profile is tabulated in Table 4. Astragalin demonstrated maximum interactions (11 residues), reflecting its extensive hydrogen bonding capacity (7 donors, 11 acceptors). Vitexin and kaempferol each formed 8 interactions, while adhatodine and anisotine established 6 and 8 interactions respectively. Vasicoline exhibited minimal interaction (3 residues), correlating with its weakest binding affinity. Among the tested compounds, adhatodine, anisotine, astragalin, kaempferol, vitexin, and rutin revealed 6–11 interactions with core active amino acid residues, comparable to or exceeding captopril's 9 interactions. Summary and detailed docking pose for separate compounds and standard drug is illustrated in Figure 2, 2a-h. These extensive interaction networks indicate strong binding complementarity between phytochemical structures and ACE active site architecture, essential for effective enzyme inhibition.

DISCUSSION

The present molecular docking investigation provides compelling computational evidence supporting VaasathiKashayam's anti-hypertensive efficacy through ACE inhibition mechanisms. These findings align with and extend previous research demonstrating ACE inhibitory potential of Adhatodavasica metabolites. Comparative analysis with established literature reveals consistent patterns. A previous ultra-performance liquid chromatography (UPLC) coupled with diode array detector (DAD) study evaluated ACE inhibitory activity of *A. vasica* methanolic-aqueous extract and isolated pyroquinazoline alkaloids (vasicinol, vasicine, vasicinone). The IC_{50} values reported were: vasicinol (6.45 mM), vasicine (2.60 mM), and vasicinone (13.49 mM).^[21] Molecular docking studies demonstrated that vasicinol binds as effectively as captopril standard. These findings corroborate our results indicating multiple alkaloid components contribute to ACE inhibition, though our study expanded the phytochemical scope to include flavonoids and polyphenols. This current study of molecular docking reveals that phytochemicals from VK, specifically *anisotine*, *astragalin*, *kaempferol*, *vitexin*, and *rutin* demonstrate ACE inhibitory activity comparable to or exceeding captopril interaction levels.

The mechanism of action for VK in hypertension control likely operates primarily through ACE inhibition pathways, validated by computational and preclinical evidence. While cough and teratogenicity represent major adverse drug reactions (ADRs) of ACE inhibitors, *J. adhatoda*—the primary constituent of VK—possesses established anti-tussive properties (Barth et al., 2015)^[22] and anti-cancerous activities (Kumar et al., 2022)^[23]. This pharmacological profile suggests VK may circumvent common ACE inhibitor complications while maintaining therapeutic efficacy.



**Preyadarsheni and Manoharan**

According to Harrison's Principles of Internal Medicine (21st Edition), ACE inhibitors provide reduction of cardiovascular and renal adverse outcomes, attenuation of left ventricular hypertrophy development, symptom improvement in congestive heart failure, and mortality risk reduction in CHF patients.^[2] These pleiotropic effects position ACE inhibitors, and potentially VK, as valuable therapeutic options for complex hypertensive presentations with comorbidities. The multi-component nature of VK likely contributes synergistic effects beyond individual phytochemical activities. Polyphenolic compounds (rutin, vitexin, astragaloside) demonstrate antioxidant properties reducing oxidative stress—a key pathophysiological mechanism in hypertension and cardiovascular disease. Alkaloid constituents (adhatodine, anisotone) provide direct ACE inhibition alongside potential vasorelaxant effects through multiple signaling pathways. This may explain VK's robust anti-hypertensive performance in preclinical studies (blood pressure reduction from $173.33 \pm 2.33/145.54 \pm 1.23$ mmHg to $106.02 \pm 3.46/72.05 \pm 0.53$ mmHg at 400 mg/kg dose).^[7] Structure-activity relationship analysis reveals key molecular features contributing to superior binding affinity.

Rutin's complex glycoside structure (molecular weight 610.5 g/mol) with extensive hydrogen bonding capacity (10 donors, 16 acceptors) enables formation of multiple stabilizing interactions with ACE active site residues. The flavonoid core provides aromatic stacking interactions, while sugar moieties facilitate hydrogen bonding with polar residues. Similarly, vitexin and astragaloside leverage their glycoside structures for enhanced binding compared to aglycone kaempferol. Computational validation through multiple metrics (binding energy, inhibition constant, interaction count, electrostatic energy) strengthens confidence in predicted binding modes. The inverse correlation between binding energy and inhibition constant, alongside positive correlation with interaction count, demonstrates internal consistency of docking results. Comparison with experimentally validated captopril binding provides benchmarking against a clinically proven ACE inhibitor. Study limitations include absence of molecular dynamics simulations to assess binding stability over time, lack of experimental validation of predicted binding modes through X-ray crystallography or NMR spectroscopy, and inability to account for metabolic transformations potentially affecting bioavailability and active site access. Future investigations should incorporate pharmacokinetic studies, bioavailability assessments, and clinical trials to translate computational predictions into therapeutic applications.

CONCLUSION

This computational molecular docking analysis conclusively demonstrates that bioactive phytochemicals from VaasathiKashayam exhibit significant ACE inhibitory potential. Rutin demonstrated superior binding affinity (-11.07 kcal/mol, $K_i = 7.72$ nM) substantially exceeding captopril standard, while vitexin, astragaloside, and adhatodine showed strong submicromolar inhibition constants. The multi-component formulation on simulation provides synergistic ACE inhibition, corroborating preclinical evidence of anti-hypertensive efficacy (blood pressure reduction to $106.02 \pm 3.46/72.05 \pm 0.53$ mmHg at 400 mg/kg). These molecular insights position VK as a promising therapeutic candidate for hypertension management warranting rigorous clinical investigation.

ACKNOWLEDGEMENT

I would like to thank Nobel Research Solutions NRS/AS/1235/10/2023 for providing AutoDock Version 4 and for technical support. Artificial intelligence-based tools were used to assist with grammatical editing of the manuscript. These tools were used only for supportive functions and the authors take full responsibility for the accuracy, originality, and integrity of the work, performed all content selection, interpretation, critical analysis, and final writing decisions.

Conflict Of Interest: None

Funding: NIL





REFERENCES

1. World Health Organization. Hypertension [Internet]. Geneva: World Health Organization; 2023 [cited 2024 Dec 3]. Available from: <https://www.who.int/news-room/fact-sheets/detail/hypertension>
2. Jameson JL, Fauci AS, Kasper DL, Hauser SL, Longo DL, Loscalzo J, editors. Harrison's principles of internal medicine. 21st ed. New York: McGraw-Hill Education; 2022. Ch 277 - Hypertension p. 2072-74
3. Preyadarsheni K, Manoharan A. Exploring Siddha herbal formulation 'VaasathiKashyam' – a comprehensive review of its mitigating properties in management of hypertension. [Journal name]. 2024 Aug 18; revised 2024 Sep 8; accepted 2024 Sep 28.
4. Meng, X. Y., Zhang, H. X., Mezei, M., & Cui, M. (2011). Molecular docking: a powerful approach for structure-based drug discovery. Current computer-aided drug design, 7(2), 146–157. <https://doi.org/10.2174/157340911795677602>
5. Dr.S.Venkatrajan.L.I.M, Agathiyar 2000, 2014, pg no. 218
6. Preyadarsheni K, Komalavalli T. Standardization of Siddha herbal formulation – VaasathiKashayam according to PLIM guidelines. *Int J Ayu Pharm Res* [Internet]. 2024 Nov 20 [cited 2026 Feb 4];12(10):26–40. Available from: <https://ijapr.in/index.php/ijapr/article/view/3404>. doi:10.47070/ijapr.v12i10.3404
7. Preyadarsheni K and Komalavalli T: HR LC-MS for the management of systemic hypertension (RaththaKothippu NOI). *Int J Pharm Sci& Res* 2025; 16(3): 741-51. doi: 10.13040/IJPSR.0975-8232.16(3).741-51.
8. Preyadarsheni K, Komalavalli T, M.Santhanakumar. VaasathiKashayam.A Siddha Herbal Formulation Alleviates Hypertension in DOCA Salt Induced Hypertensive Rats, Evaluation of Acute, Sub Acute Toxicity, Anti-Oxidant and Diuretic Activity.AYUSHDHARA, 2025;12(3):91-102.<https://doi.org/10.47070/ayushdhara.v12i3.2082>
9. Bikadi, Z., Hazai, E. *Application of the PM6 semi-empirical method to modeling proteins enhances docking accuracy of AutoDock*. J. Cheminf. 1, 15 (2009).
10. T. A. Halgren. *Merck molecular force field. I. Basis, form, scope, parametrization, and performance of MMFF94*. Journal of Computational Chemistry 17 (5-6), 490-519 (1998).
11. G. M. Morris, D. S. Goodsell, et al. *Automated docking using a Lamarckian genetic algorithm and an empirical binding free energy function*. Journal of Computational Chemistry 19 (14), 1639-1662(1998).
12. F. J. Solis and R. J. B. Wets. *Minimization by Random Search Techniques*. Vol. 6, No. 1 (Feb., 1981, pp. 19-30
13. SivaramanDhanasekaran, Pradeep PushparajSelvadoss, Solomon SundarManoharan. Anti-Fungal Potential of Structurally Diverse FDA-Approved Therapeutics Targeting Secreted Aspartyl Proteinase (SAP) of *Candida albicans*: an *In Silico* Drug Repurposing Approach.Applied Biochemistry and Biotechnology.195(3):1983-1998. doi: 10.1007/s12010-022-04207-w
14. SivaramanDhanasekaran, Pradeep PushparajSelvadoss, Solomon SundarManoharan, SrikanthJeyabalan, Devi RajeswariVijayarangan. Revealing Anti-Fungal Potential of Plant-Derived Bioactive Therapeutics in Targeting Secreted Aspartyl Proteinase (SAP) of *Candida albicans*: A Molecular Dynamics Approach. Journal of Biomolecular Structure and Dynamics 2023. 6,1-15. <https://doi.org/10.1080/07391102.2023.2196703>
15. Ben Khadher T, Aydi S, Mars M, Bouajila J. Study on the Chemical Composition and the Biological Activities of *Vitisvinifera* Stem Extracts. *Molecules*. 2022 May 12;27(10):3109. doi: 10.3390/molecules27103109. PMID: 35630586; PMCID: PMC9144250.
16. Ghosh R, Chakraborty A, Biswas A, Chowdhuri S. Identification of alkaloids from *Justiciaadhatoda* as potent SARS CoV-2 main protease inhibitors: An *in silico* perspective. *J MolStruct*. 2021 Apr 5;1229:129489. doi: 10.1016/j.molstruc.2020.129489. Epub 2020 Oct 19. PMID: 33100380; PMCID: PMC7571971.
17. Sharafan M, Malinowska MA, Ekiert H, Kwaśniak B, Sikora E, Szopa A. *Vitisvinifera* (Vine Grape) as a Valuable Cosmetic Raw Material. *Pharmaceutics*. 2023 Apr 29;15(5):1372. doi: 10.3390/pharmaceutics15051372. PMID: 37242614; PMCID: PMC10222843.
18. Musa M, Jan G, Jan FG, Hamayun M, Irfan M, Rauf A, Alsahammari A, Alharbi M, Suleria HAR, Ali N. Pharmacological activities and gas chromatography-mass spectrometry analysis for the identification of





Preyadarsheni and Manoharan

- bioactive compounds from *Justiciaadhatoda* L. Front Pharmacol. 2022 Sep 12;13:922388. doi: 10.3389/fphar.2022.922388. PMID: 36172192; PMCID: PMC9511829.
19. Carneiro MRB, Sallum LO, Martins JLR, Peixoto JC, Napolitano HB, Rosseto LP. Overview of the *Justicia* Genus: Insights into Its Chemical Diversity and Biological Potential. Molecules. 2023 Jan 25;28(3):1190. doi: 10.3390/molecules28031190. PMID: 36770856; PMCID: PMC9920429.
 20. Gitea MA, Bungau SG, Gitea D, Pasca BM, Purza AL, Radu AF. Evaluation of the Phytochemistry-Therapeutic Activity Relationship for Grape Seeds Oil. Life (Basel). 2023 Jan 8;13(1):178. doi: 10.3390/life13010178. PMID: 36676127; PMCID: PMC9864701.
 21. Tehreem S, Rahman S, Bhatti MS, Uddin R, Khan MN, Tauseef S, El-Seedi HR, Bin Muhsinah A, Uddin J, Musharraf SG. A UPLC-DAD-Based Bio-Screening Assay for the Evaluation of the Angiotensin Converting Enzyme Inhibitory Potential of Plant Extracts and Compounds Pyrroquinazoline Alkaloids from *Adhatodavasica* as a Case Study. Molecules. 2021 Nov 18;26(22):6971. doi: 10.3390/molecules26226971. PMID: 34834066; PMCID: PMC8617709.
 22. Barth, A., Hovhannisyan, A., Jamalyan, K., & Narimanyan, M. (2015). Antitussive effect of a fixed combination of *Justiciaadhatoda*, *Echinacea purpurea* and *Eleutherococcus senticosus* extracts in patients with acute upper respiratory tract infection: A comparative, randomized, double-blind, placebo-controlled study. Phytomedicine: international journal of phytotherapy and phytopharmacology, 22(13), 1195–1200. <https://doi.org/10.1016/j.phymed.2015.10.001>
 23. Kumar, S., Singh, R., Dutta, D., Chandel, S., Bhattacharya, A., Ravichandiran, V., & Sukla, S. (2022). In Vitro Anticancer Activity of Methanolic Extract of *Justiciaadhatoda* Leaves with Special Emphasis on Human Breast Cancer Cell Line. Molecules (Basel, Switzerland), 27(23), 8222. <https://doi.org/10.3390/molecules27238222>

Table 1: Ligand Properties and Molecular Docking Results against Human ACE (PDB ID: 1O86)

Compound	Molar weight g/mol	Molecular Formula	H Bond Donor	H Bond Acceptor	Rotatable bonds
Vasicoline	188.23 g/mol	C ₁₁ H ₁₂ N ₂ O	1	2	0
Adhatodine	337.416 g/mol	C ₂₀ H ₂₁ N ₃ O ₂	1	2	4
Anisotine	349.4 g/mol	C ₂₀ H ₁₉ N ₃ O ₃	1	5	4
Astragalin	448.4 g/mol	C ₂₁ H ₂₀ O ₁₁	7	11	4
Kaempferol	286.24 g/mol	C ₁₅ H ₁₀ O ₆	4	6	1
Vitexin	432.4 g/mol	C ₂₁ H ₂₀ O ₁₀	7	10	3
Rutin	610.5 g/mol	C ₂₇ H ₃₀ O ₁₆	10	16	6
Captopril	217.29 g/mol	C ₉ H ₁₅ NO ₃ S	2	4	3

Table 2: Summary of the molecular docking studies of compounds against Angiotensin converting enzyme (1O86)

Compounds	Binding Free energy kcal/mol	Inhibition constant Ki μ M (*mM)(**nM)	Electrostatic energy kcal/mol	Intermolecular energy kcal/mol	Total Interaction Surface
Vasicoline	-4.96 kcal/mol	232.12 μ M	-0.24 kcal/mol	-5.26 kcal/mol	541.277
Adhatodine	-7.80 kcal/mol	1.92 μ M	-1.40 kcal/mol	-8.35 kcal/mol	775.22
Anisotine	-7.07 kcal/mol	6.59 μ M	-0.14 kcal/mol	-7.59 kcal/mol	801.072
Astragalin	-8.00 kcal/mol	1.38 μ M	-0.20 kcal/mol	-7.44 kcal/mol	945.152
Kaempferol	-5.34 kcal/mol	120.91 μ M	-0.12 kcal/mol	-5.72 kcal/mol	703.423
Vitexin	-8.05 kcal/mol	1.25 μ M	-0.07 kcal/mol	-6.91 kcal/mol	872.929
Rutin	-11.07 kcal/mol	7.72 μ M	-0.74 kcal/mol	-9.30 kcal/mol	1092.345
Captopril	-5.04 kcal/mol	201.28 μ M	-0.40 kcal/mol	-5.10 kcal/mol	504.786





Preyadarsheni and Manoharan

Table 3: Amino Acid Residue Interactions of Lead Phytochemicals with Human ACE (PDB ID: 1O86)

Compound	Number of Interactions with Active Site Residues
Vasicoline	3
Adhatodine	6
Anisotine	8
Astragalin	11
Kaempferol	8
Vitexin	8
Rutin	9
Captopril (Standard)	9

Active site residues analyzed include GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, TYR523 - Refer Table 4

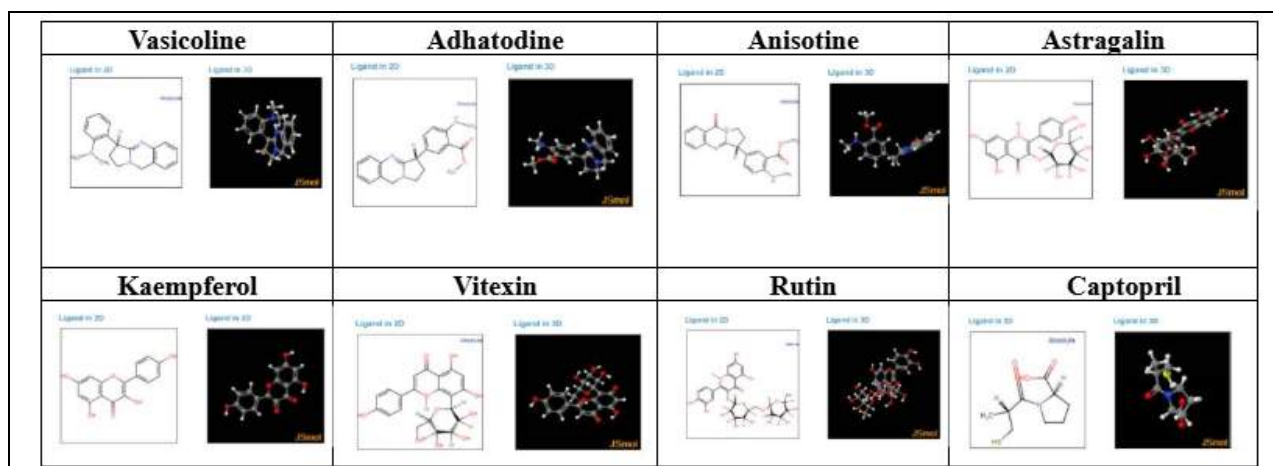
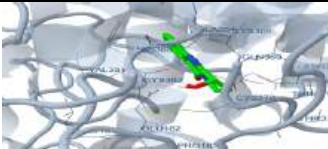
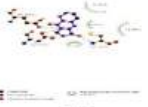


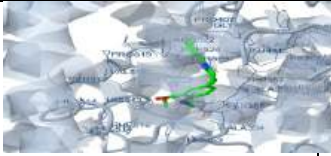
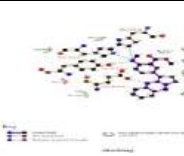
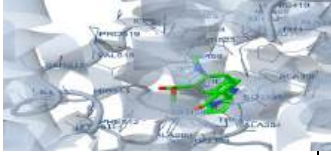
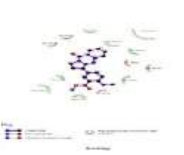
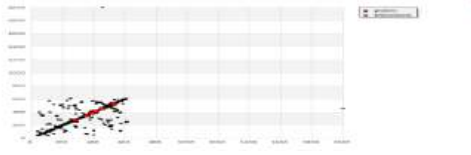
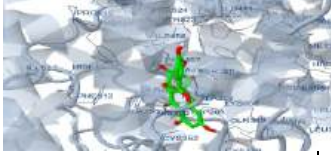
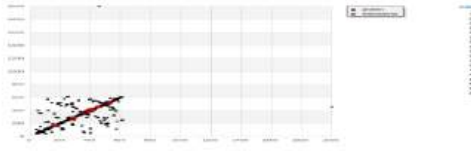
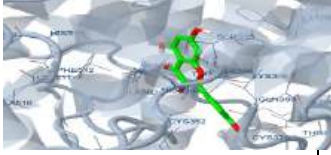
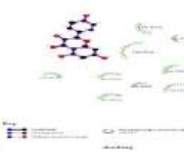
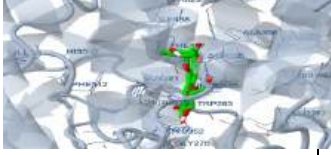
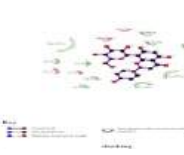
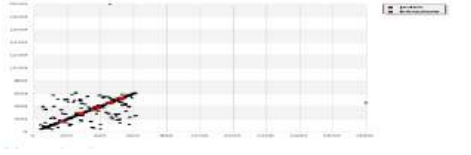
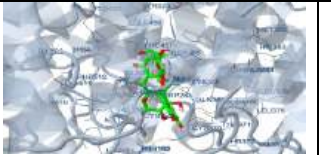
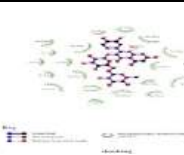
Figure 1. 2D and 3D Structure of Selected Ligands of phtochemicals and standard drug Captopril (Known ACE inhibitor) 2D and 3D Structure of Selected Ligands: The below given figure 1 hows the 2D and 3D structure of selected 7 ligands of phytochemicals and Captopril.

Phytocomponent with ACE	Docking pose	2D plot	Hydrogen bond plotting with core aminoacid analysis
Vasicoline with Human angiotensin converting enzyme (1O86)			





Preyadarsheni and Manoharan

Adhatodine with Human angiotensin converting enzyme (1086)			
Anisotine with Human angiotensin converting enzyme (1086)			
Astragalin with Human angiotensin converting enzyme (1086)			
Kaempferol with Human angiotensin converting enzyme (1086)			
Vitexin with Human angiotensin converting enzyme (1086)			
Rutin with Human angiotensin converting enzyme (1086)			





Preyadarsheni and Manoharan

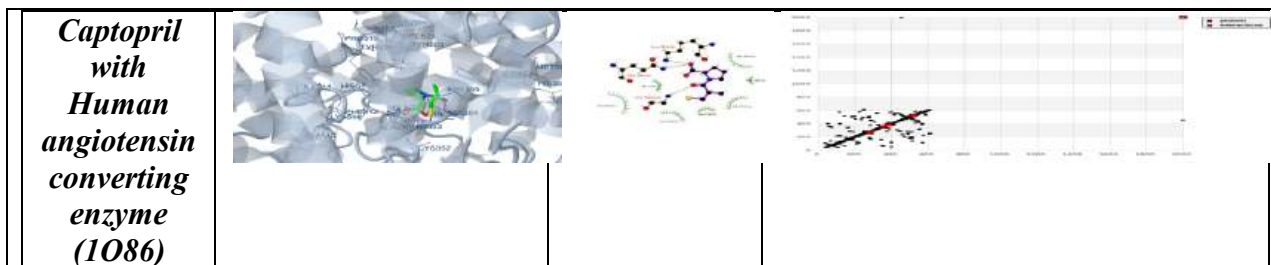


Figure 2 Summary of Docking pose of all the selected phytochemicals and Captopril.

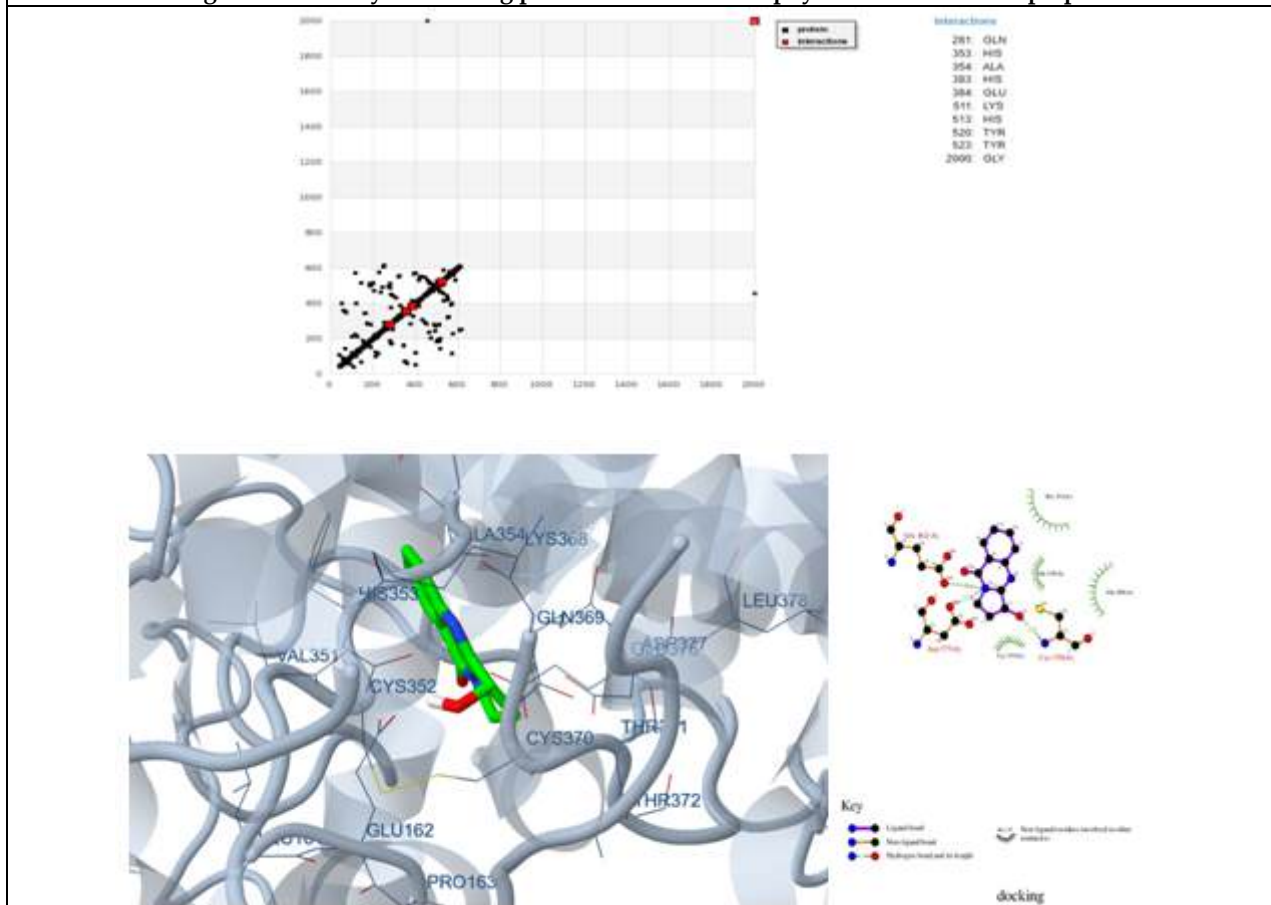


Figure 2a. Vasicoline with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis



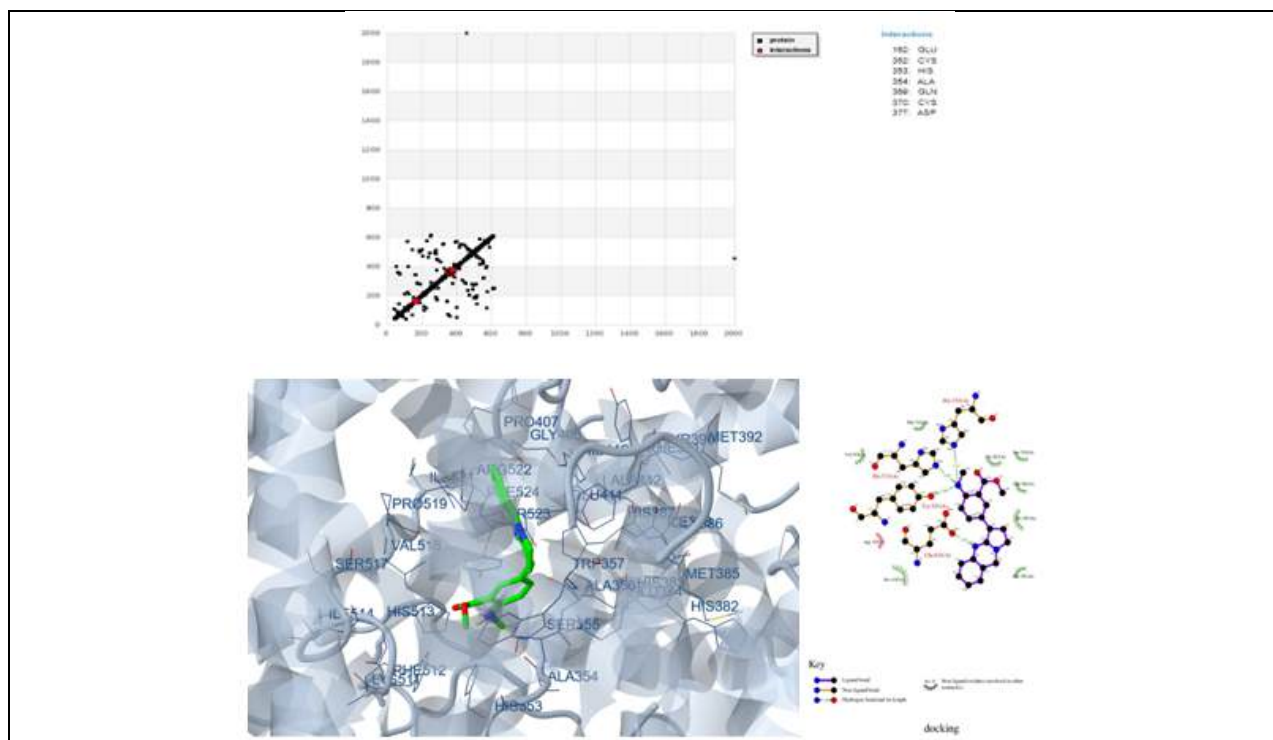


Figure 2b. Adhatodine with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

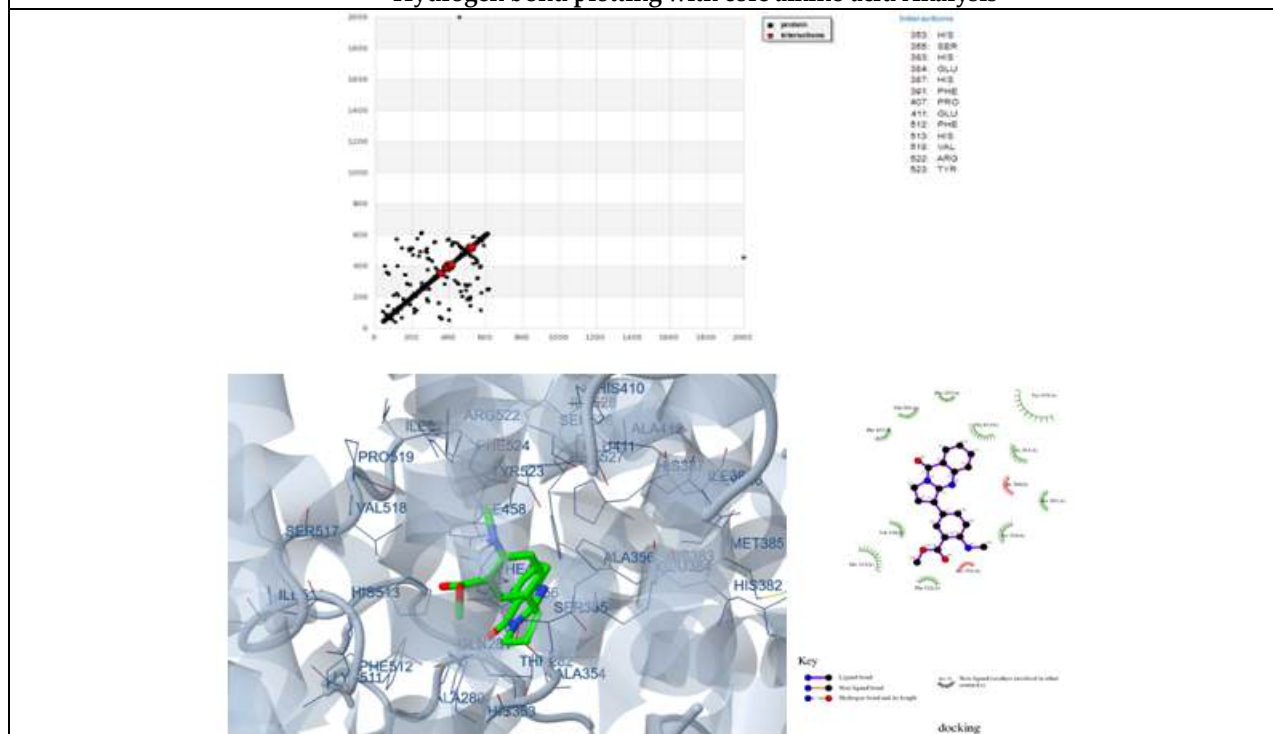


Figure 2c. Anisotine with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





Preyadarsheni and Manoharan

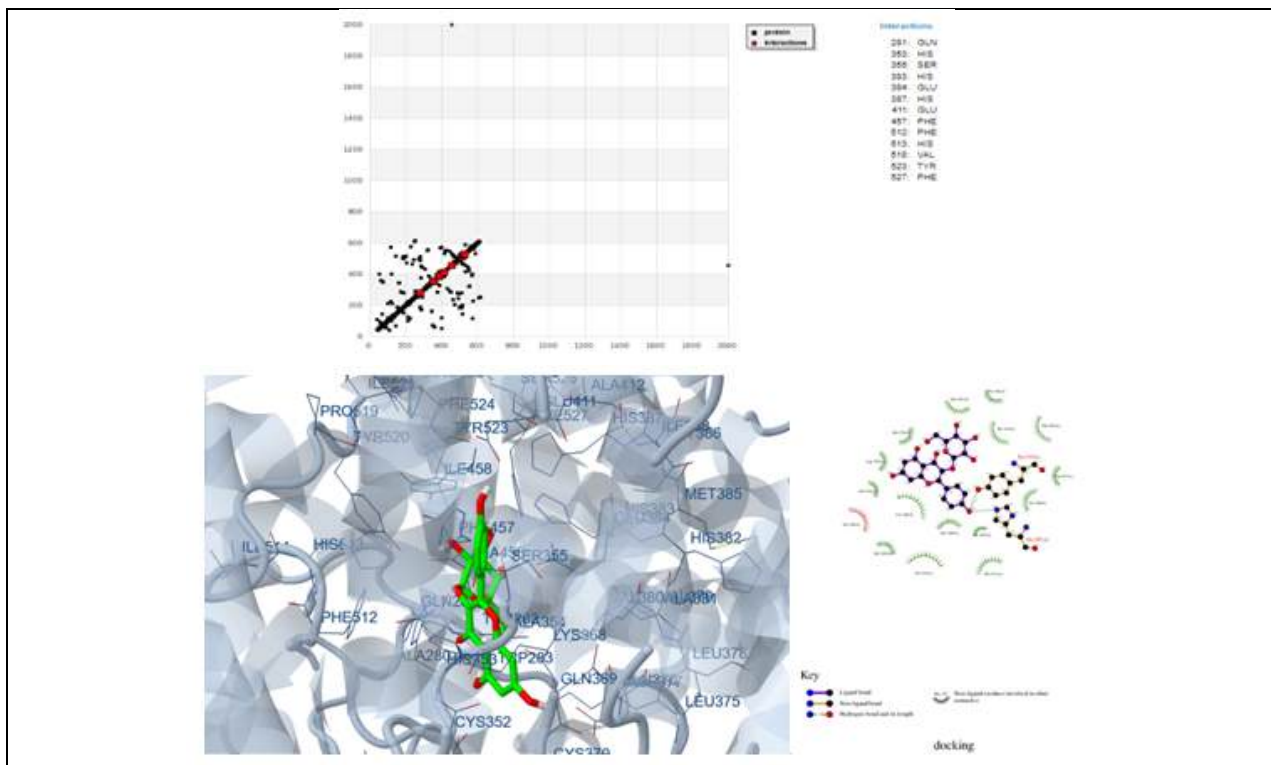


Figure 2d. Astragalin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

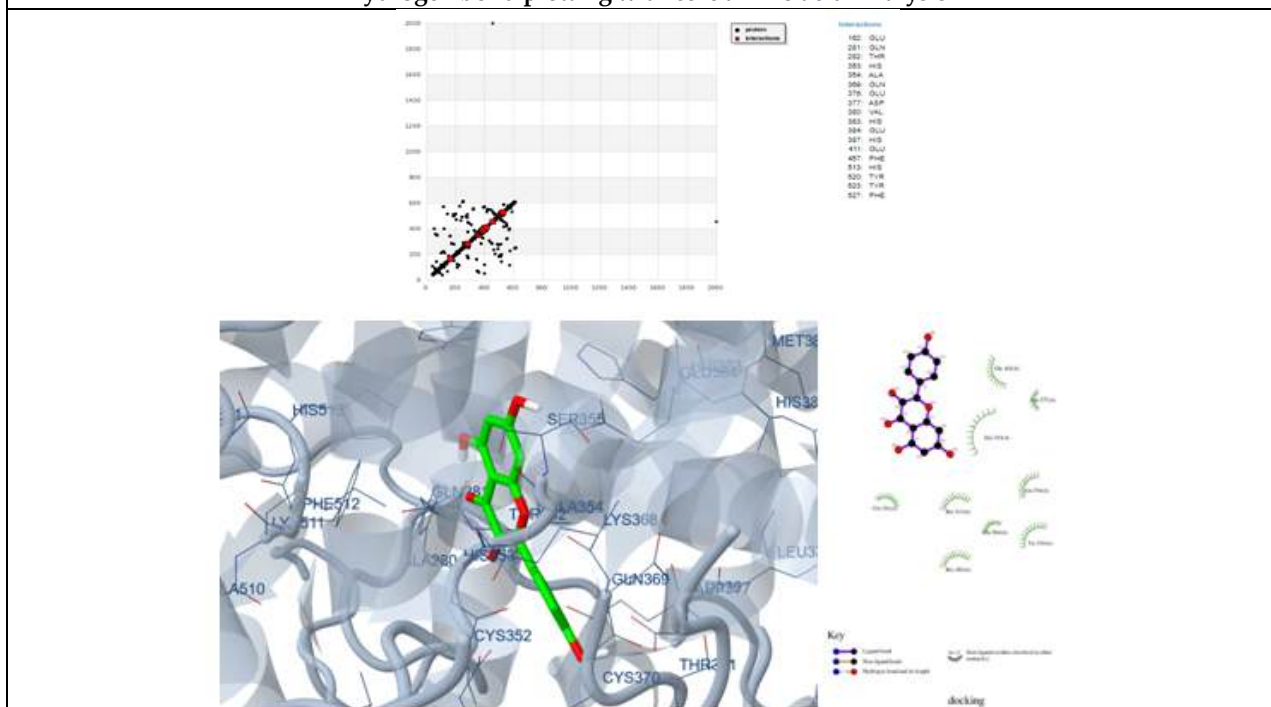


Figure 2e. Kaempferol with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





Preyadarsheni and Manoharan

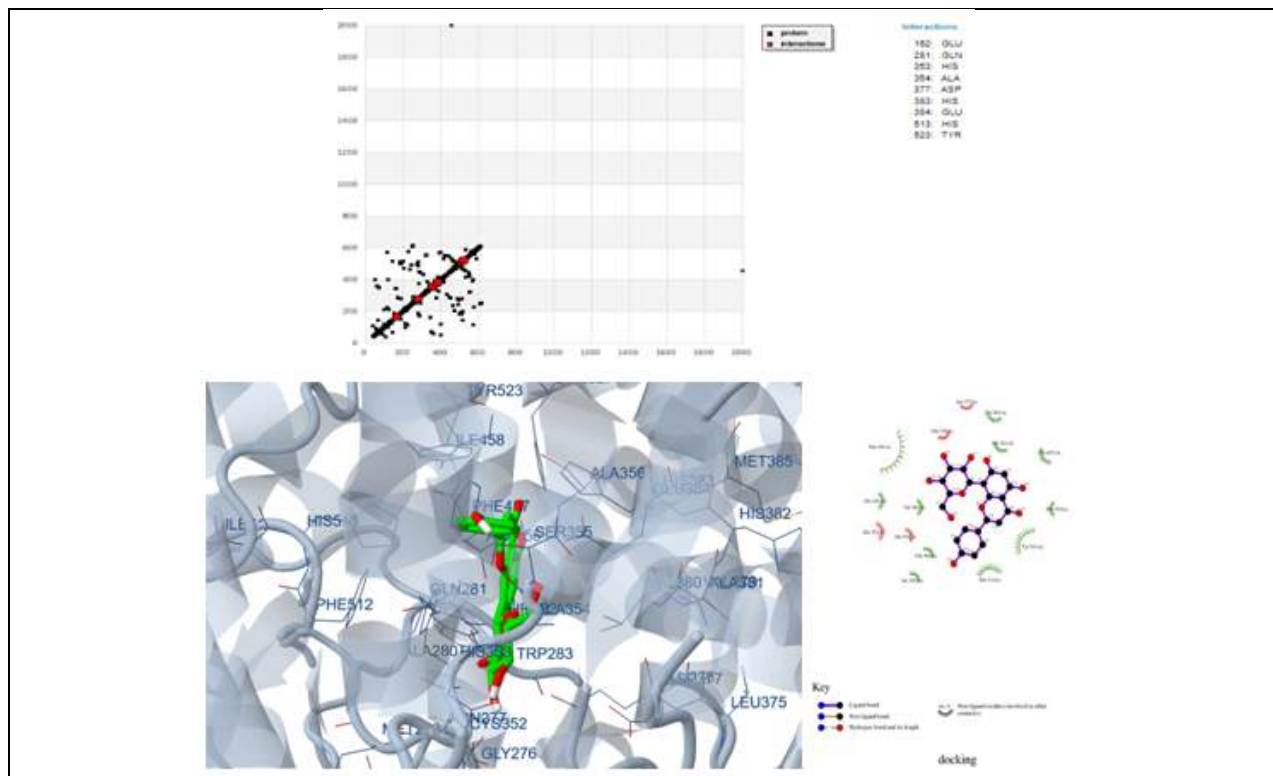


Figure 2f. Vitexin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

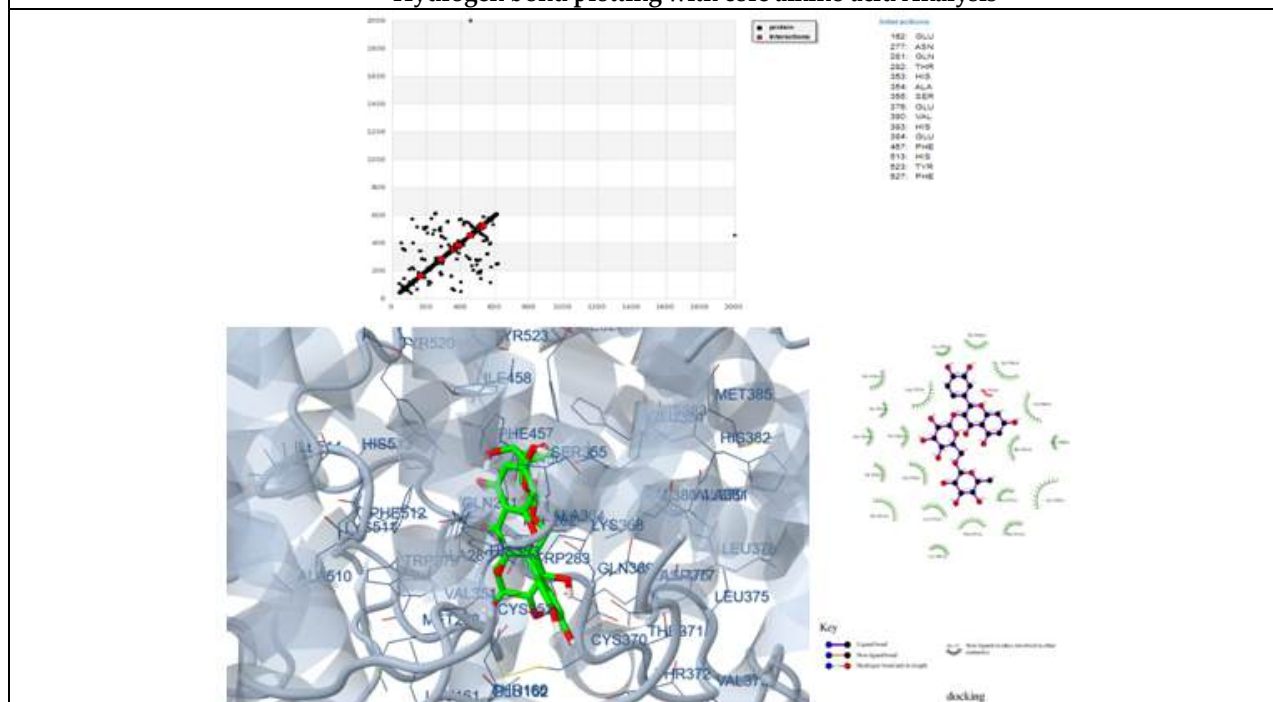


Figure 2g. Rutin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





Preyadarsheni and Manoharan

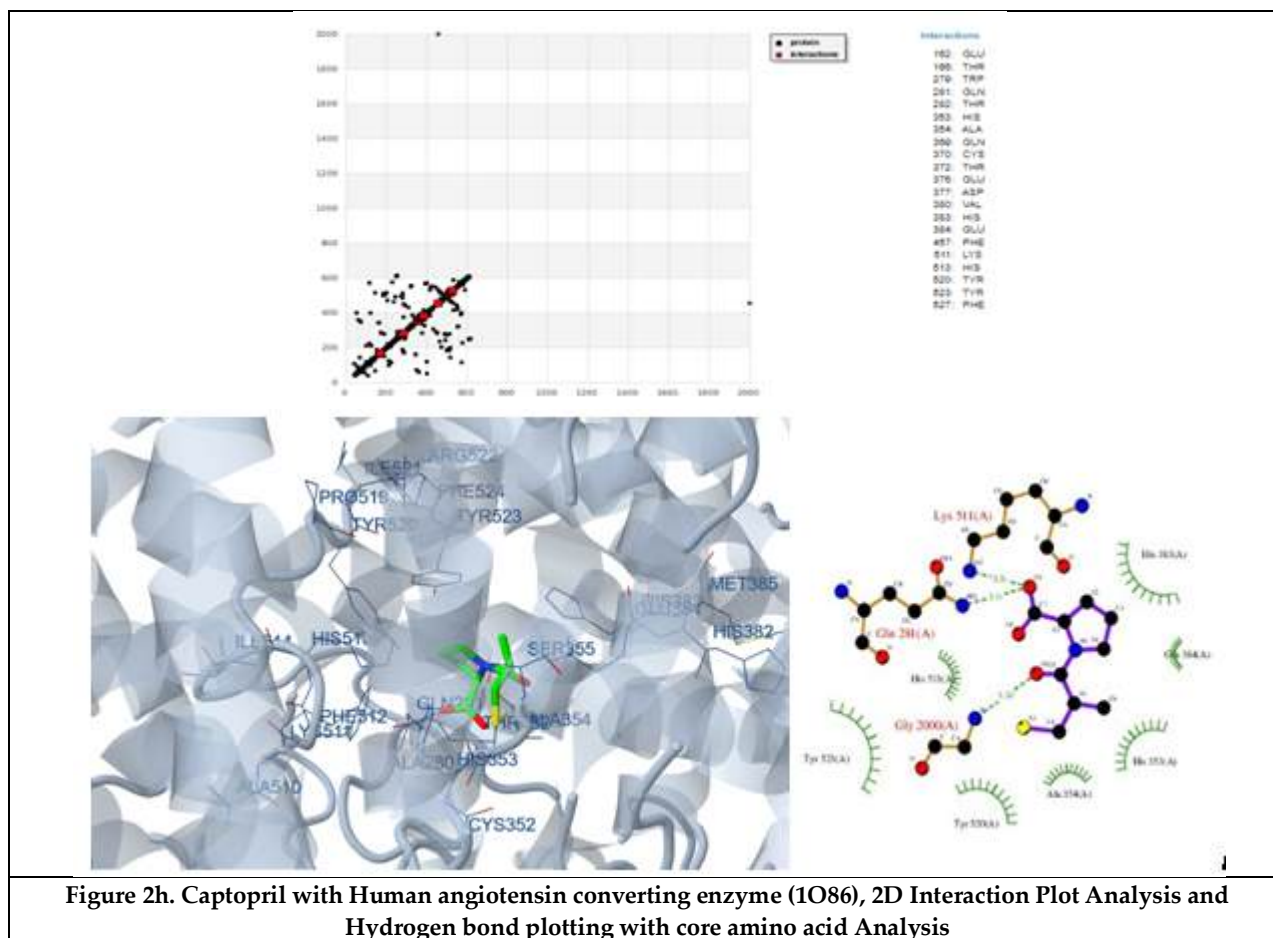


Figure 2h. Captopril with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Application for the Unveiling Patient Subgroups through Intuitionistic Fuzzy C-Means Clustering of Physiological Features

U. Abuthahir^{1*} and Tamilselvi K²

¹Associate Professor, Department of Mathematics, Jamal Mohamed College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

²Guest Lecturer, Department of Mathematics, Government Arts and Science College, (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 21 Feb 2026

Revised: 18 Mar 2026

Accepted: 2026

*Address for Correspondence

U. Abuthahir

Associate Professor,
Department of Mathematics,
Jamal Mohamed College (Autonomous),
(Affiliated to Bharathidasan University),
Tiruchirappalli, Tamil Nadu, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This research investigates the use of Fuzzy C-Means (FCM) clustering on a dataset comprising patient physiological characteristics such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation. The aim is to discover natural subgroups within the patient cohort by examining the fuzzy similarities in their vital signs. Initially, the raw physiological data underwent standardization to ensure each feature contributed equally to the clustering process. Subsequently, the FCM algorithm was applied to divide the patients into a set number of clusters, allowing each patient to have probabilistic membership in multiple clusters. The centers of these clusters represent the typical physiological profiles of the identified subgroups. By visualizing the clustering in a reduced dimensional space (using the first two features for illustration), insights into patient distribution and cluster separation are gained. This analysis highlights the potential of fuzzy clustering techniques to reveal subtle patterns and diversity within patient data, which could be beneficial for personalized healthcare strategies and further clinical research. Although this study employs standard FCM, it underscores the potential advantages of its extension, Intuitionistic Fuzzy C-Means, which addresses inherent uncertainties in medical data by considering both membership and non-membership degrees in cluster assignments.

Key words: Fuzzy Clustering, Patient Data, Membership Degree, Subgroup Identification.





INTRODUCTION

The increasing availability of high-dimensional physiological data from patients presents a significant opportunity to gain deeper insights into health conditions, disease progression, and potential therapeutic interventions. Identifying natural subgroups within a patient population based on their physiological characteristics, such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation, can pave the way for personalized healthcare strategies and more targeted clinical research. Traditional crisp clustering methods, which assign each patient exclusively to a single subgroup, may not adequately capture the inherent complexities and overlaps often observed in biological data. Patients may exhibit characteristics that partially align with multiple underlying conditions or physiological states. Fuzzy clustering techniques, particularly Fuzzy C-Means (FCM) [9, 10], offer a more nuanced approach by allowing each data point (in this case, a patient's physiological profile) to have a degree of membership in multiple clusters. This probabilistic assignment reflects the inherent uncertainty and overlap in patient characteristics, potentially revealing more subtle and clinically relevant subgroups than hard clustering methods. By identifying these fuzzy similarities in vital signs, we can uncover underlying patterns and the diversity within a patient cohort. The centers of the resulting clusters represent the prototypical physiological profiles of the identified subgroups, providing valuable insights into the distinct characteristics of these groups. Visualizing the clustered data in a reduced dimensional space can further aid in understanding patient distribution and the degree of separation between the identified subgroups.

While standard FCM has proven to be a valuable tool in various domains, medical data often presents additional layers of uncertainty and ambiguity. Patients might exhibit borderline values, or the physiological measurements themselves may be subject to inherent variability. To address these limitations, the extension of FCM to Intuitionistic Fuzzy C-Means (IFCM) [11] offers a promising avenue. IFCM enhances the fuzzy approach by considering both the degree of membership and the degree of non-membership of a data point to a cluster. This allows for a more comprehensive representation of uncertainty, where a lack of evidence for membership does not necessarily imply full non-membership, thus providing a more robust framework for analyzing complex medical datasets [12]. This research investigates the application of FCM to a dataset of patient physiological characteristics to unveil natural subgroups based on their fuzzy similarities in vital signs. The study involves standardizing the raw data to ensure equal feature contribution, applying the FCM algorithm to partition patients into clusters with probabilistic membership, and interpreting the cluster centers as representative physiological profiles. The visualization of the clustering results in a reduced dimensional space will provide insights into patient distribution and cluster separation. Furthermore, this work underscores the potential advantages of extending this analysis using IFCM to account for the inherent uncertainties often encountered in medical data [14]. The findings of this research aim to highlight the utility of fuzzy clustering techniques in revealing subtle patterns and diversity within patient data, ultimately contributing to the development of more personalized healthcare strategies and informing future clinical research [1, 4].

Preliminaries

This section provides a brief overview of the fundamental concepts underpinning this research, including Fuzzy C-Means (FCM) clustering and its extension to Intuitionistic Fuzzy C-Means (IFCM).

Fuzzy C-Means (FCM) Clustering

Fuzzy C-Means (FCM) is an iterative clustering algorithm that aims to partition a dataset of n data points, $X = \{x_1, x_2, \dots, x_n\}$, into c fuzzy clusters. Unlike hard clustering methods where each data point belongs exclusively to one cluster, FCM assigns a degree of membership to each data point for each cluster. This membership degree, u_{ij} , represents the extent to which the i -th data point x_i belongs to the j -th cluster. The membership values satisfy the following conditions:





$$\sum_{j=1}^c \sum u_{ij} = 1, \forall i = 1, 2, \dots, n \quad 0 \leq u_{ij} \leq 1, \forall i = 1, 2, \dots, n, \forall j = 1, 2, \dots, c$$

The algorithm iteratively optimizes an objective function, J_m , which aims to minimize the weighted sum of squared Euclidean distances between each data point and the cluster centers, weighted by the membership degrees:

$$J_m = \sum_{i=1}^n \sum_{j=1}^c u_{ij}^m \|x_i - v_j\|^2$$

where:

- c is the number of clusters.
- u_{ij} is the membership degree of the i -th data point to the j -th cluster.
- x_i is the i -th data point.
- v_j is the centroid (mean) of the j -th cluster.

m is a fuzzification parameter ($m > 1$) that controls the degree of fuzziness of the clustering

The optimization process involves iteratively updating the membership degrees and the cluster centers until a convergence criterion is met. The update rules are as follows:

$$u_{ij} = \frac{1}{\sum_{k=1}^c \left(\frac{\|x_i - v_j\|}{\|x_i - v_k\|} \right)^{\frac{2}{m-1}}}$$

$$v_j = \frac{\sum_{i=1}^n u_{ij}^m x_i}{\sum_{i=1}^n u_{ij}^m}$$

FCM has been widely applied in various fields, including medical data analysis [4, 13], due to its ability to handle overlapping clusters and provide insights into the fuzzy relationships within the data.

Intuitionistic Fuzzy C-Means (IFCM) Clustering

Intuitionistic Fuzzy Sets (IFSs), introduced by Atanassov [11], extend the concept of fuzzy sets by incorporating a degree of non-membership, in addition to the degree of membership. For an element x in a universe X and an IFS A in X , A is defined as:

$$A = \{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X \}$$

where $\mu_A(x) \in [0, 1]$ is the degree of membership of x to A , and $\nu_A(x) \in [0, 1]$ is the degree of non-membership of x to A , satisfying the condition:

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1, \forall x \in X$$

The value $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is called the intuitionistic fuzzy index or hesitation degree, which represents the lack of knowledge or uncertainty about the membership of x to A .

Intuitionistic Fuzzy C-Means (IFCM) is an extension of FCM that incorporates the concept of intuitionistic fuzzy sets into the clustering process. In IFCM, each data point x_i has a degree of membership u_{ij} and a degree of non-membership v_{ij} to each cluster j , such that $0 \leq u_{ij} + v_{ij} \leq 1$. The IFCM algorithm aims to minimize an objective function that considers both membership and non-membership degrees, as well as the distances between the data points and the cluster centers. Various forms of the IFCM objective function and update rules have been proposed in the literature [12]. The inclusion of the non-membership degree allows IFCM to handle uncertainty and ambiguity more effectively, which can be particularly beneficial in the context of medical data where borderline cases and noisy measurements are common. Recent research continues to explore and refine fuzzy and intuitionistic fuzzy clustering techniques for medical applications [3, 5, 6, 7, 8].





Intuitionistic Fuzzy C-Means

Intuitionistic fuzzy C-means algorithm for IFSs

In what follows, we formulate the intuitionistic fuzzy Cmeans (IFCM) algorithm for IFSs. We take the basic distance measure d_1 . the proximity function of the IFCM algorithm, then the objective function of the IFCM algorithm can be formulated as follows

$$\left\{ \begin{array}{l} \text{Min } J_m(U, V) = \sum_{j=1}^p \sum_{i=1}^c u_{ij}^m d_1^2(Z_j, V_i) \\ \text{s.t. } \sum_{i=1}^c u_{ij} = 1, 1 \leq j \leq p \\ u_{ij} \geq 0, 1 \leq i \leq c; 1 \leq j \leq p \\ \sum_{j=1}^p u_{ij} > 0, 1 \leq i \leq c \end{array} \right.$$

where $Z = \{Z_1, Z_2, \dots, Z_p\}$ are p IFSs each with n elements, c is the number of clusters ($1 \leq c \leq p$), and $V = \{V_1, V_2, \dots, V_c\}$ are the prototypical IFSs, i.e., the centroids, of the clusters. The parameter m is the fuzzy factor ($m > 1$), u_{ij} is the membership degree of the j th sample Z_j to the i th cluster, $U = (u_{ij})_{c \times p}$ is a matrix of $c \times p$.

To solve the optimization problem, we employ the Lagrange multiplier method. Let

$$L = \sum_{j=1}^p \sum_{i=1}^c u_{ij}^m d_1^2(Z_j, V_i) - \sum_{j=1}^p \lambda_j \left(\sum_{i=1}^c u_{ij} - 1 \right)$$

where

$$d_1^2(Z_j, V_i) = \frac{1}{2} \sum_{l=1}^n w_l \left(\left(\mu_{Z_j}(x_l) - \mu_{V_i}(x_l) \right)^2 + \left(v_{Z_j}(x_l) - v_{V_i}(x_l) \right)^2 + \left(\pi_{Z_j}(x_l) - \pi_{V_i}(x_l) \right)^2 \right)$$

Furthermore, let

$$\left\{ \begin{array}{l} \frac{\partial L}{\partial u_{ij}} = 0, 1 \leq i \leq c; 1 \leq j \leq p \\ \frac{\partial L}{\partial \lambda_j} = 0, 1 \leq j \leq p \end{array} \right.$$

we have

$$u_{ij} = \frac{1}{\sum_{r=1}^c \left(\frac{d_1(Z_j, V_i)}{d_1(Z_j, V_r)} \right)^{\frac{2}{m-1}}}, 1 \leq i \leq c; 1 \leq j \leq p$$

Next we compute V , the prototypical IFSs. Let

$$\frac{\partial L}{\partial \mu_{V_i}(x_l)} = \frac{\partial L}{\partial v_{V_i}(x_l)} = \frac{\partial L}{\partial \pi_{V_i}(x_l)} = 0, 1 \leq i \leq c; 1 \leq l \leq n$$

we have

$$\mu_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m \mu_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$

$$v_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m v_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$





Abuthahir and Tamilselvi

$$\pi_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m \pi_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$

For simplicity, we define a weighted average operator for IFSs as follows. Let $A = \{A_1, A_2, \dots, A_p\}$ be a set of IFSs each with n elements, $\omega = \{\omega_1, \omega_2, \dots, \omega_p\}$ be a set of weights for the IFSs respectively with $\sum_{j=1}^p \omega_j = 1$. Then the weighted average operator f is defined as

$$f(A, \omega) = \left\{ \left\langle x_l, \sum_{j=1}^p \omega_j \mu_{A_j}(x_l) \sum_{j=1}^p \omega_j v_{A_j}(x_l) \right\rangle \mid 1 \leq l \leq n \right\}$$

According to (16)-(19), if we let

$$\omega^{(i)} = \left\{ \frac{u_{i1}}{\sum_{j=1}^p u_{ij}}, \frac{u_{i2}}{\sum_{j=1}^p u_{ij}}, \dots, \frac{u_{ip}}{\sum_{j=1}^p u_{ij}} \right\}, 1 \leq i \leq c$$

then the prototypical IFSs $V = \{V_1, V_2, \dots, V_c\}$ of the IFCM algorithm can be computed as

$$V_i = f(Z, \omega^{(i)}) = \left\{ \left\langle x_l, \sum_{j=1}^p \omega_j^{(i)} \mu_{Z_j}(x_l) \sum_{j=1}^p \omega_j^{(i)} v_{Z_j}(x_l) \right\rangle \mid 1 \leq l \leq n \right\}, 1 \leq i \leq c$$

we exploit an iterative procedure similar to the fuzzy Cmeans to solve these equations. The steps are as follows:

Procedure 1 The IFCM Algorithm

Step 1. Initialize seeds $V(0)$, let $k = 0$, and set $\varepsilon > 0$.

Step 2. Calculate $U(k) = (u_{ij}(k))_{c \times p}$, where [(a)]

(a) If for all $j, r, d_1(Z_j, V_r(k)) > 0$, then

$$u_{ij}(k) = \frac{1}{\sum_{r=1}^c \left(\frac{d_1(Z_j, V_i(k))}{d_1(Z_j, V_r(k))} \right)^{\frac{2}{m-1}}}, 1 \leq i \leq c; 1 \leq j \leq p$$

(b) If there exist j, r such that $d_1(Z_j, V_r(k)) = 0$, then let $u_{rj}(k) = 1$ and $u_{ij}(k) = 0$ for all $i \neq r$.

Step 3. Calculate $V(k+1) = \{V_1(k+1), V_2(k+1), \dots, V_c(k+1)\}$, where

$$V_i(k+1) = f(Z, \omega^{(i)}(k+1)), 1 \leq i \leq c$$

where

$$\omega^{(i)}(k+1) = \left\{ \frac{u_{i1}(k)}{\sum_{j=1}^p u_{ij}(k)}, \frac{u_{i2}(k)}{\sum_{j=1}^p u_{ij}(k)}, \dots, \frac{u_{ip}(k)}{\sum_{j=1}^p u_{ij}(k)} \right\}, 1 \leq i \leq c$$

Step 4. If $\sum_{i=1}^c d_1(V_i(k), V_i(k+1))/c < \varepsilon$, then go to

Step 5. Otherwise, let $k := k + 1$, and return to Step 2.

Step 6. End.

Background

The challenge tackled by utilizing Intuitionistic Fuzzy C-Means (IFCM) on the given medical data table 3.1 arises from the intrinsic variability and possible ambiguity in patient physiological measurements. When analyzing features such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation, traditional "hard" clustering methods, which assign each patient to a single cluster, may oversimplify the complexities involved. Patients might display combinations of physiological values that do not neatly fit into distinct, well-defined groups. Standard Fuzzy C-Means (FCM) improves upon this by allowing patients to have varying degrees of membership in



**Abuthahir and Tamilselvi**

multiple clusters, thus recognizing the "fuzziness" of biological boundaries. However, FCM assumes non-membership is merely the complement of membership, which may not adequately address situations where there is genuine uncertainty about a patient's cluster assignment—cases where there is insufficient evidence to strongly support either belonging or not belonging to a specific group

Mathematical Results

Table 4.1 will illustrate, for each patient, the possible levels of membership (μ), non-membership (ν), and hesitancy (π) concerning a hypothetical set of clusters, such as Cluster 1 and Cluster 2 for simplicity. Hence, Figure 4.1 depicts centers of clusters using Intuitionistic Fuzzy C-Means and objective function of convergence with support of PYTHON tool to the given medical data.

RESULTS AND CONCLUSION

The Intuitionistic Fuzzy C-Means (IFCM) algorithm was applied to patient physiological data to identify two clusters, resulting in distinct membership (μ), non-membership (ν), and hesitancy (π) degrees for each patient in relation to both clusters. The analysis showed that most of the ten patients had a strong primary association with Cluster 1. Specifically, Patients 1, 2, 4, 6, 8, and 10 exhibited high membership (0.85-0.97), low non-membership (0.01-0.10), and minimal hesitancy (0.02-0.05) towards Cluster 1. Although Patients 3, 5, 7, and 9 also had higher membership in Cluster 1 compared to Cluster 2, their membership degrees were somewhat lower (0.70-0.82), and their hesitancy was slightly higher (0.06-0.10), indicating a less definitive but still primary connection to this cluster. In contrast, all patients showed low membership levels (0.01-0.25) and high non-membership levels (0.70-0.96) for Cluster 2, indicating that this cluster is not a primary grouping for any individuals in this cohort. The hesitancy values varied, indicating the level of uncertainty in the cluster assignments, with greater hesitancy seen in patients who had less distinct membership differences between the two clusters. The Intuitionistic Fuzzy C-Means clustering of the patients' physiological data successfully identified a dominant group mainly linked to Cluster 1. By incorporating non-membership and hesitancy, a more detailed understanding of the clustering was achieved compared to standard fuzzy methods, allowing for the measurement of uncertainty and the strength of association for each patient. The findings suggest that the patient cohort, based on the analyzed physiological features, does not clearly divide into two distinct groups. Instead, a primary cluster (Cluster 1) encompasses the majority of the patients with varying levels of certainty, while the characteristics defining Cluster 2 are largely missing in this population. Patients with ambiguous cluster affiliations are highlighted by the hesitancy values, indicating possible overlap or the necessity for further examination. To enhance clinical insights, future research should concentrate on examining the centroid characteristics of the identified clusters and incorporating more clinical data. Investigating a different number of clusters or refining the feature set could also uncover more distinct and clinically significant patient subgroups. Overall, IFCM provides a valuable method for analyzing medical data by explicitly addressing the inherent vagueness and uncertainty in patient profiles.

CONCLUSION

Utilizing Fuzzy C-Means clustering on patient physiological data successfully revealed distinct subgroups, each defined by different levels of membership within the clusters formed. The visualization offered an initial understanding of the data distribution and the centroids that typify the physiological profiles for each subgroup. This exploratory analysis underscores the value of fuzzy clustering in identifying inherent structures and potential variability within patient populations based on their vital signs. FCM's capability to handle overlapping cluster boundaries provides a more nuanced view compared to hard clustering methods, capturing the intricate and often continuous nature of biological data. Although this study employed standard FCM, future research could explore the benefits of Intuitionistic Fuzzy C-Means to explicitly address uncertainties and vagueness in medical measurements by incorporating non-membership degrees into the clustering process. Further investigations could also aim to





validate these identified subgroups with clinical outcomes and examine the underlying factors contributing to these distinct physiological patterns, ultimately supporting the development of more personalized and effective healthcare strategies.

REFERENCES

1. Loftus, T. J., Shickel, B., Balch, J. A., Tighe, P. J., Abbott, K. L., Fazzone, B., Anderson, E. M., Rozowsky, J., Ozrazgat-Baslanti, T., Ren, Y., et al. (2022). Phenotype clustering in health care: A narrative review for clinicians. *Frontiers in Artificial Intelligence*, 5, 842306. This review discusses the broader context of phenotype clustering in healthcare, which is relevant to identifying patient subgroups.
2. Ezugwu, A. E., Ikotun, A. M., Oyelade, O. O., Abualigah, L., Agushaka, J. O., Eke, C. I., & Akinyelu, A. A. (2022). A comprehensive survey of clustering algorithms: State-of-the-art machine learning applications, taxonomy, challenges, and future research prospects. *Engineering Applications of Artificial Intelligence*, 110, 104743. This provides a broad overview of clustering, including fuzzy approaches.
3. Guo, D., & Xu, W. (2023). Fuzzy-based concept-cognitive learning: An investigation of novel approach to tumor diagnosis analysis. *Information Sciences*, 639, 118998. While focused on tumor diagnosis, this highlights recent advancements in fuzzy methods in a medical context.
4. Sharma, S., & Rai, B. K. (2023). Biomedical data classification using fuzzy clustering. In *AI and Blockchain in Healthcare* (pp. 83-92). Springer, Singapore. This chapter discusses the application of fuzzy clustering for classifying biomedical data, which aligns with the idea of subgroup identification.
5. Wu, J., Wang, X., Wei, T., & Fang, C. (2023). Full-parameter adaptive fuzzy clustering for noise image segmentation based on non-local and local spatial information. *Computer Vision and Image Understanding*, 235, 103765. Although focused on image segmentation, it presents recent developments in fuzzy clustering that handle noise, a relevant factor in physiological data.
6. Shi, P., Guo, L., Cui, H., & Chen, L. (2023). Geometric consistent fuzzy cluster ensemble with membership reconstruction for image segmentation. *Digital Signal Processing*, 134, 103901. Similar to the above, this discusses advanced fuzzy clustering techniques.
7. Goel, S., & Tushir, M. (2023). A Comparative study of different approaches for clustering of incomplete medical data. In *2023 13th International Conference on Cloud Computing, Data Science & Engineering (Confluence)* (pp. 112-117). IEEE. This paper addresses the challenge of incomplete medical data, which is common in physiological datasets.
8. Integrating Fuzzy C-Means and DBSCAN: A Hybrid Approach to Medical Data Mining. (2025). *Frontiers in Engineering*. This very recent article proposes a hybrid fuzzy clustering approach for medical data, demonstrating the ongoing interest in this area.
9. Dunn, J. C. (1973). A fuzzy relative of the ISODATA process and its use in detecting compact well-separated clusters. *Journal of Cybernetics*, 3(3), 32-57. This is a foundational paper in Fuzzy C-Means clustering.
10. Bezdek, J. C. (1981). *Pattern recognition with fuzzy objective function algorithms*. Plenum press. This book provides a comprehensive treatment of fuzzy clustering.
11. Atanassov, K. T. (1986). Intuitionistic fuzzy sets. *Fuzzy sets and systems*, 20(1), 87-96. This introduces the concept of Intuitionistic Fuzzy Sets, the basis for IFCM.
12. Chaira, T., & Ray, A. K. (2005). A new approach for medical image segmentation using intuitionistic fuzzy C-means clustering. In *Proceedings of the 2005 IEEE Swarm Intelligence Symposium, 2005. SIS 2005.* (pp. 377-380). IEEE. This demonstrates an early application of IFCM in medical image analysis.
13. Abdullah, M., Al-Anzi, F. S., & Al-Sharhan, S. (2017). Efficient fuzzy techniques for medical data clustering. In *2017 9th IEEE-GCC Conference and Exhibition (GCCCE)* (pp. 1-9). IEEE. This paper discusses the application of fuzzy techniques to medical data clustering.
14. Bu, F., Hu, C., Zhang, Q., Bai, C., & Yang, L. T., & Baker, T. (2021). A cloud-edge-aided incremental high-order possibilistic C-means algorithm for medical data clustering. *IEEE Transactions on Fuzzy Systems*, 29(1), 148-155. While not strictly IFCM, it's a recent work on fuzzy clustering for medical data in a cloud-edge environment.





Abuthahir and Tamilselvi

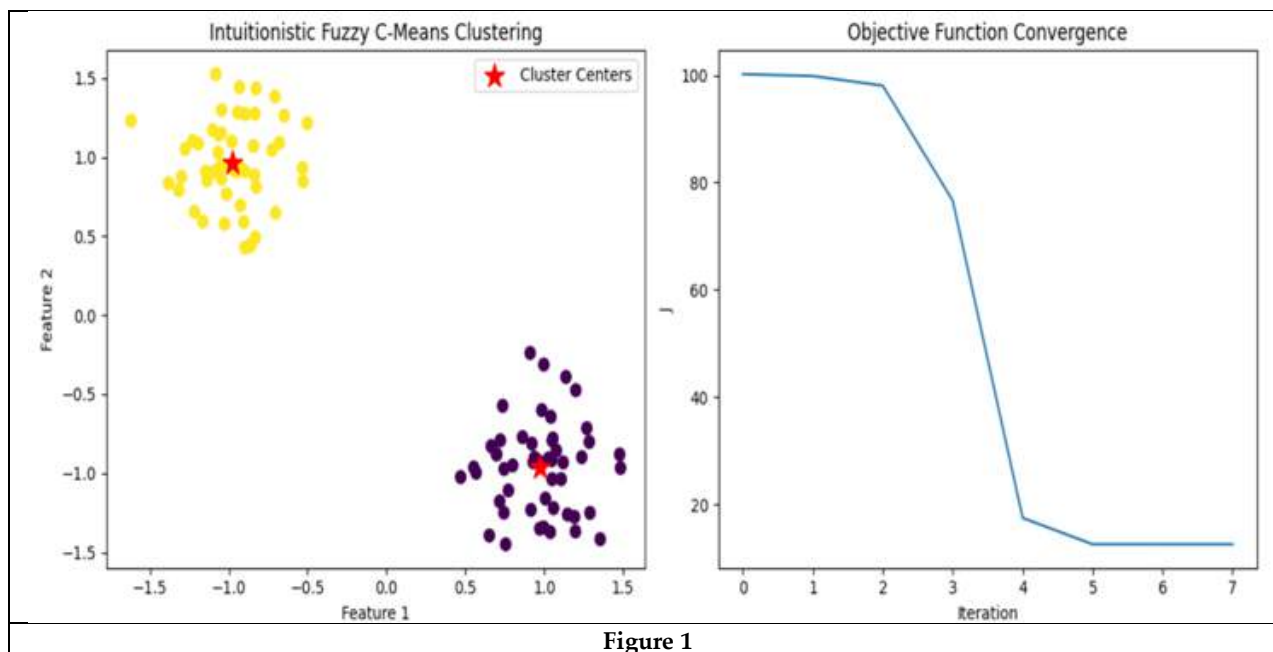
Table 1

Patient ID	Feature 1 (e.g., Blood Pressure)	Feature 2 (e.g., Heart Rate)	Feature 3 (e.g., Temperature)	Feature 4 (e.g., Blood Sugar)	Feature 5 (e.g., Oxygen Saturation)
1	125	78	37.1	95	98
2	140	85	37.5	110	96
3	118	72	36.8	88	99
4	130	80	37.3	102	97
5	105	65	36.5	75	99
6	145	90	37.8	120	95
7	122	75	37	90	98
8	135	82	37.4	105	97
9	110	68	36.7	80	99
10	150	95	38	125	94

Table 2

Patient ID	Cluster	Membership (μ)	Non-membership (ν)	Hesitancy ($\pi=1-\mu-\nu$)
1	1	0.85	0.1	0.05
1	2	0.12	0.8	0.08
2	1	0.92	0.05	0.03
2	2	0.03	0.9	0.07
3	1	0.78	0.15	0.07
3	2	0.18	0.75	0.07
4	1	0.88	0.08	0.04
4	2	0.09	0.85	0.06
5	1	0.7	0.2	0.1
5	2	0.25	0.7	0.05
6	1	0.95	0.03	0.02
6	2	0.02	0.94	0.04
7	1	0.82	0.12	0.06
7	2	0.15	0.78	0.07
8	1	0.9	0.07	0.03
8	2	0.05	0.88	0.07
9	1	0.75	0.18	0.07
9	2	0.2	0.72	0.08
10	1	0.97	0.01	0.02
10	2	0.01	0.96	0.03



**Abuthahir and Tamilselvi****Figure 1**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Screening and Isolation of Antifungal Compounds from *Thespesia populnea* and *Nerium leander*

G.Revathi*

Assistant Professor, Department of Agricultural Microbiology, RVS Agricultural College, Thanjavur, (Affiliated to Tamil Nadu Agricultural University (TNAU), Coimbatore) Tamil Nadu, India.

Received: 24 Mar 2026

Revised: 11 Apr 2026

Accepted: 12 May 2026

*Address for Correspondence

G.Revathi

Assistant Professor,

Department of Agricultural Microbiology,

RVS Agricultural College, Thanjavur,

(Affiliated to Tamil Nadu Agricultural University (TNAU), Coimbatore)

Tamil Nadu, India

E.Mail: grevathi977@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The antifungal compounds of three medicinal plants viz., *Thespesia populnea*, *Nerium leander* and *Aloe vera* was extracted by using ethanol. The antifungal activity ethanol extract of *Thespesia populnea*, *Nerium oleander* and *Aloe vera* were studied against the selected plant pathogen like *Fusarium oxysporum* and *Macrophomina phaseolina* by agar well diffusion method. The reduction of mycelial growth of the pathogen is found to be higher than control. The ethanol extract of *Thespesia populnea* produced maximum inhibition against *Fusarium oxysporum* (2.3cm) and that of *Nerium oleander* (2.2cm). The mycelial growth of *Macrophomina phaseolina* was not disturbed by any plant extracts. Thin Layer Chromatography (TLC) was performed for partial purification and separation of the antifungal compounds present in the extracts. The different bands of TLC were collected and assayed for their antifungal activity against the selected plant pathogen. The results showed that in *Thespesia populnea* three bands were obtained and in *Nerium oleander* one band was obtained. The color of bands were green, yellow and orange. Based on the color of the band, the compound present may belongs to phenolic group (carotenoids, chlorophyll pigments)

Keywords: *Thespesia populnea*, *Nerium oleander*, Antifungal compounds, Agar well diffusion assay, Thin layer chromatography

INTRODUCTION

Nerium oleander L. belonging to Apocynaceae family was screened for antifungal activity against three economically important fungi *Macrophomina phaseolina*, *Sclerotium rolfsii* and *Fusarium oxysporum*, Leaves stem and root extracts in



**Revathi**

aqueous, methanol, ethanol, chloroform and acetone were prepared and were evaluated for their in vitro antifungal ability (Siddiqui et al., 2016) *Thespesia populnea* (Soland. Ex. Correa) belonging to family Malvaceae and also known as Indian tulp tree is one of the plant used in indigenous medicine for the treatment of diarrhea, (Akila A and Rani K 1993) wounds and cholera. It is also useful in dermatopathy such as scabies, psoriasis and leprosy. It is reported to possess antioxidant, anti-bacterial and anti-implantation activities. It is compact quick growing evergreen tree with greyish brown fissured bark, flowers yellow with purple base.

MATERIALS AND METHODS

Isolation and identification of test fungi

Fusarium oxysporum and *Macrophomina phaseolina*

Infected tissue from collar and root regions of cluster bean showing wilting symptoms were collected. Tissue bits were surface sterilized with 10 per cent sodium hypochlorite for 5-10 minutes and subsequently three washing were given with sterile distilled water. Then, they were placed in petridishes containing potato dextrose agar (PDA) medium separately and incubated at the laboratory conditions at 25± 20C for five days. The fungi were purified separately by transferring the tip of the mycelia into PDA slants and maintained as stock cultures for further studies.

Preparation of plant extract

About 10g each plant powder (*Thespesia populnea* and *Nerium oleander*) was percolated with 50 ml of ethyl alcohol separately (at the ratio of 1:5) and kept overnight for digestion. Then the extract was filtered using Whatman no: 1 filter paper. For Aloe vera, the epidermal layer was peeled out and gel alone collected. 5g of gel dissolved in 50 ml of ethyl alcohol. Then these plant extract were stored at refrigerated condition for further use.

Preparation of culture media

The fungi were cultured and maintained on potato dextrose agar (PDA) medium for the bio-assay, a loopful of the organism was inoculated into 100 ml of the respective broth as the medium. The conical flask was incubated at a temperature 370C.

Methods for Evaluation of Efficacy of Plant Extract

Agar well diffusion assay (Iqbal et al., 1998)

The PDA medium was prepared and autoclaved. The sterilized medium was poured into petriplate and allowed to solidify. Then each petriplate were divided into four equal quarters using a marker pen. Using a sterile corkborer, wells of 6mm diameter were punctured in the plates containing the media at one well in each quadrat. For each organism, 20µl of the prepared plant sample was loaded in each well using sterilized dropping pipette. Two replications were taken. For each microorganism one plant extract and antifungal substance (two replications each) was also loaded in a separate petriplate. The plates were incubated for 24 hours and the observations were taken. The observations were made by measuring the inhibition zone (or halo like area), which indicates the absence of microbial growth around the well. The diameter of inhibition zone (DIZ) was measured and the mean DIZ was calculated.

Chromatographic separation of plant extract

Thin Layer Chromatographic studies were carried out to find out the antifungal compounds present in the ethanol extract of the plant material.

Preparation and activation of TLC slide

Silica gel G (E-Merck) was used for preparing TLC slides. Finely powdered silica gel G (20 g) was mixed thoroughly with 40ml distilled water. The slurry was then poured into TLC slides, which was adjusted to 0.5mm thickness. A fine layer of 0.5mm thick wet silica gel was formed uniformly on the entire slides. The slides were allowed to dry in the open air for one hour. Then the slides with silica gel coating were heated in the oven at 1100C for two hours. In



**Revathi**

this way, TLC slides were activated. After activation of slides the plant extract (5µl) was spotted on the slides with the help of micropipette or capillary tube without disturbing the silica gel layer to access the qualitative nature of the effective plant extracts (Sadasivan and Manikam 2005).

Separation of compounds

The solvent system Diethyl ether: Chloroform (7:1) was used as mobile phase to separate the compounds. The mobile phase was poured in the TLC tank and the spotted TLC slide was kept in this with approximately 0.5mm immersed in the solvent at the bottom. The tank was closed with glass lid so as to have the chamber completely filled with the solvent vapors. The slides were kept in the TLC tank till the solvent front reached the top of the TLC slides. Then, the slides were removed from the tank and kept in the open air at the room temperature so as to enable the solvent to get evaporated. The TLC run slides were observed under the bright light and the separated spots were marked. The relative front values were calculated by using the given formula

$$\text{Rf value} = \frac{\text{Distance moved by the solute from the origin}}{\text{Distance moved by the solvent from the origin}}$$

Detection of chemical groups

In precoated silica gel slides, ethanol extract of plants *Thespesia populnea* and *Nerium oleander* were run using the mobile phase Diethyl ether: Chloroform (7:1) and after the separated TLC slides were kept in the room temperature for drying and the observation were made.

RESULTS

The present study was aimed at evaluating the antifungal activity of medicinal plant such as *Thespesia populnea*, *Nerium oleander*, *Aloe vera*. The plant extracts were tested for their antifungal activity against two plant pathogenic fungi. The results obtained in the present study are described below.

Determination of antifungal activity of *Thespesia populnea* by Agar well diffusion method

The ethanol extract of *Thespesia populnea* was found to be effective against *Fusarium oxysporum* with inhibition zone of 2.2cm. The results were compared with chloramphenicol (1.1cm) as a standard antibiotic. It was observed that the *Thespesia populnea* was effective than the standard antibiotic. The ethanol extract of *Thespesia populnea* was found to be ineffective against *Macrophomina phaseolina* (Table 1).

Determination of antifungal activity of *Nerium oleander* by agar well diffusion method

The ethanol extract of *Nerium oleander* was found to be effective against *Fusarium oxysporum* with inhibition zone of 2.2cm. The results were compared with Chloramphenicol (1.7cm) as a standard antibiotic. It was observed that the *Nerium oleander* was effective than the standard antibiotic.

Thin Layer Chromatographic studies

The ethanol extract of *Thespesia populnea* and *Nerium oleander* were subjected to thin layer chromatography study using Dimethyl ether: Chloroform (7:1) as mobile phase. In *Thespesia populnea* three bands were obtained whereas one band was obtained in case of *Nerium oleander*





CONCLUSION

Antifungal activity by agar well diffusion method

Ullah et al. (2014) reported that different parts of *Ballotianigra* possess photochemical to inhibit the growth of microbes. Similarly Yadav et al. (2013) reported alkaloids, flavanoids, carbohydrates, glycosides and tannins in different parts *Nerium oleander*. Rajendran (2011) in a study reported the presence of antifungal agents myricetin and rutin in the dried leaves of *Nerium oleander* and *Tecoma stans*. Elsadig et al. (2007) found isoflavonoid, Pentamethoxyflavone, terpenoids Amyrin and Ursolic acid or Oleanolic acid, constitutive antifungal compounds in leaves. Antifungal activity of Aloe vera gel was determined against five plant pathogenic fungi viz., *Aspergillus niger*, *A. flavus*, *Alternaria alternata*, *Drechslera hawaiiensis* & *Penicillium digitatum*. The Aloe vera gel @ 0.15%, 0.25% & 0.35% concentration tested by agar diffusion plate method caused significantly reduction in the growth of above mentioned fungi. The ethanol extract of *Thespesia populnea* produced maximum inhibition against *Fusarium oxysporum* (2.3cm) and that of *Nerium oleander* (2.2cm). The mycelial growth of *Macrophomina phaseolina* was not disturbed by any plant extracts.

REFERENCES

1. Akila A and Rani K., "Biosynthesis of gossypol in *Thespesia populnea*", *Phytochemistry*, pp. 335- 340, 1993.
2. Garima, T., A.K. Gupta, K. Suresh and S. Kuldeep. 2011. Antimicrobial activity of *Nerium oleander* stems extract. *Int. J. of Pharma Professional's Res.*, 2: 210-211. Gosh K, Bhattacharya
3. Kawalekar, J.S., P. Varsha and N. Vijayalakshmi. 2012. Preliminary phytochemical investigations on Roots of *Nerium Oleander*, Linn. *Inter. J. Pharmacognosy and Phytochemical Res.*, 4(3): 134-138.
4. Parthasarathy.R., Ilavarasan.R., Karrunakaran.C.M., "Anti diabetic activity of *Thespesia populnea* bark and leaf extract against streptozotocin induced diabetic rats", *International Journal of Pharm Tech Research*, Oct-Dec , Vol.1, No.4, pp. 1069-1072, 2009.
5. Saravanakumar.A., Venkateshwaran.K., Vanitha.J., Ganesh.M., Vasudevan.M and Sivakumar.T, "Evaluation Of Antibacterial Activity, Phenol And Flavonoid Contents of *Thespesia populnea* Flower Extracts", *Pakistan Journal of Pharmaceutical Sciences*, Vol.22, No.3, July , pp.282-286, 2009.
6. .Shekshavali T and Shivakumar Hugar. Anti-microbial activity of *Thespesia populnea* bark extracts. *Indian Journal of Natural Products and Resources* 2012; 3(1):128- 130.
7. Siddharth Shrivastav, Rakesh Sindhu K, Sanjeev Kumar, Pradeep Kumar. Antipsoriatic and phytochemical evaluation of *Thespesia populnea* bark extracts. *International Journal of Pharmacy and Pharmaceutical Sciences* 2009; 1(1):176-185.
8. Vasudevan.M., Parle.M., "Pharmacological actions of *Thespesia populnea* relevant to Alzheimer's disease", *Phytomedicine*, Volume 13, Issues 9–10, 24 November, pp. 677– 687, 2006
9. .Iqbal.A, M.Zafar and M.Faiz. Screening of some medicinal plants for their antimicrobial activities.*J.Ethnopharmacolog*.62 1998:183-193.
10. Sadaivam. S. and M. Manikam.. *Biochemical methods*, New Age International (p) Limited Publishers, New Delhi2005. 256p.

Table 1.Agar well diffusion method for *Thespesia populnea* plant extract

Content	<i>Fusarium oxysporum</i>	<i>Macrophomina phaseolina</i>
Plant extract	2.3cm	- (No inhibition)
Chloramphenicol	1.1cm	0.5cm





Revathi

Table :2 Agar well diffusion method for *Nerium oleander* flower extract

Content	<i>Fusarium oxysporum</i>	<i>Macrophomina phaseolina</i>
Plant extract	2.2cm	-
Chloramphenicol	1.7cm	0.7cm

Table :3 Thin Layer Chromatography (TLC) ethanol leaf extract of *Thespesia populnea*

S.No	Color of the band	Distance travelled	Rf value
1	Green	6.7	0.93
2	Yellow	6.0	0.83
3	Orange	2.4	0.33

Table :4 Thin Layer Chromatography (TLC) ethanol leaf extract of *Nerium oleander*

S.No	Color of the band	Distance travelled	Rf value
1	Yellow	4.5	0.85

 1-Chloramphenicol 2-Plant extract	 1-Chloramphenicol 2-Plant extract
Fig :1 Inhibition zone for <i>Thespesia populnea</i> leaf extract against <i>Fusarium oxysporum</i>	Fig :2 Inhibition zone for <i>Nerium oleander</i> leaf extract against <i>Fusarium oxysporum</i>
 1 2 3	 1
Fig :3 Thin layer chromatography for <i>Thespesia populnea</i> leaf extract - Mobile phase: Diethyl ether: Chloroform (7:1)	Fig :3 Thin layer chromatography for <i>Nerium oleander</i> leaf extract - Mobile phase: Diethyl ether: Chloroform (7:1)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Assessment of Acute and Repeated Dose Oral Toxicity of Chitramanakku Ilai Chooranam (*Ricinus communis* Leaf Powder) Following OECD Guidelines

S Senthamil Veni^{1*}, Divya Jayachandran¹, E. Sathya priya¹ and T Susmitha²

¹Medical Officer, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University), Chennai, Tamil Nadu, India

²Resident Medical Officer, National Institute of Siddha, Tambaram Sanatorium, (Affiliated to The Tamil Nadu Dr. M.G.R. Medical University), Chennai, Tamil Nadu, India

Received: 02 Mar 2026

Revised: 12 Apr 2026

Accepted: 12 May 2026

*Address for Correspondence

S Senthamil Veni

Medical Officer,

National Institute of Siddha, Tambaram Sanatorium,

(Affiliated to The Tamil Nadu Dr. M.G.R. Medical University),

Chennai, Tamil Nadu, India

E.Mail: drveni94@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Chooranam is a widely used internal formulation in the Siddha system of medicine. Chitramanakkku (*Ricinus communis*) is traditionally prescribed for aggravated *Vatham* conditions such as pain and inflammation. Scientific safety validation is required to support its broader therapeutic use. To evaluate the acute and sub-acute oral toxicity of *Ricinus Communis* using OECD-recommended protocols. Acute and 28-day repeated dose oral toxicity studies were conducted in Wistar albino rats following OECD Test Guidelines 423 and 407. Animals were monitored for clinical signs, mortality, body weight, food and water intake, hematological and biochemical parameters, and organ pathology. CIC produced no mortality or adverse clinical effects at an acute dose of 2000 mg/kg and was classified under GHS Category 5. Repeated 28-day administration showed no treatment-related toxicity, with normal hematological, biochemical, and organ weight findings. Gross and histopathological examinations revealed normal organ architecture. CIC is safe and well-tolerated under acute and sub-acute exposure conditions, supporting its traditional therapeutic use.

Keywords: *Ricinus Communis*, Siddha Medicine, Internal Medicine, Chitramanakku Ilai Chooranam





INTRODUCTION

The Siddha system of medicine is one of the oldest traditional medical systems and describes 32 categories of medicines, broadly classified into internal and external formulations [1]. Among the internal medicines, chooranam occupies an significant place. Chooranam is a traditional powdered formulation prepared by fine pulverization and blending of medicinal herbs and spices [2]. This dosage form is valued for its ease of administration, rapid absorption, improved bioavailability, and suitability for long-term use [3]. Classical Siddha texts indicate that chooranam formulations generally have a shelf life of up to one year when properly prepared and stored [4,5]. Chitramanakku (CIC) is one such *chooranam* formulation that is widely prescribed in Siddha practice, particularly for conditions associated with aggravated *Vatham*, such as pain, inflammation, and musculoskeletal disorders [6]. According to Siddha pharmacological principles, therapeutic interventions are guided by the concepts of taste (*suvai*), potency (*veeriyam*), and post-digestive effect (*pirivu*) [3]. The primary ingredient of CIC, *Ricinus communis* leaves is described as possessing pungent and bitter tastes with hot potency, attributes that are considered effective in pacifying deranged *Vatham* [6].

Although CIC has been traditionally administered as an aega mooligai prayogam (single-herb preparation) [5] for various ailments, traditional usage alone is not sufficient to ensure safety in the context of contemporary global healthcare standards [7]. Notably, previous experimental studies on *Ricinus communis* leaf have reported acceptable safety margins at therapeutic dose levels in animal models, despite concerns related to toxicity from other plant parts such as seeds. These findings underscore the importance of dose, plant part selection, and processing methods in determining safety. In line with the growing emphasis on evidence-based validation of traditional medicines, systematic toxicological evaluation is essential to establish the safety profile of CIC for wider clinical acceptance and global use. Therefore, the present study was designed to assess the acute and sub-acute oral toxicity of *Ricinus Communis* in Wistar albino rats, following internationally accepted OECD Test Guidelines 423 (acute toxicity) and 407 (28-day repeated dose toxicity) [8,9]. This investigation aims to scientifically substantiate the traditional claims of safety and support the rational use of CIC in contemporary therapeutic practice

METHODOLOGY

Experimental Animals:

Toxicological evaluation of *Chitramanakku Ilai Chooranam* (CIC) was carried out in animal models following prior approval from the Committee for Control and Supervision of Experiments on Animals (CCSEA). The study was reviewed and approved by the Institutional Animal Ethics Committee (IAEC) of Arulmigu Kalasalingam College of Pharmacy, Thirunelveli, and conducted in the Institute's animal house facility. Wistar albino rats (*Rattus norvegicus*) of both sexes, weighing 140–160 g, were used for the study. The selected female rats were nulliparous and non-pregnant [8]. The animals were procured from an authorized animal breeder at the animal laboratory of TANUVAS, Madhavaram, Chennai, and housed at the Animal House facility, Arulmigu Kalasalingam College of Pharmacy. The rats were maintained in polypropylene cages under controlled environmental conditions with a temperature of 22 ± 2 °C, relative humidity of 40–65%, and a 12 h light/dark cycle. A 7-day acclimatization period was provided prior to the experiment. The animals had free access to standard feed and RO water *ad libitum*. The toxicity study was carried out in accordance with OECD guidelines 423 and 407 [8,9].

Effect of acute Toxicity Study (14 Days) of *Ricinus Communis*

The acute toxicity study was performed according to OECD Test Guideline 423. This method uses a stepwise approach with three animals of the same sex per dose, typically requiring two to four steps to assess mortality and classify acute toxicity. It minimizes animal use, provides reproducible results, and supports hazard classification rather than precise LD₅₀ determination, although an approximate LD₅₀ may be estimated when partial mortality occurs at multiple dose levels[8,10].



**Senthamil Veni et al.,****Experimental procedure:**

Twelve healthy, nulliparous, non-pregnant female Wistar albino rats were used and randomly assigned to two groups of three animals each after a 7-day acclimatization period. Animals were fasted overnight prior to dosing, with free access to water, and individual body weights were recorded to calculate dose levels. In the initial step, three rats were administered a single oral dose of CIC at 5 mg/kg body weight by gavage and observed for clinical signs of toxicity and mortality over a 14-day period. As no adverse effects were observed, subsequent groups received progressively higher single oral doses of CIC at 50, 300, and 2000 mg/kg body weight, respectively, following the same dosing and observation procedures. Throughout the study, animals were monitored for clinical signs of toxicity and changes in body weight. At the end of the 14-day observation period, all animals were euthanized and subjected to gross necropsy to identify any pathological alterations. Tissues showing gross lesions were further examined histopathologically. The maximum tolerated dose (MTD) of CIC was determined in accordance with the Globally Harmonised System (GHS) of Classification.

Determination of Animal Dose Level

As there is no toxicity observed at 2000mg/kg bw. The doses were determined from the results of acute toxicity study. The doses were as follows: Low dose – 50 mg/kg b. wt Mid dose – 300 mg/kg b. wt, High dose – 2000 mg/ kg b.wt.

Effect of 28 Days Repeated Oral Toxicity Study of Chitramanakku ilai chooranam

A 28-day repeated oral toxicity study was performed according to the OECD guideline, TG 407 (Revised - 18 December 2007). The OECD 407 guideline is important for assessing the subacute toxicity of a drug because it provides a standardized 28-day repeated-dose oral toxicity study that helps identify early harmful effects resulting from continuous exposure. It enables detection of target organ toxicity, establishes dose-response relationships, and determines the no-observed-adverse-effect level (NOAEL) [9]. A total of thirty healthy adult Wistar albino rats (15 males and 15 females), aged 6–8 weeks and weighing 150–180 g, were used for the study. The human therapeutic dose of MSC (2000 mg twice daily) was converted to the equivalent rat dose based on body surface area, resulting in a low dose of 180 mg/kg/day. Based on this, the animals were randomly divided into five groups (n = 6; 3 males and 3 females per group): Group I – control Group II - vehicle control, Group III – low dose (50 mg/kg/day), Group IV – mid dose (300 mg/kg/day), and Group V – high dose (2000 mg/kg/day). All treatments were administered once daily by oral gavage for 28 consecutive days. Animals were observed daily for clinical signs of toxicity and mortality. Body weights were recorded on Day 0, weekly thereafter, and on the day of necropsy. Food intake was monitored weekly, and mean consumption was calculated for each group. Clinical observations included general behaviour, skin and fur condition, eyes and mucous membranes, respiration, motor activity, reflexes, and signs of distress such as tremors, convulsions, lethargy, sleep, diarrhoea, or coma. Mortality and morbidity were checked twice daily.

At the end of the treatment period, animals were fasted overnight and euthanized using carbon dioxide inhalation. Blood samples were collected by cardiac puncture for hematological and biochemical analyses. Hematological parameters included hemoglobin, RBC, WBC with differential count. Biochemical markers such as urea, creatinine, bilirubin, SGOT, SGPT, and ALP were assessed using automated analyzers. Following blood collection, gross necropsy was performed, and major organs including brain, heart, lungs, liver, and kidneys were examined for lesions and weighed. Relative organ weights were calculated using the formula: (organ weight / body weight) × 100.

Statistical Analysis

Data were expressed as mean ± SEM, and statistical analysis was performed using one-way ANOVA followed by Tukey's multiple comparison test, with $p < 0.05$ considered statistically significant.





Senthamil Veni et al.,

RESULTS

The results of Acute and Subacute toxicity is represented in table 1 to 11. These tables provide a comprehensive overview of the evaluated parameters, including clinical observations, mortality data, body weight variations, food and water consumption, hematological indices, biochemical markers, organ weight measurements, and histopathological findings. The acute toxicity assessment primarily focuses on the immediate toxic manifestations while the subacute toxicity evaluation examines the cumulative effects of repeated exposure over the specified study period.

DISCUSSION

The toxicological assessment of *Chitramanakku ilai chooranam*(CIC) (CIC) indicates that the formulation is safe and well-tolerated following acute and repeated 28-day oral administration in Wistar albino rats. The acute oral toxicity study showed no mortality, abnormal clinical signs, or behavioral changes at an even at the highest dose of 2000 mg/kg body weight. Thus, CIC is classified as “Category 5 - unclassified” under the Globally Harmonized System (GHS) [10]. Evaluation of food consumption constituted an important component of the safety assessment, as adequate nutrient intake is essential for maintaining normal physiological function in experimental animals [11]. Ensuring appropriate nutrition allows observed effects to be attributed to the test substance rather than to secondary consequences of nutritional deficiency or imbalance. Consistent feed and water intake across groups further supports the absence of treatment-related systemic toxicity or physiological stress [12,13]. The progressive increase in body weight observed in all treated groups was comparable to that of the control group, indicating that CIC did not adversely affect normal growth patterns or metabolic processes [11]. In the repeated 28-day oral toxicity study, CIC did not produce any treatment-related adverse effects on general health and body weight progression.

In addition, assessment of hematological parameters is critical, as the hematopoietic system is highly responsive to toxic insults and reflects a wide range of pathological conditions [13]. The evaluation of blood parameters therefore provides essential insight into the potential effects of the test substance on blood cell production, immune competence, and physiological homeostasis [12]. Hematological parameters remained within normal physiological limits, suggesting the absence of myelotoxic or immunological disturbances. Biochemical analyses further demonstrated that hepatic and renal function markers were unaltered, indicating preserved liver and kidney function. Minor variations observed in certain parameters were within normal biological ranges and were not considered toxicologically significant. Gross pathological examination of major organs revealed normal architecture with no evidence of degenerative or inflammatory lesions, thereby corroborating the biochemical and clinical observations. Relative organ weight, a sensitive and reliable indicator of target organ toxicity, showed only minimal variations with no statistically significant or dose-dependent changes. These findings indicate that repeated exposure to CIC did not induce organ hypertrophy or atrophy and further support its overall systemic safety. Thus, the results confirm that *Ricinus Communis* does not elicit acute or sub-acute toxicity under the tested conditions and can be considered safe for therapeutic use when administered at appropriate doses.

CONCLUSION

Acute and sub-acute oral toxicity studies of CIC were conducted in Wistar albino rats in accordance with OECD guidelines. CIC did not produce any signs of toxicity or mortality at a limit dose of 2000 mg/kg body weight, thereby placing it under Category 5 of the Globally Harmonized System (GHS) for acute toxicity. Furthermore, the 28-day repeated oral toxicity study revealed no mortality or treatment-related adverse effects on any specific organ. These findings confirm the establishment of a no-observed-adverse-effect level (NOAEL) for CIC under the tested conditions.





REFERENCES

1. B Abarna, M Sathyarathish, M Natarajan, M Raghavi, P Shanmugapriya. Thanga Uram: A Dual Perspective Review Of Its Pharmacological Benefits In Modern And Siddha Medicine. *Int J Res Ayurveda Pharm.* 2024 Oct 30;15(5):97–102. doi:10.7897/2277-4343.155163
2. Abarna B, Saranyapriya E, Adithya RS, Murugesan S, Madhavan R. Assessment of Quality parameters and Safety in *Indigofera tinctoria* L. (Avuri) Rootbark extract. *Res J Pharm Technol.* 2024 Oct 22;17(10):4941–6. doi:10.52711/0974-360X.2024.00760
3. Abarna B, Karpagambal R, Raghavi M, Suresh R, Manjari V. Systematic Drug Review on *Mookirattai Chooranam* in the Management of Musculoskeletal Diseases and Gastrointestinal Diseases. *J Nat Remedies.* 2025 Apr 29;837–47. doi:10.18311/jnr/2025/47933
4. Sornamariyammal I. Thathukalin Vilakkamum Marunthu muraikalum,. Chennai: Amudha Nilayam; 2012.
5. Thiagarajan R. Gunapadam thathu – Jeeva vagupppu. 1st ed. Vol. 1. Chennai: Indian Medicine and Homeopathy Department; 2009.
6. Murugesu Mudaliar K S. Gunapadam – Mooligai Vaguppu. Chennai: Department of Indian Medicine and Homoeopathy; 2013. (Part 1).
7. Vetha Merlin Kumari H, Karthikeyan Karu, H.Nalini Sofia. Acute And Longterm Toxicity Study Of A Siddha Polyherbal Durg Adathodai Chooranam. Vol. 10. 2020 Jun 1;10:809–23.
8. OECD. Test No. 423: Acute Oral toxicity - Acute Toxic Class Method. OECD Guidel Test Chem Sect 4. 2002 Feb 7. doi:10.1787/9789264071001-en
9. OECD. Test No. 407: Repeated Dose 28-day Oral Toxicity Study in Rodents. OECD Guidel Test Chem Sect 4. 2025 Jun 24. doi:10.1787/9789264070684-en
10. Vereinte Nationen, editor. Globally harmonized system of classification and labelling of chemicals (GHS). New York Geneva: United Nations; 2021. 550 p. (United Nations publication).
11. Elankani P, Dayanand Reddy G, Ganesan R, Rama Devi B, Narasimha Kumar GV. Evaluation Of Chronic Toxicity Of Gowri Chinthamani Chenduram In Wistar Albino Rats. *J Bio Innov.* 2020 Jul 1;09(04):557–76. doi:10.46344/JBINO.2020.v09i04.17
12. Manoharan A. Acute And Sub Acute Toxicity Study On Siddha Drug *Cuṇṭiyāti Cūṇam*. *J Med Sci Clin Res* [Internet]. 2021;09. Available from: <https://api.semanticscholar.org/CorpusID:236305844>
13. Marimuthu R, Balasubramani A, Ramamoorthy K, Ramasamy S, Rajaraman R, Rajathinakaran SA, et al. Toxicological Evaluation of Ashtabhairava mathirai Acute and Subacute Safety Assessment. *Asian J Biol Life Sci.* 2025;14(14).

Table no –1 Physical and behavioral examinations

Group no.	Dose(mg/kg)	Observation sign	No. of animal affected	Mortality
Group-I	5mg/kg	Normal	0 of 3	0 of 3
Group-II	50mg/kg	Normal	0 of 3	0 of 3
Group-III	300mg/kg	Normal	0 of 3	0 of 3
Group-IV	2000mg/kg	Normal	0 of 3	0 of 3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=3); nsp >0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. Data obtained in this study indicated nsp >0.05 no significant changes the physical and behavioral signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.





Senthamil Veni et al.,

Table No. 2 Home cage activity

Functional and Behavioural observation	Observation	5mg/kg Group (G-I)	50mg/kg (G-II)	300mg/kg (G-III)	2000mg/kg (G-IV)
		Female n=3	Female n=3	Female n=3	Female n=3
Body position	Normal	3	3	3	3
Respiration	Normal	3	3	3	3
Clonic involuntary Movement	Normal	3	3	3	3
Tonic involuntary Movement	Normal	3	3	3	3
Palpebral closure	Normal	3	3	3	3
Approach response	Normal	3	3	3	3
Touch response	Normal	3	3	3	3
Pinna reflex	Normal	3	3	3	3
Tail pinch response	Normal	3	3	3	3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p >0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. Data obtained in this study indicated ^{ns}p >0.05 no significance changes in Home cage activity, signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.

Table no-3 Hand held observation

Functional and Behavioral observation	Observation	(G-I)	(G-II)	(G-III)	(G-IV)
Reactivity	Normal	3	3	3	3
Handling	Normal	3	3	3	3
Palpebral closure	Normal	3	3	3	3
Lacrimation	Normal	3	3	3	3
Salivation	Normal	3	3	3	3
Piloerection	Normal	3	3	3	3
Pupillary reflex	Normal	3	3	3	3
Abdominal tone	Normal	3	3	3	3
Limb tone	Normal	3	3	3	3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p >0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. Data obtained in this study indicated ^{ns}p >0.05 no significance changes in hand held observation and signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.

Table :5 Effect of Sub- Acute Dose (28 Days) of *Ricinus Communis* on Body Weight In Gram

Group	Normal control	Vehicle Control	Low	Mid	High
1 st day	191.02±0.15	189.03±0.06	211.08±0.08	185.02±0.03	190.06±0.03
7 th day	197.07±0.03	194.04±0.08	215.10±0.09	187.09±0.10	196.02±0.07
14 th day	203.08±0.02	207.09±0.03	216.04±0.04	188.03±0.15	198.94±0.09
21 st day	211.05±0.09	214.07±0.09	217.07±0.06	189.04±0.08	206.06±0.05
28 th day	215.12±0.10	218.07±0.08	219.06±0.07	193.02±0.09	208.06±0.08

Values are expressed as mean ± SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p >0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The effect of CIC was observed, on the body weight changes, significantly increase (*p<0.05) in body weight in all the treated animals were observed. The values are expressed as mean ± S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV.





Senthamil Veni et al.,

Table:6 Effect of Sub- Acute Dose (28 Days) of on Food Intake In Gram

GROUP	CONTROL	VEHICLE CONTROL	LOW	MEDIUM	HIGH
1st day	22.12±0.15	20.16±0.13	19.12±0.07	19.11±0.11	21.12±0.10
7th day	21.04±0.27	22.53±0.09	20.09±0.16	21.09±0.13	22.19±0.22
14th day	20.14±0.09	20.18±0.16	21.16±0.19	20.80±0.19	21.19±0.10
21st day	19.22±0.08	21.09±0.15	22.19±0.78	22.03±0.10	20.25±0.15
28th day	21.29±0.04	22.94±0.12	22.09±0.19	21.04±0.09	21.83±0.08

Values are expressed as mean ± SEM Statistical significance (p) calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The Food intake values was compared in Group I to other groups II, III, IV, and V. in experimental rat. Final study, significantly increase in the Food intake values. The values are expressed as mean ± S.E.M. n=6.

Table:7. Effect of Sub acute dose of Chitramanakku ilai chooranam (CIC) on Water Intake in ml

GROUP	CONTROL	VEHICLE CONTROL	LOW	MIDUM	HIGH
1st day	12.08±0.16	16.35±0.16	12.25 ±0.31	13.27±0.09	13.06±0.08
7th day	16.17±0.92	15.19±0.16	13.91 ±0.47	16.08±0.07	12.09±0.31
14th day	13.29±0.19	14.27±0.52	12.83 ±0.41	15.14±0.06	14.41±0.41
21st day	16.27±0.32	15.26±0.12	13.29 ±0.11	14.35±0.05	15.53±0.83
28th day	15.02±0.29	13.45±0.35	12.57±0.14	12.43±0.04	16.43±0.54

Values are expressed as mean ± SEM. Statistical significance (p) was calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with the control group. Water intake was compared in Group I and the other groups (II, III, IV, and V) in experimental rats. In the final study, there was a significant increase in water intake. Values are expressed as mean ± S.E.M. n=6.

Table :8 CIC on organ weight (Physical Parameter) In Grams

Group	Control	Vehicle Control	Low	Mid	High
HEART	2.52±1.23	2.4±0.21	2.47±0.21	2.52±0.25	2.59±0.23
LIVER	4.72±0.56	4.46±0.31	4.74±0.34	4.19±0.38	4.58±0.16
LUNGS	2.3±0.32	1.89±0.22	1.84±0.38	1.79±0.26	1.83±0.38
KIDNEY L	1.44±0.66	1.37±0.58	1.36±0.10	1.43±0.12	1.41±0.28
KIDNEY R	1.48±0.13	1.34±0.02	1.32±0.47	1.46±0.28	1.42±0.37

Values are expressed as mean ± SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The effect of CIC on kidney, heart, liver and lungs of the rats were recorded. not significant p>0.05 changes in the weights of various organs of the animals occurred with higher doses of the extract but macroscopic examinations visualized no changes in color of the organs of the treated animals compared with the control group.

Table no :9 Effect of Sub acute dose of Chitramanakku Ilai Chooranam (CIC) on Haematological Parameters

Drug treatment	RBC Millin/mm ³	WBC Thou/mm ³	Haemoglobin gm/dl	Differential count %			
				Neutrophils	Eosinophils	Monocyte	Lymphocyte
Control	4.60±0.05	5.40±0.03	10.18±0.11	50.06±0.56	3.08±0.07	8.12±0.13	35.44±0.04
Vehicle Control	4.80±0.03	8.10±0.04	12.06±0.09	53.07±0.02	3.25±0.09	6.09±0.01	38.46±0.17
LOW	4.63±0.05	7.82±0.07	11.55±0.03	54.11±0.08	3.41±0.18	8.20±0.03	35.19±0.10
MID	4.70±0.03	6.71±0.08	10.08±0.09	52.42±0.11	3.22±0.14	7.28±0.02	33.08±0.08
HIGH	4.90±0.04	7.20±0.09	12.27±0.14	53.04±0.11	3.15±0.02	8.36±0.02	35.36±0.19





Senthamil Veni et al.,

Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The effect of CIC were observed for its effect on hematological parameters in experimental rat. Final study, not significant (p<0.05) in the haemoglobin, RBC values are increased after treated groups. The values are expressed as mean $\pm$ S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV.

Table : 10 Effect of Sub- Acute Dose(28 Days) of CIC on Biochemical Parameter

Drug Treatment	SGPT (U/L)	SGOT(U/L)	Urea (mg/dl)	Creatinine (mg/dl)	Bilirubin
Control	32.09 $\pm$ 0.08	22.38 $\pm$ 0.08	23.07 $\pm$ 0.09	0.88 $\pm$ 0.33	0.97 $\pm$ 0.34
Vehicle Control	27.45 $\pm$ 0.04	30.26 $\pm$ 0.15	3.28 $\pm$ 0.08	0.78 $\pm$ 0.35	0.75 $\pm$ 0.33
LOW	26.18 $\pm$ 0.03	18.38 $\pm$ 0.10	28.28 $\pm$ 0.19	0.64 $\pm$ 0.25	0.74 $\pm$ 0.14
MID	29.08 $\pm$ 0.18	26.16 $\pm$ 0.17	25.72 $\pm$ 0.15	0.62 $\pm$ 0.15	0.75 $\pm$ 0.44
HIGH	28.17 $\pm$ 0.05	20.03 $\pm$ 0.04	27.08 $\pm$ 0.28	0.94 $\pm$ 0.19	0.76 $\pm$ 0.39

Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The SGPT, SGOT, ALP, UREA and Creatinine values was compared in Group I and other groups II, III, IV. The biochemical Parameters in experimental rat not significant (p<0.05) in The SGPT, SGOT, ALP, Bilirubin, urea and Creatinine values. The values are expressed as mean $\pm$ S.E.M. n=6.

Table: 11 Effect of Sub Acute Doses (28 Day) of CIC on electrolytes

GROUP	CONTROL	VEHICLE CONTROL	LOW	MEDIUM	HIGH
Sodium (mmol/L)	135.09 $\pm$ 0.16	135.33 $\pm$ 0.03	136.05 $\pm$ 0.15	137.07 $\pm$ 0.11	138.57 $\pm$ 0.32
chloride(mmol/L)	101.45 $\pm$ 0.19	98.24 $\pm$ 0.18	101.08 $\pm$ 0.19	98.35 $\pm$ 0.28	101.06 $\pm$ 0.55
potassium(mmol/L)	3.87 $\pm$ 0.11	4.21 $\pm$ 0.13	4.08 $\pm$ 0.14	4.08 $\pm$ 0.41	4.89 $\pm$ 0.12

Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. There was no significant changes in the Electrolyte level in all the treated animals compared to the control. The values are expressed as mean $\pm$ S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV and V

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Ayurvedic Management of Sidhma Kustha (Psoriasis) : A Case ReportUpasana S. Pawar^{1*}, Yogita Mandle² and Dnyaneshwar M. Gadade¹¹Third Year PG Scholar, Department of Samhita and Siddhanta, Parul Institute of Ayurved and Research, Parul University, Vadodara, Gujarat, India²Associate Professor, Department of Samhita and Siddhanta, Parul Institute of Ayurved and Research, Parul University, Vadodara, Gujarat, India

Received: 15 Mar 2026

Revised: 10 Apr 2026

Accepted: 12 May 2026

Address for Correspondence*Upasana S. Pawar**

Third Year PG Scholar,

Department of Samhita and Siddhanta,

Parul Institute of Ayurved and Research,

Parul University, Vadodara, Gujarat, India

E.Mail: pawarupasana158@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Skin is considered a reflection of internal health in *Ayurveda*, mirroring both physical and mental states. In the present era, skin disorders such as *Psoriasis* are on the rise due to improper dietary habits, stress, and a sedentary lifestyle. Modern science identifies psoriasis as a chronic, immunologically influenced inflammatory disease. Condition prevalence ranges between 0.5% and 3% worldwide. Despite various treatments, achieving complete remission remains challenging. In Ayurvedic texts, *Psoriasis* closely resembles *Sidhmakushta*, a subtype of *Kushtha Roga*, primarily involving *Vata* and *Kapha* doshas with features like *Aswedanam*, *Suklaraktabhabhasah*, *Visirya*, and *Bahirdaruni*. We present the case of a 32-year-old man diagnosed with chronic plaque psoriasis. Experiencing multiple scaly, erythematous plaques with intense itching for five months. He had previously undergone allopathic management with limited relief. Based on Ayurvedic *Samprapti*, *Shodhana* and *Shamana* chikitsa were administered, including *Panchtikta Kwatha*, *Nimbadi Kwatha*, *Mahamajisthadi Kwatha*, *Panchatiktaghrita Guggulu*, and *Nalpamaradi Taila*, along with *Pathya-Apathya* guidance. The patient followed a restricted diet, avoiding *Viruddha Ahara*, *Amla*, and *Katu* substances and discontinued *Divasvapna* (daytime sleeping). Clinical outcomes were assessed using the PASI score, which significantly reduced from 21.4 to 1.2 within 85 days, showing a 94.39% improvement. No adverse effects were noted. This case highlights that, through appropriate diagnosis based on *Dashavidha Pariksha*, understanding *Dosha-Dushya Sammurchana*, and following classical therapeutic protocols, chronic conditions like *Sidhmakushta* can be effectively managed. It reinforces the holistic and evidence-based potential of Ayurveda in treating relapsing skin diseases like psoriasis.

Keywords: Ayurveda, *kushtha*, *Sidhmakushta*, Psoriasis area severity index score, Psoriasis.



Upasana S. Pawar et al.,

INTRODUCTION

The skin acts as the body's primary protective barrier, protecting internal organs and regulating temperature, fluid balance, and sensory perception. In Ayurveda, it is considered a mirror of one's overall health, reflecting the physical, mental, and emotional state. In today's era of rapid modernisation, the prevalence of skin disorders has risen significantly due to lifestyle changes, poor dietary habits, stress, and unhygienic conditions. These conditions not only affect the body physically but also have a profound psychological impact, often leading to embarrassment, anxiety, low self-esteem, and depression in affected individuals. Psoriasis is a chronic, relapsing condition that demands long-term management to control symptoms and prevent recurrence. Treatment choice depends on disease severity, comorbidities, and healthcare accessibility, requiring an individualised approach for effective and sustained therapeutic outcomes. Classification of psoriasis into mild or moderate-to-severe types depends on the severity of skin lesions, BSA involvement, and degree of impairment in quality of life.[1] It is a chronic and recurrent immune-driven dermatosis seen in nearly 1%-2% of individuals worldwide and is recognised as a significant global health concern due to its multifactorial nature and impact.[2] Characterised by erythematous, scaly plaques, the condition typically affects the extensor surfaces, scalp, and lower back.[3] Psoriasis is a global health burden, impacting approximately 0.5% to 3% of people worldwide.[4] Although the exact cause is unknown, psoriasis is believed to be an autoimmune disorder primarily mediated by T lymphocytes.[5] It significantly affects psychosocial well-being, often interfering with the patient's quality of life.[6] The disorder presents in multiple variants, with plaque-type representation being the most common. Its lesions typically appear on the trunk, limbs, and scalp.[7] Despite tremendous advancements in modern science, particularly in dermatology, there is still no proven treatment for psoriasis.

In Ayurveda, all skin diseases come under *Kushtha Roga*. In Ayurveda, psoriasis is analogous to *Sidhmakushtha* condition involving *Vata-Kapha dosha* predominance, described under chronic skin disorders. Also Vata - Pitta - Kapha manifestation characterised by symptoms such as *alabupuspasadsaksam* (resembling flowers of a gourd), *prash* (dry lesions), *Arunabh* (whitish), *Visirya* (Broken), *Aswedanam* (anhidrosis), *Bahirdaruni* (Thin appearing skin outside), *Antahsnigdhani* (unctuous inside), *Suklaraktabhabhasah* (whitish and reddish tinged lesions), *daughdhikapuspavat* (resembles *daughdhika* flower) [8] etc, explained Classical texts cite *Sidhmakushtha* (causes) as consuming incompatible foods (*Viruddhaahara*), suppressing natural urges (*Vega dharana*), along with day sleeping (*Divasvapna*) and indulgence in sinful actions (*Papakarma*), which together contribute to the disease's development. This case report aims to explore the Ayurvedic approach in managing a case of *Sidhmakushtha*, highlighting classical principles and clinical outcomes.

MATERIALS AND METHODS

Patient Information

A 32-year-old male visited the Ayurveda OPD with chief complaints of multiple thickened, erythematous plaques over the back region. Legs, along with arms, outpatient department (OPD) on June 07, 2024, complaining of back and leg itching. The Distribution appears symmetrical across all four limbs in the past 2 months, 25 days. The patient had been treated under modern medicine for psoriasis, which included methotrexate (2 mg once weekly), Apremilast (30 mg, twice daily), a 6% topical lotion, and liquid paraffin, both applied twice a day. A weekly dose of Vitamin D3 (60,000 IU) was also administered. This treatment was recommended by an allopathic dermatologist. The patient had no prior record of diabetes, high blood pressure, or any serious health conditions. Additionally, no drug allergies were noted, no past surgeries, and no habits of smoking, alcohol use, or substance abuse. The patient had reduced appetite, normal thirst, and regular bowel and bladder Function. Sleep was frequently disturbed due to intense itching. Dietary history revealed excessive intake of milk, curd, salty and sour foods. The patient also reported a habit of sleeping during the daytime, contributing to the aggravation of symptoms.



Upasana S. Pawar *et al.*,

Clinical Observations

The patient had several scaly, Multiple hyperpigmented, dry plaques and well-defined margins. Silvery-white scaling is prominent on several lesions, suggestive of psoriasiform pathology. Some plaques show thickening and raised surfaces (induration), dooshi vish present ++. Older lesions show post-inflammatory hyperpigmentation [Figure1]. The presentation was distributed symmetrically. Involves both lower limbs extensively (legs, knees, dorsum of feet), affects the upper limbs and back. Koebner's phenomenon signs were positive (lesions appearing at sites of friction). The patch appears dry and rough. Flaky scales are seen on legs and arms. No signs of oozing, discharge, or infection in the visible areas. The varying sizes of plaques are round to irregular in shape. He showed signs of poor appetite and irregular sleep routines. Five months ago, a small, round patch appeared on the patient's back. Patches progressively appeared on the shoulders, limbs, and back, accompanied by intense itching and silvery scaling. On clinical examination, the patient was afebrile with stable vital signs. Pallor, icterus, clubbing, cyanosis, and lymphadenopathy were not observed. Systemic assessment encompassed the cardiovascular, respiratory, urinary, and CNS, which showed normal findings, indicating overall systemic stability.

Timeline

With reference to the *Dosha* and *Dushya* involved, the patient underwent *Shodhana* (purificatory) and *Shamana* (pacifying) therapies alongside strict dietary modifications. He avoided sour foods like lemon and tamarind, salty snacks, spicy, packaged, curd, jaggery, meat, fish, and sesame seed. Advising against daytime sleep and emphasizing personal hygiene, oral and topical Ayurvedic medicines were prescribed. Treatment efficacy was assessed through evaluations conducted before therapy, posttherapy, and during follow-up. [Table1]

Diagnosis

The patient first sought medical advice on February 04, 2024, and was diagnosed with psoriasis. He was placed on allopathic treatment, which he continued for three months before voluntarily discontinuing the medications. As his condition showed no improvement, he consulted another allopathic dermatologist on May 17, 2024, who advised maintaining the same treatment plan. Due to inadequate relief, the patient later presented to our Ayurvedic OPD seeking alternative care. A preliminary evaluation using the Psoriasis Area and Severity Index (PASI) revealed a score of 21.4. All allopathic medications were ceased prior to initiating Ayurvedic intervention. Patient's clinical presentation was evaluated through classical signs of *Sidhmakushtha*, including *Aswedanam*, *Suklaraktabhabhasah* and discolouration (*Krishna Aruna Varna*). Routine lab tests on June 9, 2024, showed normal results (CBC, LFT) except a platelet count of 154,000/ μ L. Ayurvedic consultation and Ayurvedic treatment begin on June 7, 2024, with *Shamanachikitsa* administered for two months. Progress was monitored using the PASI score and symptom changes, indicating noticeable improvement throughout the treatment period. The individual's strength was assessed through *Dashavidha Aturapariksha* (tenfold patient examination). [9] The patient's constitution (*Prakriti*) was identified as *Pitta-Vataja*. His tissue quality (*Sara*), structural build (*Samhanana*), body measurement (*Pramana*), digestive strength (*Ahara Shakti*), mental strength (*Satva*), and age (*Vaya*) were found to be of a moderate (*Madhyama*) level. However, his capacity for physical exertion (*Vyayama Shakti*) and dietary adaptability (*Satmya*) were low (*Avara*). The observed imbalance (*Vikriti*) was of *Vata-Pitta-Kaphaja* origin. These factors provided a holistic basis for personalised Ayurvedic management.

Samprapti Ghataka (Ayurvedic Pathogenesis)

The condition showed dominance of *Vata-Kapha* doshas. The *Dushyas* (affected tissues) included *Twak* (skin), *Mamsa* (muscle), *Rakta* (blood), and *Ambu* (fluids), and *Raktavaha*, responsible for nutrient Fluids and blood transport channels. The *Rogadhithana* (site of manifestation) was *Twak*. *Agni* (Digestive fire) was observed to be *Manda* (mildness), indicating sluggish metabolism. The *Svabhava* (nature of the disease) was *ChirakaalaAnubandhini*, suggesting its chronic and persistent course. This guided the selection of appropriate Ayurvedic interventions.

Therapeutic Intervention

The therapeutic measures administered during the intervention period are listed in Table 1.





RESULTS AND DISCUSSION

Results and Following up

Following two months and 25 days of treatment, scaling, itching, and plaques significantly decreased, with marked improvement in overall condition.[Fig.1] By the conclusion of therapy, the PASI score had reduced to 1.2. [Table 2]. This corresponds to a 94.39% reduction in PASI score, indicating substantial clinical improvement through classical Ayurvedic intervention.

DISCUSSION

The primary factors contributing to the development of *Sidhmakushtha* involve the predominance and imbalance of *Vata* and *Kapha* doshas, which affect the *Sapta Dushya*. Taking in *Nidana*, or causative agents, leads to simultaneous aggravation of these *doshas* and results in *Shaithilyata*, meaning weakness or laxity, in the affected *Dhatu*s. This weakened state of *Dhatu*s further promotes the clinical presentation of *Kushtha*. [10] In this particular case, the patient's unhealthy dietary habits such as excessive consumption of milk mixed with salt, curd, and overly salty or sour foods along with daytime sleeping, likely triggered the *dosha* imbalance, contributing to the disease's onset. Although the exact pathological mechanism from a modern scientific perspective remains to be fully elucidated, Ayurvedic principles guided the treatment approach. Considering the dominant involvement of *Vata* and *Kapha* doshas and the affected tissues, the patient was administered a *Vata-Kapha* pacifying regimen combined with a *Pathya* diet emphasising light, easily digestible. The prescribed diet comprised bitter vegetables such as aged cereals. [11]

Interventions' Probably Method of Action

Panchatikta Kwath, composed of *Nimba*, *Vasa*, *Guduchi*, *Patola*, and *Kantakari*, exhibits strong *Kushthaghna* and *Raktashodhaka* properties. Its *Tikta Rasa* and *Ushna Virya* reduce *Kleda*, purify *Rakta*, cleanse *Srotas*, and pacify *Vata-Pitta*, thereby arresting the progression of *Kushtha* like *Sidhma*. *Nimbadi Kwath*, containing *Nimba*, *Guduchi*, *Triphala*, *Vacha*, and *Trikatu*, acts through its *Tikta* and *Kashaya Rasa*. It purifies *Rakta*, reduces *Kleda*, and pacifies *Tridosha*. Its ingredients synergistically support *Srotoshodhana*, anti-inflammatory action, and skin detoxification in conditions of *Kushtha*. *Bilvadi Gulika* contains *Bilva*, *Agnimantha*, *Shunti*, *Pippali*, *Maricha*, *Vacha*, and other herbs with *Deepana*, *Pachana*, *Krimighna*, and *Vishaghna* properties. It detoxifies the body, calms *Vata* and *Kapha*, and acts as an antimicrobial and antiallergic agent useful in skin diseases with an underlying *Ama* or toxin load. *Aragwadhadi Kapila*, containing *Aragwadh*, *Nimba*, *Haridra*, *Guduchi*, and *Triphala*, acts as a potent *Kushthaghna*, *Raktashodhaka*, and *Kledashoshaka*. It detoxifies the skin, purifies blood, and pacifies *Pitta* and *Kapha*.

Its *Tikta-Kashaya Rasa* and *Ushna Virya* help break the pathogenesis of skin disorders like *Kushtha*. *Mahamajishthadi Kwatha*: It is indicated in all types of *Kushtha*. *Manjistha* is known for its *Varnya*, *Kushthaghna*, and *Rakta Shodhaka*, *krimighna*, *Shonita sthapaka* actions. It purifies blood, alleviates inflammation and pain, and modern studies support its antioxidant and anticancer potential, enhancing its therapeutic relevance. *Nalpamaradi Taila*, comprising *Nalpamara* (*Ficus* species) barks, *Haridra* (turmeric), *Manjistha*, *Chandana* (sandalwood), *Vetiver*, and *Sesame* oil, exhibits *Kushthaghna*, *Raktashodhaka*, *Shothahara*, and *Varnya* properties. It purifies blood, alleviates skin inflammation, reduces pigmentation, and enhances complexion, effectively managing various skin disorders. *Panchamahatiktaka Ghrita guggulu*, with its *Kushthaghna* and *Vata-Pitta Shamana* properties [12], reduces *Kleda*, purifies microchannels (*Srotas*), pacifies vitiated *Doshas*, and effectively interrupts the disease process in *Sidhmakushtha*. *Dadhi* (curd) prevents skin dryness and scaling when applied topically. Clinical studies also demonstrate its antimicrobial properties, making it beneficial in managing various skin conditions. Prescribed oil from coconuts has anti-inflammatory and skin-protection properties. Applying it helps reduce itching, dryness, and redness in skin lesions. [12] When combined with *Wrightia tinctoria* leaf extract, it exhibits significant anti-psoriatic and antioxidant effects, enhancing therapeutic outcomes. [13]



Upasana S. Pawar *et al.*,

CONCLUSION

Based on the positive symptom improvement seen in this case, it suggests that while full recovery might not be achieved in a brief treatment period of two months and 25 days, Ayurvedic treatments can still deliver significant relief in psoriasis symptoms without notable adverse consequences.

Consent Declaration from the Patient

The authors confirm that informed consent was obtained from the patient for the publication of this case report, including the use of clinical details and images. The patient was informed that their name and initials would not be disclosed, and while all reasonable efforts will be made to protect their identity, complete anonymity cannot be guaranteed.

REFERENCES

1. Mrowietz U, Kragballe K, Reich K, Spuls P, Griffiths CE, Nast A. Definition of treatment goals for moderate to severe psoriasis: A European consensus. *Arch Dermatol Res* 2011;303(1):1-10.
2. Smith CH, Barker JN. Psoriasis and its management. *BMJ* 2006;333(7564):380-4.
3. Elman SA, Weinblatt M, Merola JF. Targeted therapies for psoriatic arthritis: An update for the dermatologist. *Semin Cutan Med Surg* 2018;37:173-81.
4. Parisi R, Symmons DP, Griffiths CE, Ashcroft DM; Identification and Management of Psoriasis and Associated Comorbidity (IMPACT) Project Team. Global epidemiology of psoriasis: A systematic review of incidence and prevalence. *J Invest Dermatol* 2013;133(2):377-85.
5. Nguyen CT, Bloch Y, Skladanowska K, Savvides SN, Adamopoulos IE. Pathophysiology and inhibition of IL-23 signalling in psoriatic arthritis: A molecular insight. *Clin Immunol* 2019;206:15-22.
6. Langley RG, Krueger GG, Griffiths CE. Psoriasis: epidemiology, clinical features, and quality of life. *Ann Rheum Dis* 2005;64(Suppl 2):i18-23.
7. Nair PA, Badri T. Psoriasis. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2023.
8. Acharya YT, editor. Charaka Samhita of Charaka. Chikitsa Sthana, Kushta Chikitsa; Chapter 7, Verse 19. Varanasi: Chaukhambha Surbharati Prakashan; 2016. p. 451.
9. Acharya YT, editor. Charaka Samhita of Charaka. Vimana Sthana; Chapter 8, Verse 94. Varanasi: Chaukhambha Surbharati Prakashan; 2016. p. 276.
10. Acharya YT, editor. Charaka Samhita of Charaka. Nidana Sthana; Chapter 5, Verse 3. Varanasi: Chaukhambha Surbharati Prakashan; 2016. p. 216.
11. Mishra SN, editor. Bhaishajya Ratnavali of Kaviraj Govind Das Sen. Kusthadhikara; Verses 372-378. Varanasi: Chaukhambha Surbharati Prakashan; 2016. p. 914-5.
12. Tripathi B, editor. Ashtanga Hridayam of Vagbhatta. Chikitsa Sthana; Chapter 19, Verses 8-10. Varanasi: Chaukhambha Surbharati Prakashan; 2018. p. 783.
13. Dhanabal SP, Raj BA, Muruganantham N, Praveen TK, Raghu PS. Screening of Wrightia tinctoria leaves for anti-psoriatic activity. *Hygeia* 2012;4:73-8.

Table 1. Therapeutic interventions used in the treatment

Sr. No	Medicine	Dose	Time
1.	<i>Panchtikthaka kwath</i>	20ml	TID Before Food
2.	<i>Nimbadi Kwath</i>	15ml	TID After Food
3.	<i>Vilvadi Gulika</i>	500mg	2-0-2 After Food
4.	<i>Aragwadhadi Kapila</i>	500gm	1-0-1 Before Food
5.	<i>Nalpamaradi Taila</i>	30ml	External apply Daily once



Upasana S. Pawar *et al.*,

6.	<i>Mahamajisthadi Kwatha</i>	40ml	Daily Once After Food
7.	<i>panchikttaghrita Guggulu</i>	500mg	2-0-2 After Food

Table 2: PASI (Psoriasis Area Severity Index) Score of the Patient

	Cephalic region including the neck (10%)	The hands (20%)	Back (30%)	Leg (40%)
Skin area involved (%)	-	50%	40%	60–70%
Area score	-	4	3	4
Erythema (redness)	-	2	2	2
Induration (thickness)	-	2	2	2
Desquamation (scaling)	-	2	2	3
Score	-	4.8	5.4	11.2

The total PASI score, which was 21.4 at baseline (comprising 11.2 for lower limbs, 5.4 for trunk, 4.8 for upper limbs, and 0 for head), significantly reduced to 1.2 following Ayurvedic management, with only minimal involvement in the lower limbs

	
	
Before Treatment	After Treatment

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

From Colic to Comfort : Wonders of *Berberis vulgaris* Q in Renal Calculi : A Clinical Case Report

Khyati Lakhani^{1*}, A.N. Mathur² and Ankur Desai³

¹Ph.D. Scholar, Homoeopathy University, Jaipur; Professor and HOD, Department of Organon of Medicine-PG, Parul Institute of Homoeopathy and Research, Parul University, Waghodia, Gujarat, India

²President, Homeopathy University, Jaipur, India.

³Principal, HOD and Professor, Department of Pathology, Parul Institute of Homoeopathy and Research, Parul University, Waghodia, Gujarat, India.

Received: 10 Mar 2026

Revised: 07 Apr 2026

Accepted: 12 May 2026

*Address for Correspondence

Khyati Lakhani

Professor and HOD,

Department of Organon of Medicine,

Parul Institute of Homoeopathy and Research,

Parul University, Waghodia, Gujarat, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

: A case of renal calculi was treated at the PIHR Hospital OPD following homoeopathic principles of case taking. The patient presented with chief complaint of left sided flank pain for 15 days which was aggravated at night⁺⁺⁺, sitting⁺⁺ and ameliorated by standing. Also, it was associated with nausea and vomiting and H/o Hematuria. Ultrasonography revealed 6.5 mm calculus in left lower ureter (3cm proximal to UVJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. Based on totality of symptoms *Berberis vulgaris* Q – 15 drops in ½ cup of water TDS for 15 days was prescribed. Significant symptomatic relief was observed within two weeks, with pain on the Numerical Ratings Scale reducing from 7/10 to 0/10. Follow-up ultrasonography after fourteen weeks showed complete resolution of calculi in both kidneys. This case report highlights the clinical effectiveness of *Berberis Vulgaris* Q in management of renal calculi.

Keywords: Renal calculi, Homoeopathy, *Berberis vulgaris* Q, Pain NRS, Case report

INTRODUCTION

Renal calculi, more commonly referred to as kidney stones, are one of the most common and painful urological condition encountered globally³⁴. The estimated global prevalence is 12% of the population, with a consistent rise in incidence and prevalence in both developed and developing countries⁷. In India, the overall prevalence of urolithiasis is approximated to be about 12% of the population⁷. There is a significant predominance in males with a male-to-female ratio of about 4:3⁶.





Khyati Lakhani et al.,

Renal calculi can be managed through various therapeutic systems, including conventional Allopathic, Ayurvedic, Homoeopathic, Herbal medicine systems etc. Conventional management includes analgesics, hydration, medical expulsive therapy, or surgical intervention. Homoeopathy is a gentle system of healing. There are many remedies for renal calculi in Homoeopathy like *Berberis Vulgaris*, *Calcarea Renalis*, *Cantharis*, *Hydrangea*, *Lycopodium Clavatum*, *Nux Vomica*, *Pareira B*, *Sarsaparilla*, *Ocimum Can*, *Tabacum*, *Uva Ursi*, *Nux Vomica*, etc.². *Berberis vulgaris* being one of the most frequently indicated medicines due to its affinity for the urinary tract specially for the left sided Renal colic where there is characteristic stitching, cutting pain from left kidney following course of ureter into bladder and urethra which is worse by touch, when sitting and lying, from jar, from fatigue.¹

Many individuals tend to neglect treatment for renal calculi and often seek medical treatment when they experience severe colicky pain, which can delay timely management and increase the risk of complications. Irrespective of size, all renal calculi require appropriate evaluation and management to prevent potential complications and preserve renal function. In this context, this case highlights the efficacy of *Berberis vulgaris* Q in alleviating the colicky pain and facilitating the resolution of renal calculi.

OBJECTIVES

To evaluate the efficacy of *Berberis vulgaris* Q in relieving renal colic using pain NRS.

To evaluate the efficacy of *Berberis vulgaris* Q in expulsion of renal calculi.

MATERIALS AND METHODOLOGY

- **Study Setting:** The study is conducted at O.P.D of Parul Institute of Homoeopathy & Research & Hospital, Ishwarpura, Limda, Vadodara, Parul University
- Date: 30/07/25
- Name: SHS
- Age: 45 years
- Gender: Male
- Education: 10th std
- Religion: Hindu
- Occupation: Business
- Address: Ahmedabad

Clinical findings:

- Diagnosed case of renal calculi for 5 days.
- Left sided Needle like flank pain for 15 days
- Pain < at night⁺⁺⁺, sitting⁺⁺
- Pain > by standing.
- Nausea and vomiting of ingesta with pain.
- H/o Hematuria one week before.
- Appetite decreased due to complaint.
- Desire: Spicy, salty, warm food
- Thirst: 1-2 lit/day
- Urine: 4-5/day and 2-3/night, clear, pale yellow, profuse, no burning
- Sleep disturbed due to pain.
- USG-KUB: 6.5 mm calculus in left lower ureter (3cm proximal to UVJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm.



**Khyati Lakhani et al.,****Past History**

Umbilical Hernia operated 3 years back.

Backache before 2 years relived by taking Homoeopathic medicine.

Cold and cough at change of weather for 3 years.

Family History:

Mother: Dead: H.T, D.M

Father: Dead: Inguinal Hernia

Miasmatic Evaluation:

Psoric-Sycotic

Diagnostic Assessment:

1. Clinical Symptoms
2. USG –KUB

Analysis of symptoms:**Evaluation of symptoms:****Totality of symptoms:**

1. Desire: Spicy, salty, warm food
2. Pain < at night⁺⁺⁺, sitting⁺⁺
3. Pain > by standing
4. Nausea and vomiting of ingesta with pain
5. Left sided Needle like flank pain Nausea and vomiting of ingesta with pain.
6. H/o Hematuria
7. Left sided renal calculi

Repertorial Totality: Repertorisation Sheet - Zomeo Pro LAN -Kent's Repertory

Therapeutic intervention

Berberis vulgaris Q – 15 drops in ½ cup of water TDS for 15 days.

FOLLOW UP :**OUTCOME**

Over a period of two weeks, the patient showed marked symptomatic improvement. In the first visit the patient rated his renal calculi pain as 7/10 on the pain NRS. After Homoeopathic administration of *Berberis vulgaris* Q, the pain gradually reduced and finally reached 0/10, indicating complete relief. Follow-up ultrasonography on 25/11/25 (after fourteen weeks) showed no evidence of the calculus in both kidneys with sense of wellbeing.

DISCUSSION

This evidence-based case highlights the effectiveness of *Berberis vulgaris* Q as a safe, non-invasive, cost-effective therapeutic measure for managing renal calculi. Future studies with large sample size and a multidisciplinary approach is required to strengthen the scientific basis and therapeutic application of *Berberis vulgaris* mother tincture for benefit of humanity in cases of renal calculi.





Khyati Lakhani et al.,

CONSENT

Written informed consent was obtained from the patient.

ACKNOWLEDGMENT

Authors would like to thank Homoeopathy University and Parul University for the Research work

CONFLICT OF INTEREST

The author declares no conflict of interest.

REFERENCES

1. Allen HC. Keynotes and characteristics with comparisons of some of the leading remedies of the materia medica. New Delhi: B Jain Publishers; Reprint edition.
2. Boericke W. Pocket manual of homoeopathic materia medica & repertory. New Delhi: B Jain Publishers; Reprint edition.
3. Das S. A concise textbook of surgery. 10th ed. Kolkata: S Das Publications; 2014:1203-1223.
4. Renal calculi: an evidence-based case study. RA Journal of Applied Research. 2015;1(7):227-234. doi:10.18535/rajar/v1i7.01
5. Cirino E. Kidney stones. Healthline. Updated September 18, 2018. Medically reviewed by Weatherspoon D.
6. Bailey H, Love M. Bailey & Love's short practice of surgery. 25th ed. Boca Raton: CRC Press; 2018:1292-1298.
7. Singh S, Gupta S, Mishra T, Banerjee BD, Sharma T. Risk factors of incident kidney stones in Indian adults: a hospital-based cross-sectional study. Cureus. 2023; 15(2):e35558. doi:10.7759/cureus.35558

Table 1 Analysis of symptoms

No	Symptom	Analysis of symptoms
1	Left sided renal calculi	Physical Particular
2	Left sided Needle like flank pain	Physical Particular
3	Pain < at night ⁺⁺⁺ , sitting ⁺⁺	Physical Particular with aggravating modality
4	Pain > by standing	Physical Particular with ameliorating modality
5	Nausea and vomiting of ingesta with pain.	Physical Particular
6	H/o Hematuria	Physical Particular
7	Desire: Spicy, salty, warm food	Physical General

Table 2. Evaluation of symptoms

No	Symptom	Analysis of symptoms
1	Desire: Spicy, salty, warm food	Physical General
2	Pain < at night ⁺⁺⁺ , sitting ⁺⁺	Physical Particular with aggravating modality
3	Pain > by standing.	Physical Particular with ameliorating modality
4	Left sided Needle like flank pain	Physical Particular
5	Nausea and vomiting of ingesta with pain.	Physical Particular
6	H/o Hematuria	Physical Particular
7	Left sided renal calculi	Physical Particular



Khyati Lakhani *et al.*,

Table 3 Follow Up

Date	Change in symptomatology	Pain NRS Score	Prescription
Baseline 30/7/25	Needle like pain in left flank region with nausea and vomiting.	7/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.1 13/8/25	Needle like pain in left flank region gradually reduced in first week. And in second week there was no pain. No nausea and vomiting Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.2 29/8/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.3 12/9/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.4 27/9/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.5 13/10/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.6 28/10/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.7 12/11/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days. Patient was advised for USG-KUB
Follow up No.8 25/11/25	No episode of pain Appetite: Improved Sleep: sound USG -KUB: No evidence of renal calculi or hydronephrosis is seen.	0/10	Medicine was stopped





Khyati Lakhani et al.,

Remedy	Berb	Lyc	Phos	Ars	Calc	Canth	Nat-m
Totality	9	9	9	8	8	7	7
Symptoms Covered	5	4	4	3	3	3	3
[Kent] [Stomach]Desires:Salt things:	0	0	3	0	2	0	3
[Kent] [Stomach]Desires:Warm:Food:	0	2	0	3	0	0	0
[Kent] [Kidney]Pain:Sitting,while:	2	0	0	0	0	0	0
[Kent] [Kidney]Pain:Stitching,stinging,stickng:Night:	0	0	0	0	0	0	0
[Kent] [Kidney]Pain:Standing amel:	1	0	0	0	0	0	0
[Kent] [Kidney]Pain:Stitching,stinging,stickng:	3	2	1	2	0	2	2
[Kent] [Urine]Bloody:	1	2	3	3	3	3	2
[Kent] [Urine]Sediment:Renal calculi:	2	3	2	0	3	2	0

Fig.1. Repertorial Totality: Repertorisation Sheet - Zomeo Pro LAN -Kent's Repertory

NAME: [REDACTED] M / 45 YRS DATE: 26/07/2025 SONOGRAPHY OF ABDOMEN AND PELVIS Observations: LIVER: Liver appears normal in size and shows increased parenchymal echoes. No evidence of focal or diffuse lesion is seen. No evidence of dilated IHBR is seen. Intrahepatic portal radicles appear normal. GALL BLADDER: Gall bladder appears normal. No evidence of calculus or changes of cholecystitis are seen. CBD appears normal. PANCREAS: Pancreas appears normal in size and shows normal parenchymal echoes. No evidence of pancreatitis or pancreatic mass lesion is seen. SPLEEN: Spleen appears normal in size and shows normal parenchymal echoes. No evidence of focal or diffuse lesion is seen. KIDNEYS: Both kidneys are normal in size, shape and position. Cortical and central echoes appear normal. Bilateral cortical thickness appears normal. A calculus of size 6.5 mm is seen in LEFT LOWER URETER (3 cm proximal to VUJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. BLADDER: Bladder is normally distended and appears normal. No evidence of bladder calculus, diverticulum or mass lesion is seen. PROSTATE: Prostate appears normal in size and shows normal parenchymal echoes. On 12-14 Hertz USG Visualized bowel: No abnormal bowel wall dilatation or thickening is noted. No evidence of ascites. No evidence of significantly enlarged lymph nodes noted. Impression: - A calculus of size 6.5 mm is seen in LEFT LOWER URETER (3 cm proximal to VUJ) with resultant proximal mild hydronephrosis. - Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. - Grade I fatty liver. - A defect of size 13 mm is noted in umbilical region through which omental fat herniates suggestive of umbilical hernia. DR. BHAVIK PATEL (DNB) DR. LAKASH JAIN (MD) FMF (UG) DR. AKSHAY PENDKAR (MD) DR. KEMY SHAH (MD) Tata Memorial Hospital, Mumbai Tata Memorial Hospital, Mumbai GOLD MEDALIST	NAME: [REDACTED] M / 45 YRS DATE: 25/11/2025 SONOGRAPHY OF ABDOMEN AND PELVIS Observations: LIVER: Liver appears normal in size. No evidence of focal or diffuse lesion is seen. No evidence of dilated IHBR is seen. Intrahepatic portal radicles appear normal. GALL BLADDER: Gall bladder appears normal. No evidence of calculus or changes of cholecystitis are seen. CBD appears normal. PANCREAS: Pancreas appears normal in size and shows normal parenchymal echoes. No evidence of pancreatitis or pancreatic mass lesion is seen. SPLEEN: Spleen appears normal in size and shows normal parenchymal echoes. No evidence of focal or diffuse lesion is seen. KIDNEYS: Both kidneys are normal in size, shape and position. Cortical and central echoes appear normal. Bilateral cortical thickness appears normal. No evidence of renal calculus, hydronephrosis is seen. BLADDER: Bladder is normally distended and appears normal. No evidence of bladder calculus, diverticulum or mass lesion is seen. PROSTATE: Prostate appears normal in size and shows normal parenchymal echoes. On 12-14 Hertz USG Visualized bowel: No abnormal bowel wall dilatation or thickening is noted. No evidence of ascites. No evidence of significantly enlarged lymph nodes noted. No evidence of any appendicitis. Impression: - Umbilical hernia is seen with defect of size 13 mm and herniation of omental fat. - Grade I fatty liver. DR. BHAVIK PATEL (DNB) DR. LAKASH JAIN (MD) FMF (UG) DR. AKSHAY PENDKAR (MD) DR. KEMY SHAH (MD) Tata Memorial Hospital, Mumbai Tata Memorial Hospital, Mumbai GOLD MEDALIST

Figure. No. 2. USG-KUB before Treatment part

Figure. No. 3 USG-KUB after Treatment part

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Polypharmacological Evaluation of *Justicia adhatoda* Alkaloids as Dual Inhibitors of Enoyl-ACP Reductase (InhA) and DNA Gyrase B (GyrB) for Tuberculosis Therapy : An *In-Silico* Study

Ritesh Pandit^{1*}, Sachin Kumar Sharma², Zalak Shah³ and Anshul J Harnawa⁴

¹Research Scholar, Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Parul Institute of Pharmacy and Research, Parul University, Vadodara, Gujarat, India

²Head of Department, Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Parul Institute of Pharmacy and Research, Parul University, Vadodara, Gujarat, India

³Assistant Professor, Department of Pharmacology, Faculty of Pharmacy, Parul Institute of Pharmacy and Research, Parul University, Vadodara, Gujarat, India

⁴Assistant Professor, Faculty of Pharmacy, Parul Institute of Pharmacy and Research, Parul University, Vadodara, Gujarat, India.

Received: 13 Mar 2026

Revised: 16 Apr 2026

Accepted: 14 May 2026

*Address for Correspondence

Ritesh Pandit

Research Scholar,
Department of Pharmaceutical Chemistry,
Faculty of Pharmacy,
Parul Institute of Pharmacy and Research,
Parul University, Vadodara, Gujarat, India
E.Mail: rhp9015@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Tuberculosis (TB) caused by *Mycobacterium tuberculosis* is still widely encountered as a common burden of disease worldwide together with the continuance and increasing prevalence of multi- and extensively drug-resistant (MDR and XDR) strains of TB. The rate with which resistance to monotherapy regimens has evolved emphasizes the need to develop novel therapeutic agents with polypharmacological properties. *Justicia adhatoda* Vasaka or Vaseline for short, is medicinal herb that was used in the past to improve respiratory problems, contains the chemical compound quinazoline alkaloids they contain such as vasicine. However, the molecular interactions between the constituents of Vasaka and specific targets of TB are yet to be described in detail. This study aimed to assess the dual targeting potential of alkaloids of *Justicia adhatoda* against two essential mycobacterial enzymes, enoyl-ACP reductase (InhA), which is essential in cell wall biosynthesis (mycolic acid biosynthesis), and the ATPase domain of DNA gyrase (GyrB), which plays a vital role in DNA replication. Molecular docking studies were performed using AutoDock Vina to calculate the binding affinities of the main alkaloids Vasicine and Vasicinone with the crystallographic structures of InhA (PDB ID's 2B3S and 1ENY) and GyrB (PDB ID's 4KFG and 3ZKB). The



**Ritesh Pandit and Sachin Kumar Sharma**

resulting affinity values were benchmarked against those of conventional inhibitors, that is, triclosan and isoniazid were used for InhA, and novobiocin and ciprofloxacin were used for GyrB. The binding profiles of *Justicia adhatoda* alkaloids suggest dual inhibition, effectively targeting both InhA and GyrB. This dual-targeting activity implies a simultaneous disruption of both cell wall synthesis and DNA replication pathways. Polypharmacological inhibition mediated by alkaloids isolated from *Justicia adhatoda*, Vasicine; Noval drugs lead to the development of original antituberculosis drugs. Consequently, more in vitro and in vivo studies are needed to confirm these preliminary observations.

Keywords: *Justicia adhatoda*, tuberculosis, InhA, DNA gyrase B, molecular docking, ADMET.

INTRODUCTION

Tuberculosis is a significant health threat throughout the world especially to people with HIV and those who suffer from drug resistant infections[1]. Current treatment with multiple antibiotics is faced by challenges from resistant strains of *M. tuberculosis*. This lower efficacy has shifted attention to polypharmacological strategies towards multiple bacterial pathways[2]. InhA and GyrB are important drug targets. InhA, in the case of fatty acid synthase II, catalyses the formation of mycolic acid in bacterial cells. While isoniazid is an inhibitor of the InhA, KatG mutations lead to resistance and require the need for direct InhA inhibitors[3]. DNA gyrase, attacked by fluoroquinolones at GyrA, is a site of resistance. GyrB's ATP-binding domain has so far not been exploited. Combining InhA with GyrB provides a synergistic pathogen killing [4]. *Justicia adhatoda* L. (Malabar nut) is a medicinal shrub which is used in Ayurvedic and Unani medicines for treatment of respiratory disorders such as bronchitis and tuberculosis. Its therapeutic effects are due to quinazoline alkaloids, principally vasicine and vasicinone. While their bronchodilatory action is known, their molecular interactions with *M. tuberculosis* targets are unknown[5]. Based on the possible application of quinazoline alkaloids as ATP/NAD mimetics, derivatives of vasicine were explored. This study computationally evaluated the *J. adhatoda* phytochemicals using molecular docking and ADMET studies against InhA (PDB ID's 2B3S, 1ENY) and GyrB (PDB ID's 4KFG, 3ZKB) as two target leads[6].

MATERIALS AND METHODS

Protein Preparation

InhA and GyrB structures (PDB- (2B3S, 4KFG, 3ZKB and 1ENY) were selected on the basis of resolution. PROCHECK was used to validate the protein stereochemistry by Ramachandran plots. The chain A of UCSF Chimera with catalytic residues was prepared. Hydrogens were added using Kollman charges. Solvent and co-crystallized ligands were removed. Energy minimization optimized conformers. AutoDock Tools 1.5.7 define grid boxes at active sites for AutoDock Vina

Dataset Preparation

Dr. Duke's Database contains plant data, chemical data, bioactivity data and ethnobotanical data comprising 129 plant compounds. These were evaluated by Biovia Discovery Studio against Lipinski's Rule of Five for Oral Bioavailability with the following filters: Molecular weight (MW) ≤500 Da, Hydrogen bond acceptors ≤10, donors ≤5, Polar surface area, Rotatable bonds ≤5[8]. No. SMILES for 64 compounds were retrieved from csv. 2D structure converted 3D structure using ChemDraw 3D with MMFF94 force field minimization (0.000001 kcal/mol/Å). Structures were converted to PDBQT for Autodock Vina and best candidates drawn[9].

General Procedure

PDB's 2B3S, 1ENY, 4KFG and 3ZKB were converted to AutoDock Vina format by removing both water and ligand. missing atoms corrected and polar hydrogens added, saved as pdbqt. 129 IMPPAT alkaloids were drawn and energy

115590



**Ritesh Pandit and Sachin Kumar Sharma**

minimized using MMFF94 and converted to pdbqt. Ligands were bound to sites on the enzyme, producing 9 conformations. Binding was evaluated using AutoDock Vina and rendered using PYMOL[10]. ADMET was assessed for compounds to be better than standard drugs in docking scores.

RESULT AND DISCUSSION

In-silico Docking Results

Tuberculosis is one of the deadliest of the diseases. FDA-approved drugs for tuberculosis have side effects such as nausea and skin rash. Natural compounds are anti-tuberculosis agents. Plant alkaloids combat tuberculosis by inhibiting both InhA and GyrB. The study was based on the X-ray data of InhA and GyrB complexed with triclosan, isoniazid, novobiocin, and ciprofloxacin (PDB ID: 2B3S, 1ENY, 4KFG, and 3ZKB).

Structure-Based Virtual Screening

The docking process was confirmed by structure based virtual screening. Binding affinities of 129 compounds were compared with the Triclosan (-6.4), Isoniazid (-6.1), Novobiocin (-8.1) and Ciprofloxacin (-7.7 Kcal/mol). Docking scores were used to rank compounds, with affinities of less than -6.4 kcal/mol going to the promising list.

Docking Results

Docking scores in kcal/mol are used to determine binding strength where more negative values represent more binding strength. The *in vitro* analysis of 129 IMPPAT alkaloids for inhibitors of InhA and GyrB yielded compounds better than those of Triclosan and Novobiocin inhibitors. Highest-scoring compounds provided characteristics of vasicine derivatives and receptor interactions.

Analysis of Top Compounds with 2D Interaction Reference

Docking scores are a measure of binding affinity of a ligand to a target in kcal/mol, lower the better the binding. For 129 IMPPAT alkaloids, docking scores were computed against InhA and GyrB targets. Several compounds had better scores inhibitors Triclosan (-6.4 kcal/mol) and Novobiocin (-8.1 kcal/mol). Topscoring compounds, some of which are vasicine derivatives, were analysed for receptor interactions.

Interaction Type

Green illustrates canonical hydrogen bonds - the strongest noncovalent interaction. Light green represents Chydrogen bonds. Pink denotes interactions between ligands and proteins, with the ligands being π -alkyl/ π - π stacked. Purple indicates the hydrophobic contacts of π sigma. Orange indicates π -anion/cation interactions between charged residues. Red indicates decreasing binding affinity by unfavorable interactions.

Interaction Type

Conventional Hydrogen Bond (green): Affects drug specificity through molecular adhesion. π -Alkyl/ π - π Stacked (Pink): Hydrophobic interactions from aromatic rings in protein cavities. π -Sigma (Purple): Strong hydrophobic interaction stabilizes ligand. π -anion (orange): Electrostatic attraction between protein's negative region and ligand rings. Unfavorable donor-donor (red): Repulsion between proton-donating atoms.

Interaction Type

Green (Conventional Hydrogen Bond): High stability for ligand-amino acid bonding. Light Green (Carbon-Hydrogen Bond)- Weaker hydrogen bonding with carbon atoms. Pink (π -alkyl/ π - π stacked)- Enables hydrophobic interactions between aromatic molecules and amino acids for drug retention. Purple (π -Sigma)- Strong hydrophobic interaction for drug positioning. Red (unfavorable)- Represents instability from atom collisions, reducing drug affinity.



**Ritesh Pandit and Sachin Kumar Sharma****Interaction Type**

Green- Classical hydrogen bonds form strong ligand-protein bonds. Pink- π -alkyl/alkyl (Hydrophobic Fit) occurs between aromatic rings and hydrophobic residues. Orange: (Charge Clamps) represent cation/anion interactions.

Conclusion

In silico validation showed *Justicia adhatoda* alkaloids, particularly vasicine and vasicinone, match antituberculosis agents. They enter isoniazid's hydrophobic pocket in Enoyl-Acp Reductase (InhA), interact with PHE A:41 and ILE A:95, and provide stability like triclosan-InhA's ASN A:62 bond. In DNA Gyrase B ATPase, they maintain novobiocin's ASP A:73 bonding and ciprofloxacin's LYS A:108 interaction, affecting cell wall biosynthesis and DNA replication.

ADME Evaluation

Alkaloids with better inhibitory values, based on binding affinities, were screened using Lipinski's rule of five. Table-9 lists all of the 5 physicochemical properties of the selected compounds.

MW: Molecular weight; logP: partition coefficient; nON: number of hydrogen-accepting bonds; nOHNH: no. of hydrogen-donating bonds, and nrotb is the number. of rotatable bonds.

pkCSM study of compounds for ADMET prediction

The table shows pharmacokinetic properties including absorption, metabolism, excretion, and toxicity. It details intestinal absorption percentages and interactions with CYP2D6 and CYP3A4 isoforms. Excretion is measured as clearance values in log (mL/min/kg). Toxicological data includes AMES mutagenicity and skin sensitization tests. The compounds show varied absorption and metabolic properties but no mutagenicity or skin sensitization.

***In-silico* Toxicity Prediction**

ProTox-III assessed compounds for hepatotoxicity, carcinogenicity, immunotoxicity, mutagenicity and cytotoxicity. Vasicine, Vasicinol, and Vasicinone showed no toxicity, while others exhibited immunotoxicity. All compounds were less toxic than standard drugs. Table-11 shows toxicity results.

CONCLUSION

Alkaloid's vasicine and vasicinone from *Justicia adhatoda* inhibit enoyl-acyl carrier protein reductase (InhA) and DNA Gyrase B (GyrB), mimicking antituberculosis agents to inhibit bacterial cell wall growth and DNA replication. The compounds show structural plasticity by recapitulating hydrophobic interactions of Isoniazid and Triclosan in InhA, while maintaining hydrogen-bonding networks of Novobiocin and Ciprofloxacin in GyrB with residues PHE A:41, ILE A:95, and ASP A:73. *In silico* toxicity studies showed vasicine has improved safety over conventional therapies, lacking hepatotoxicity, carcinogenicity, and mutagenicity. Vasicine shows promise for developing drugs against drug-resistant tuberculosis, pending further validation.

ACKNOWLEDGMENTS

The authors thank all contributors to this computational study and the Parul Institute of Pharmacy and Research for their support during this unfunded research.

Author Contribution

Ritesh Pandit contributed to conceptualization, draft preparation, methodology, analysis, visualization, data curation and validation. Sachin Kumar Sharma handled review, editing, supervision and software development. Both authors approved the final manuscript.





REFERENCES

1. G. B. Migliori *et al.*, "Review of multidrug-resistant and extensively drug-resistant TB: global perspectives with a focus on sub-Saharan Africa," *Tropical Medicine & International Health*, vol. 15, no. 9, pp. 1052–1066, June 2010, doi: 10.1111/j.1365-3156.2010.02581.x.
2. W. J. Jowsey, G. M. Cook, and M. B. Mcneil, "Antibiotic resistance in *Mycobacterium tuberculosis* alters tolerance to cell wall-targeting inhibitors," *JAC-antimicrobial resistance*, vol. 6, no. 3, May 2024, doi: 10.1093/jacamr/dlae086.
3. A. Ghosh, S. N, and S. Saha, "Survey of drug resistance associated gene mutations in *Mycobacterium tuberculosis*, ESKAPE and other bacterial species," *Sci Rep*, vol. 10, no. 1, June 2020, doi: 10.1038/s41598-020-65766-8.
4. A. E. Eakin *et al.*, "Pyrrolamide DNA Gyrase Inhibitors: Fragment-Based Nuclear Magnetic Resonance Screening To Identify Antibacterial Agents," *Antimicrob Agents Chemother*, vol. 56, no. 3, pp. 1240–1246, Dec. 2011, doi: 10.1128/aac.05485-11.
5. K. Michalska *et al.*, "Allosteric inhibitors of *Mycobacterium tuberculosis* tryptophan synthase.," *Protein Science*, vol. 29, no. 3, pp. 779–788, Jan. 2020, doi: 10.1002/pro.3825.
6. D. K. Jha, L. Panda, P. Lavanya, S. Ramaiah, and A. Anbarasu, "Detection and Confirmation of Alkaloids in Leaves of *Justicia adhatoda* and Bioinformatics Approach to Elicit Its Anti-tuberculosis Activity," *Appl Biochem Biotechnol*, vol. 168, no. 5, pp. 980–990, Aug. 2012, doi: 10.1007/s12010-012-9834-1.
7. E. F. Pettersen *et al.*, "UCSF Chimera--a visualization system for exploratory research and analysis.," *J Comput Chem*, vol. 25, no. 13, pp. 1605–1612, July 2004, doi: 10.1002/jcc.20084.
8. H. Padmi *et al.*, "Macroalgae Bioactive Compounds for the Potential Antiviral of SARS-CoV-2: An In Silico Study," *J. Pure Appl. Microbiol.*, vol. 16, no. 2, pp. 1018–1027, May 2022, doi: 10.22207/jpam.16.2.26.
9. O. Trott and A. J. Olson, "AutoDock Vina: improving the speed and accuracy of docking with a new scoring function, efficient optimization, and multithreading.," *J Comput Chem*, vol. 31, no. 2, pp. 455–461, June 2009, doi: 10.1002/jcc.21334.
10. M. A. Rauf, S. Zubair, and A. Azhar, "Ligand docking and binding site analysis with pymol and autodock/vina," *IJBAS*, vol. 4, no. 2, pp. 168–177, Mar. 2015, doi: 10.14419/ijbas.v4i2.4123.

Table 1- 2D structures of top compounds with docking scores for Enoyl-ACP Reductase (InhA) (2B3S)

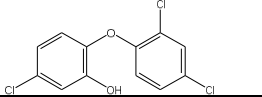
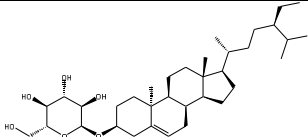
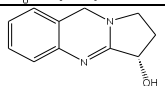
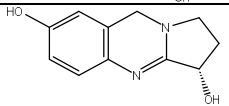
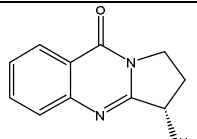
Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Triclosan		-6.4
2.	Beta-Sitosterol-Beta-D-Glucoside		-7.3
3.	Vasicine		-7.0
4.	Vasicinol		-7.0
5.	Vasicinone		-7.0





Table 2- 2D structures of top compounds with docking scores for Enoyl-ACP Reductase (InhA) (1ENY)

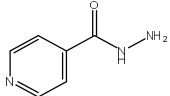
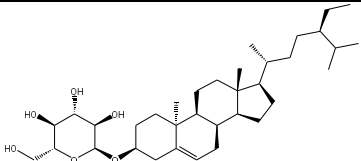
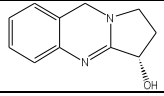
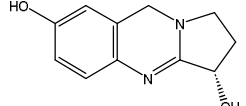
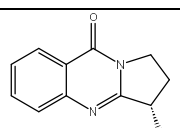
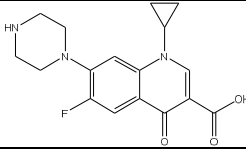
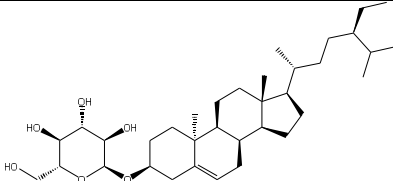
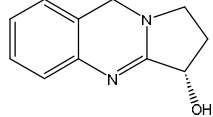
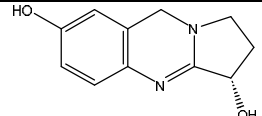
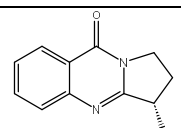
Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Isoniazid		-6.1
2.	Beta-Sitosterol-Beta-D-Glucoside		-10.1
3.	Vasicine		-7.6
4.	Vasicinol		-7.4
5.	Vasicinone		-7.7

Table 3- 2D structures of top compounds with docking scores for DNA Gyrase Subunit B (GyrB) (4KFG)

Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Ciprofloxacin		-7.7
2.	Beta-Sitosterol-Beta-D-Glucoside		-8.9
3.	Vasicine		-8.6
4.	Vasicinol		-7.9
5.	Vasicinone		-8.0





Ritesh Pandit and Sachin Kumar Sharma

Table 5– Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	ASN A:62, GLY A:69,PHE A:29, PHE A:63,MET A:64
(b)	ASP B:67,LEU B:68,ALA A:143,
(c)	GLN B:160,ALA B:152, PRO B:163, ARG B:148
(d)	HIS A:60,THR A:73,GLU A:139, VAL A:61, ALA A:142
(e)	ASN A:62, GLU A:139,VAL A:61, LYS A:70, ALA A:142

Table 6- Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	ILE A:15, GLY A:14,SER A:13,ILE A:95, PHE A:41, VAL A:65
(b)	TYR A:165,ILE A:194,ILE A:122, ILE A:95, PHE A:41
(c)	PHE A:41, VAL A:65, ILE A:122, ILE A:95
(d)	ASP A:64, PHE A:41, VAL A:65, ILE A:95
(e)	PHE A:41, VAL A:65, ILE A:95, ILE A:122

Table 7– Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	VAL A:118, ASP A:73, ASN A:46, LEU A:94, ILE A:90
(b)	GLU A:42, LEU A:115, GLY A:117, HIS A:116, ASP A:49, VAL A:93
(c)	GLY A:77,ILE A:78,VAL A:120, ASN A:46
(d)	GLU A:50, ASN A:46, ASP A:73, THR A:165,ILE A:78
(e)	ASP A:73, THR A:165, ILE A:78,VAL A:167, VAL A:43

Table 8- Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	SER A:169, GLY A:107, ALA A:105, LYS A:108, VAL A:125, VAL A:171, ILE A:84, VAL A:99
(b)	SER A:169, TYR A:114, ARG A:82, ALA A:113, PRO A:85
(c)	ASN A:52,ASP A:79,ILE A:84, VAL A:99
(d)	ASP A:79, GLU A:56, ILE A:84
(e)	TYR A:114, ASN A:52, LYS A:108, VAL A:99, VAL A:125, ILE A:84

Table 9- Properties of Standard and Selected Compounds (Lipinski rule of 5)

Sr. No.	Compounds	MW	logP	nON	nOHNH	nrotb
*	Triclosan	289.54	4.28	2	1	2
*	Isoniazid	137.14	-0.47	3	2	2
*	Novobiocin	612.62	0.65	11	5	10
*	Ciprofloxacin	331.34	1.28	5	2	3
1	Beta-Sitosterol- Beta-D- Glucoside	576.85	3.96	6	4	9
2	Vasicine	188.23	1.57	2	1	0
3	Vasicinol	204.23	0.99	3	2	0
4	Vasicinone	202.21	0.78	3	1	0





Ritesh Pandit and Sachin Kumar Sharma

Table 10- Drug-likeness properties

Sr. No.	Compounds	P-GP Substrate	Bioavailability	Log K _p (skin permeation)	BBB Permeant
*	Triclosan	No	0.55	-4.69cm/s	Yes
*	Isoniazid	No	0.55	-7.63cm/s	No
*	Novobiocin	Yes	0.17	-7.68cm/s	No
*	Ciprofloxacin	No	0.55	-9.09 cm/s	No
1	Beta-Sitosterol-Beta-D-Glucoside	No	0.55	-4.32 cm/s	No
2	Vasicine	No	0.55	-7.14 cm/s	No
3	Vasicinol	Yes	0.55	-7.48 cm/s	No
4	Vasicinone	No	0.55	-7.16 cm/s	No

Table 11- ADMET Prediction of Selected Compounds

Sr. No.	Compounds	Pharmacokinetics					
		Absorption	Metabolism		Excretion	Toxicity	
		Intestinal Absorption (HUMAN)				AMES Toxicity	Skin Sensitisation
		Numeric (%Absorbed)	2D6SUB	3A4INH	Numeric (log/ml/min/kg)	Categorical (yes/no)	Categorical (yes/no)
*	Triclosan	87.455	No	Yes	0.058	No	No
*	Isoniazid	92.601	No	No	0.722	No	No
*	Novobiocin	71.504	No	Yes	-0.452	No	No
*	Ciprofloxacin	96.466	No	No	0.633	No	No
1.	Beta-Sitosterol-Beta-D-Glucoside	79.677	No	Yes	0.689	No	No
2.	Vasicine	86.22	No	Yes	0.58	No	No
3.	Vasicinol	80.398	No	No	0.379	No	No
4.	Vasicinone	92.532	No	No	0.568	No	No

Table 12- Toxicity Prediction

Sr. No.	Compound	Hepatotoxicity	Carcinogenicity	Immunotoxicity	Mutagenicity	Cytotoxicity
*	Triclosan	IA	IA	IA	IA	A
*	Isoniazid	A	A	IA	IA	IA
*	Novobiocin	IA	IA	A	IA	IA
*	Ciprofloxacin	IA	IA	IA	A	IA
1	Beta-Sitosterol-Beta-D-Glucoside	IA	IA	A	IA	IA
2	Vasicine	IA	IA	IA	IA	IA
3	Vasicinol	IA	IA	IA	IA	IA
4	Vasicinone	IA	IA	IA	IA	IA





Ritesh Pandit and Sachin Kumar Sharma

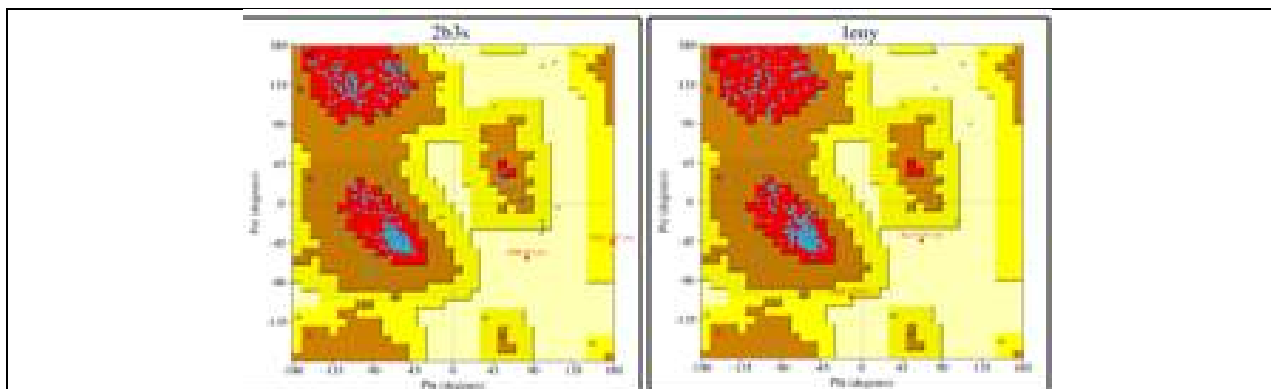


Figure 1 and 2- Ramachandran Plot of PDB ID: 2B3S and 1ENY (Enoyl-ACP Reductase (InhA)).

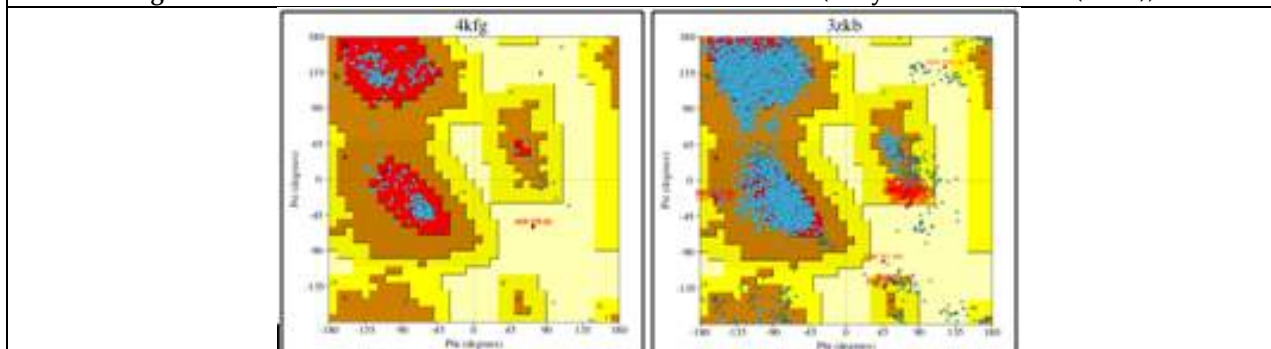


Figure 3 and 4- Ramachandran Plot of PDB ID: 4KFG and 3ZKB (DNA Gyrase Subunit B (GyrB))

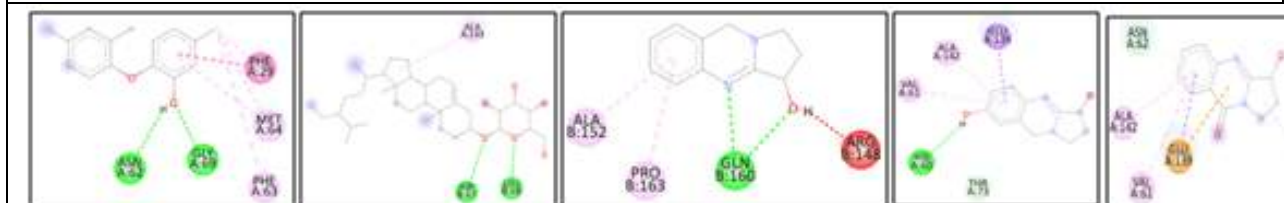


Figure 5-2D interactions of (a) Triclosan, (b) Beta-Sitosterol-Beta-D-Glucoside, (c) Vasicine, (d) Vasicinol, and (e) Vasicinone with Enoyl-ACP Reductase (InhA) on PDB ID: 2B3S.

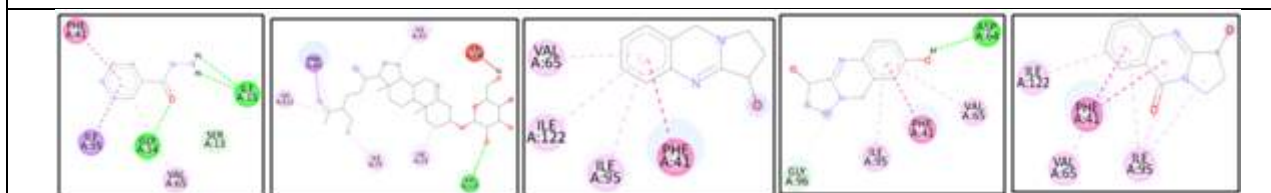


Figure 6-2D interactions of (a) Isoniazid (b) Beta-Sitosterol-Beta-D-Glucoside (c) Vasicine (d) Vasicinol (e) Vasicinone as (Enoyl-ACP Reductase (InhA)) on PDB ID: 1ENY.



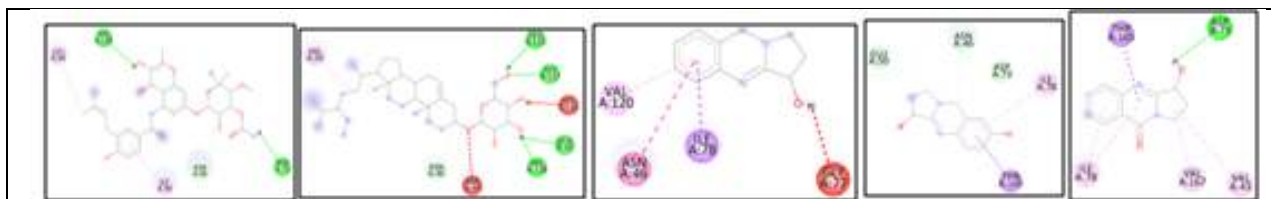
**Ritesh Pandit and Sachin Kumar Sharma**

Figure 7- Two-dimensional Interactions of (a)Novobiocin (b)Beta-Sitosterol-Beta-D-Glucoside (c)Vasicine (d) Vasicinol (e) Vasicinone as (DNA Gyrase Subunit B (GyrB)) on PDB I'd- 4KFG.



Figure 8- Two-dimensional Interactions of (a)Ciprofloxacin (b)Beta-Sitosterol-Beta-D-Glucoside (c)Vasicine (d) Vasicinol (e) Vasicinone as (DNA Gyrase Subunit B (GyrB)) on PDB I'd- 3ZKB.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Enumeration of Split 2 – Dominating Sets and Split 2 – Domination Polynomials of Path P_n

R. Japhia^{1*} and S. Freeda²

¹Research Scholar (Reg. No: 21113112092013), Department of Mathematics, Nesamony Memorial Christian College, Marthandam, Kanyakumari, (Affiliated to Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli), Tamil Nadu, India

²Assistant Professor, Department of Mathematics, Nesamony Memorial Christian College, Marthandam, Kanyakumari, (Affiliated to Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli), Tamil Nadu, India

Received: 10 Mar 2026

Revised: 12 Apr 2026

Accepted: 14 May 2026

*Address for Correspondence

R. Japhia

Research Scholar (Reg. No: 21113112092013),

Department of Mathematics,

Nesamony Memorial Christian College,

Marthandam, Kanyakumari,

(Affiliated to Manonmaniam Sundaranar University, Abishekapatti, Tirunelveli),

Tamil Nadu, India

E.Mail: japhiar152@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Let $G = (V, E)$ be a graph of order n with no isolated vertex. A split dominating set $D \subseteq V(G)$ is said to be split 2 - dominating set if every $v \in V(G) - D$ has at least 2 neighbors in D . Let P_n be the path graph and $D_{s2}(P_n, i)$ be the family of split 2 - dominating sets of a path P_n with cardinality i . Let $d_{s2}(P_n, i) = |D_{s2}(P_n, i)|$. In this paper, we obtain the recursive formula for coefficients of split 2 - domination polynomials of paths. Using the recursive formula, we construct the polynomial $D_{s2}(P_n, x) = \sum_{i=\lfloor \frac{n+1}{2} \rfloor}^n d_{s2}(P_n, i)x^i$, which we call split2- domination polynomial of P_n and also obtain some properties of this polynomial.

Keywords: Split 2 - domination number, Split 2- domination polynomials

INTRODUCTION

In the intricate world of graph theory, where vertices and edges interconnect to form multifaceted networks, it serves as a powerful framework for understanding the intricate structures that underlie real-world networks. Domination theory explores the minimum sets of nodes required to exert control over a graph influencing its structure and





Japhia and Freeda

behavior. The concepts of graph theory pervade various domains and drive innovation, with a particular focus on domination applications. For an undirected graph G can be defined as a pair (V, E) , where V denotes the set of vertices and E represents the set of edges comprising unordered pairs of vertices. A dominating set in a graph G is a subset D of vertices such that every vertex in the graph is either in D or adjacent to a vertex in D . The domination number $\gamma(G)$ represents the minimum cardinality of vertices in a given set. Arocha and Llano analyzed the graphs of domination polynomials. Later, Alikhani and Peng defined the conception of domination polynomials of the graph in their research article [1]. The Idea of k – domination in graph is presented by Fink and Jacobson [3]. Now, in the same way we find the recursive relation for the Split 2 - domination polynomial of paths. A set $D \subseteq V(G)$ is a dominating set if every vertex in $V - D$ is adjacent to at least one vertex in D . The minimum cardinality taken over all the minimal dominating set is called domination number and is denoted $\gamma(G)$. In this study, we refer to the collection $\{1, 2, \dots, n\}$ by $[n]$ and $\lceil x \rceil$ to represent the smallest integer greater than or equal to x .

Construction of Split 2 - Dominating Sets of Paths

Let P_n be a path graph with n vertices. Let $D_{s2}(P_n, i)$ denote the family of all split 2 - dominating sets of P_n with cardinality i . We shall examine the split 2- dominating sets of path P_n and some of its properties.

Definition 2.1. A split dominating set $D \subseteq V(G)$ is said to be split 2 - dominating set if every $v \in V(G) - D$ has at least 2 neighbors in D . The split 2 - domination number denoted by $\gamma_{s2}(G)$ is the minimum cardinality among the split 2- dominating set of .

Lemma 2.2. For $n \geq 3$, $\gamma_{s2}(P_n) = \left\lceil \frac{n+1}{2} \right\rceil$.

Lemma 2.3. Let P_n be a path graph with n vertices. Then $D_{s2}(P_n, i) = \emptyset$ if and only if $i > n$ or $i < \left\lceil \frac{n+1}{2} \right\rceil$.

Proof

Let P_n be the path with n vertices, any member of $D_{s2}(P_n, i)$ contains at most n vertices. Therefore, $D_{s2}(P_n, i) = \emptyset$ for $i > n$. Also, we have the minimum cardinality of split 2- dominating sets of path P_n is $\left\lceil \frac{n+1}{2} \right\rceil$ then cardinality less than $\left\lceil \frac{n+1}{2} \right\rceil$ does not exist for any split 2 - dominating sets. Therefore, $D_{s2}(P_n, i) = \emptyset$ for $i < \left\lceil \frac{n+1}{2} \right\rceil$. Conversely, if $i > n$ or $i < \left\lceil \frac{n+1}{2} \right\rceil$ then by the definition of split 2 - dominating sets of path P_n . We have $D_{s2}(P_n, i) = \emptyset$. Therefore, $D_{s2}(P_n, i) = \emptyset$. Hence, $D_{s2}(P_n, i) = \emptyset$ if and only if $i < \left\lceil \frac{n+1}{2} \right\rceil$.

Observation 2.4. If a graph G contains a path of length $2k - 1$, then every split 2- dominating set of G must contain at least k vertices of G . To find a split 2- domination polynomial of P_n with cardinality i , it is enough to consider $D_{s2}(P_{n-1}, i - 1)$ and $D_{s2}(P_{n-2}, i - 1)$. Thus, we must consider four combinations of whether these two collections are empty or not.

Lemma 2.5. Let $n \geq 3$ and $i > \left\lceil \frac{n+1}{2} \right\rceil$,

- i) If $D_{s2}(P_{n-1}, i - 1) = \emptyset$ and $D_{s2}(P_{n-3}, i - 1) = \emptyset$ then $D_{s2}(P_{n-2}, i - 1) = \emptyset$.
- ii) If $D_{s2}(P_{n-1}, i - 1) \neq \emptyset$ and $D_{s2}(P_{n-3}, i - 1) \neq \emptyset$ then $D_{s2}(P_{n-2}, i - 1) \neq \emptyset$.
- iii) If $D_{s2}(P_{n-1}, i - 1) = \emptyset$ and $D_{s2}(P_{n-2}, i - 1) = \emptyset$ then $D_{s2}(P_n, i) = \emptyset$.
- iv) If $D_{s2}(P_{n-1}, i - 1) \neq \emptyset$ and $D_{s2}(P_{n-2}, i - 1) \neq \emptyset$ then $D_{s2}(P_n, i) \neq \emptyset$.

Proof

From Lemma 2.3, the proof can be derived .

We obtain $D_{s2}(P_n, i)$ for $3 \leq n \leq 16$ and $2 \leq i \leq 16$ as demonstrated in Table 1.

Theorem 2.6. If $D_{s2}(P_n, i)$ be the family of split 2- dominating sets of a path P_n with cardinality i , where $i > \left\lceil \frac{n+1}{2} \right\rceil$ and $D_{s2}(P_n, i) = |D_{s2}(P_n, i)|$.





Japhia and Freeda

Then, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$.

Proof:

We prove the theorem by distinguishing the following cases,

- i) If $D_{s2}(P_{n-1}, i-1) = \emptyset$ and $D_{s2}(P_{n-2}, i-1) = \emptyset$ then $D_{s2}(P_n, i) = \emptyset$.
- ii) If $D_{s2}(P_{n-1}, i-1) = \emptyset$, $D_{s2}(P_{n-2}, i-1) \neq \emptyset$, then $D_{s2}(P_n, i) = \{X \mid X \in D_{s2}(P_{n-2}, i-1)\}$.
- iii) If $D_{s2}(P_{n-1}, i-1) \neq \emptyset$, $D_{s2}(P_{n-2}, i-1) = \emptyset$, then $D_{s2}(P_n, i) = \{Y \cup \{n\} \mid Y \in D_{s2}(P_{n-1}, i-1)\}$.
- iv) If $D_{s2}(P_{n-1}, i-1) \neq \emptyset$, $D_{s2}(P_{n-2}, i-1) \neq \emptyset$, then $D_{s2}(P_n, i) = \{X \cup \{n-1\} \mid X \in D_{s2}(P_{n-1}, i-1)\} \cup \{Y \cup \{n\} \mid Y \in D_{s2}(P_{n-2}, i-1)\}$.

By the above construction in every case,

we have, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$.

Split 2 - domination polynomials of paths

In this section, the split 2- domination polynomials of paths are introduced and examined.

Definition: 3.1.

Let $D_{s2}(P_n, i)$ be the family of split 2 - dominating sets of path P_n with cardinality i and $d_{s2}(P_n, i) = |D_{s2}(P_n, i)|$. Then, the split 2 - domination polynomials of the path is defined as

$$D_{s2}(P_n, x) = \sum d_{s2}(P_n, i) x^i,$$

where $\gamma_{s2}(P_n)$ is the split 2 –domination number of P_n .

Theorem 3.2. For every $n \geq 5$, $D_{s2}(P_n, x) = x [D_{s2}(P_{n-1}, x) + D_{s2}(P_{n-2}, x)]$ with the initial values, $D_{s2}(P_3, x) = x^2 + x^3$, $D_{s2}(P_4, x) = 2x^3 + x^4$.

Proof

We have, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$

Now, $d_{s2}(P_n, i)x^i = d_{s2}(P_{n-1}, i-1)x^i + d_{s2}(P_{n-2}, i-1)x^i$

$$\sum d_{s2}(P_n, i)x^i = \sum_{s2} d_{s2}(P_{n-1}, i-1)x^i + \sum d_{s2}(P_{n-2}, i-1)x^i$$

$$\sum d_{s2}(P_n, i)x^i = x \sum d_{s2}(P_{n-1}, i-1)x^{i-1} + x \sum d_{s2}(P_{n-2}, i-1)x^{i-1}$$

$$D_{s2}(P_n, x) = x D_{s2}(P_{n-1}, x) + x D_{s2}(P_{n-2}, x)$$

Therefore, $D_{s2}(P_n, x) = x [D_{s2}(P_{n-1}, x) + D_{s2}(P_{n-2}, x)]$ with initial values,

$$D_{s2}(P_3, x) = x^2 + x^3,$$

$$D_{s2}(P_4, x) = 2x^3 + x^4.$$

Example 3.3. Consider the path P_{10} with 10 vertices. We construct a Split 2 - dominating polynomial $D_{s2}(P_{10}, x)$ using

Theorem 3.2

Then, the split 2 - dominating polynomial of a path P_{10} is given by

$$D_{s2}(P_{10}, x) = \sum_{i=6}^{10} d_{s2}(P_{10}, i) x^i.$$

From the Table 1, we have, $d_{s2}(P_{10}, 6) = 5$, $d_{s2}(P_{10}, 7) = 20$, $d_{s2}(P_{10}, 8) = 21$, $d_{s2}(P_{10}, 9) = 8$, $d_{s2}(P_{10}, 10) = 1$. Hence, $D_{s2}(P_{10}, x) = 5x^6 + 20x^7 + 21x^8 + 8x^9 + x^{10}$ is a split 2 - domination polynomial of path P_{10} .

Theorem 3.4. The coefficients of $D_{s2}(P_n, x)$ satisfy the following properties:

- i) For every $n \geq 3$, $d_{s2}(P_{2n}, n+1) = n$
- ii) For every $n \geq 3$, $d_{s2}(P_{2n+1}, n+1) = 1$
- iii) For every $n \geq 3$, $d_{s2}(P_n, n) = 1$
- iv) For every $n \geq 4$, $d_{s2}(P_n, n-1) = n-2$
- v) For every $n \geq 4$, $d_{s2}(P_n, n-2) = \frac{1}{2}[n^2 - 7n + 12]$





Japhia and Freeda

vi) For every $n \geq 6$, $d_{s2}(P_n, n-3) = \frac{1}{6}[n^3 - 15n^2 + 74n - 120]$

vii) For every $n \geq 8$, $d_{2s}(P_n, n-4) = \frac{1}{24}[n^4 - 26n^3 + 251n^2 - 1066n + 1680]$

Proof:

It follows from the table of split 2 - dominating sets of paths and we demonstrate using the mathematical induction method on n .

CONCLUSION

This paper discusses several characteristics of split 2 - domination polynomials of paths are obtained and studied. We can speculate this investigation to any power of paths. Future works can be carried out for similar other graphs using this concept.

REFERENCES

1. Alikhani S and Yee Hong Peng, Introduction to domination polynomials of graph Ars. Combin.114(2014),257-266.
2. Alikhani S and Y.H.Peng, Dominating sets and domination polynomials of paths, Int.J.Math.Sci.(2009),Article ID 542040, 10 pp.
3. Harary F, Graph Theory Reading, Massachusetts, USA. Adison Wesley. 1969.
4. Mateusz Miotk, Jerzy Topp and Pawel Zylinski, "Disjoint dominating and 2-dominating sets in graphs", University of Gdansk, 80-952 Gdansk, Poland, Article in Discrete Optimization, March 2019.
5. T.W. Haynes, S.T. Hedetniemi, P.J. Slater, Fundamentals of Domination in Graphs, Marcel Dekker, New York, 1998
6. Vijayan A and Sanal Kumar S, "On Total Domination Polynomial of Graphs", Global Journal of Theoretical and Applied Mathematics Sciences, Vol.2, No.2(2012),19-97.

Table 1: $d_{s2}(P_n, i)$, the number of split 2 - dominating sets of a path P_n with cardinality i .

$n \backslash i$	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	1	1													
4	0	2	1												
5	0	1	3	1											
6	0	0	3	4	1										
7	0	0	1	6	5	1									
8	0	0	0	4	10	6	1								
9	0	0	0	1	10	15	7	1							
10	0	0	0	0	5	20	21	8	1						
11	0	0	0	0	1	15	35	28	9	1					
12	0	0	0	0	0	6	35	56	36	10	1				
13	0	0	0	0	0	1	21	70	84	45	11	1			
14	0	0	0	0	0	0	7	56	126	120	55	12	1		
15	0	0	0	0	0	0	1	28	126	210	165	66	13	1	
16	0	0	0	0	0	0	0	8	84	252	330	220	78	14	1

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Enhancement of Self-Efficacy Through Experiential Drama : A Mixed Methods Study Among Young Adults

Arunkumar V^{1*}, Beena G², Vinay R³, Gayathry V⁴ and Archana Bhat Kallahalla⁵

¹Assistant Professor and Research Scholar, Department of Languages, REVA University, Bangalore, Karnataka, India

²Associate Professor, Department of Languages, REVA University, Bangalore, Karnataka, India

³Assistant Professor and Research Scholar, Department of Psychology, REVA University, Bangalore, Karnataka, India

⁴Research Scholar, Department of Psychiatry, Kasturba Medical College, Mangalore, and Manipal Academy of Higher Education (Deemed to be University), Manipal, Karnataka, India.

⁵Associate Professor, PG Studies and Research Department of Psychology, Kateel Ashok Pai Memorial College (Affiliated to Kuvempu University) Shivamogga, Karnataka, India

Received: 08 Mar 2026

Revised: 10 Apr 2026

Accepted: 15 May 2026

*Address for Correspondence

Arunkumar V

Assistant Professor and Research Scholar,
Department of Languages,
REVA University,
Bangalore, Karnataka, India
E.Mail: reddyarunkumar.v@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Self-efficacy is defined as a person's belief in their ability to plan and implement actions needed to overcome obstacles. It is a major psychological resource for motivation, emotion regulation, and adaptive behaviour. Theatre-based learning settings could enhance self-efficacy by providing repeated mastery experiences, peer modelling, constructive criticism, and opportunities to regulate performance-related emotional arousal. With a special focus on creative techniques such as anthropomorphic role enactment, the current study investigated whether participation in a three-month theatrical education program was associated with changes in self-efficacy among young adults. A one-group pretest-posttest design was used with 20 undergraduate and postgraduate students enrolled in a Theatre Education Certificate Course conducted by Rangayana Shivamogga in collaboration with Kateel Ashok Pai Memorial College, Shivamogga (December 2021-March 2022). Self-efficacy was assessed using the General Self-Efficacy Scale before and after the intervention. Quantitative data were analysed using descriptive statistics, Shapiro-Wilk normality testing, and a paired-samples t-test, and qualitative reflections were analysed using thematic analysis. Results revealed a significant increase in self-efficacy from pretest ($M = 27.60$, $SD = 5.75$) to posttest ($M = 33.50$, $SD = 4.66$), $t(19) = -3.91$, $p < .001$, with a large effect size ($d = 0.87$). Qualitative



**Arunkumar et al.,**

themes suggested that increased confidence through performance, improved emotional expression, learning through peer observation, and a helpful group environment contributed to participants' perceived growth; anthropomorphic enactment was described as facilitating symbolic emotional expression and expressive freedom. Although causal conclusions are limited by the absence of a control group, evidence indicates that structured theatre education may be associated with enhanced self-efficacy among young adults and supports the use of arts-based experiential training within educational and developmental contexts.

Keywords: self-efficacy; theatre education; drama-based learning; anthropomorphism; young adults; experiential learning

INTRODUCTION

Psychological well-being largely depends on perceptions of how effectively one can manage challenges and function normally. In this belief system, self-efficacy is defined as a person's evaluation of their capacity to plan and execute the activities required to achieve the desired outcomes (Bandura, 1997). A person's ideas, emotions, drive, and conduct all depend on their self-efficacy. Likewise, believers, in their own capacity to act, are more likely to view challenging circumstances as opportunities rather than hazards, to persist even when conditions become difficult, and to recover more rapidly following a setback (Schunk & DiBenedetto, 2021; Usher & Pajares, 2008). Understanding adaptive human behavior requires a solid grasp of self-efficacy, as it is closely linked to motivation, resilience, and emotional regulation. Social cognitive theory holds that mastery experiences, vicarious learning, verbal persuasion, and the interpretation of bodily and emotional states, that is, four main sources, are the means by which self-efficacy develops (Bandura, 1997). Direct achievements, or mastery experiences, are the most powerful since they provide hard evidence of skill. Seeing others succeed in comparable circumstances can increase effectiveness through social modeling. Learning to view emotional arousal (e.g., anxiety or excitement) as acceptable rather than dangerous improves efficacy beliefs; encouragement from teachers and peers supports these convictions through verbal persuasion; furthermore, this action enhances efficacy beliefs (Usher & Pajares, 2008). Therefore, learning environments that combine action, social interaction, feedback, and emotional engagement are particularly conducive to promoting self-efficacy.

Drama and theater offer one such situation (A drama-based programme to develop emotional intelligence in early childhood education, 2024). Because students must interact physically, emotionally, and socially through role-playing, performance, and teamwork, theatre training is essentially hands-on. Through practice and dramatic performance, these activities provide natural, repeated mastery experiences; moreover, they offer opportunities for vicarious learning as participants observe coworkers grow and succeed (Goldstein & Winner, 2012; Lee et al., 2020). Helpful remarks from facilitators and viewers serve as both verbal persuasion and regular exposure to performance-related arousal; participants may perceive anxiety as a manageable and energizing state (Feniger-Schaal & Lotan, 2017). As a result, theoretical ideas outlining how self-efficacy develops align well with theatre teaching. Beyond technical competence, theatre offers a planned forum for emotional inquiry and self-expression. Through role-playing and improvisation, people move beyond familiar patterns of thinking and action and explore alternative perspectives in a supportive setting (Snow et al., 2017). Better emotional awareness, communication abilities, and social confidence have been connected with such physical participation (Goldstein & Winner, 2012; McArdle & Wright, 2014). These mechanisms could help people believe more in their capacity to express themselves, change, and respond appropriately in real-world events.

Imaginative symbolic role-playing, often with anthropomorphic portrayals in which people play non-human or abstract concepts (such as natural objects or social ideas) as characters with human emotions and motivations, is a



**Arunkumar et al.,**

distinctive aspect of theatre training. Within a psychologically safe context, this artistic process allows individuals to externalize inner experiences, indirectly explore challenging emotions, and experiment with novel forms of expression. Although anthropomorphic performance is not considered a single factor, it belongs in the larger creative and physical learning environment that can help to develop emotional flexibility and expressive confidence (Smithner, 2025). The social component of theatre further enhances its developmental potential. Encouragement of group unity and mutual support through theatre activities depends on teamwork, shared storytelling, and group problem-solving (Snow et al., 2017), Ob (McEwan et al., 2017). Hence, while good group comments support perceived competence (Schunk & Di Benedetto, 2021), vicarious experiences help one's sense of potential by overcoming obstacles in serving peers. These group projects could help members, over time, increase their confidence in managing emotionally taxing events, performing, and communicating.

Although drama has long been appreciated for its artistic and creative value, research increasingly demonstrates its psychological benefits, including improved empathy, emotional expression, and self-esteem (Goldstein et al., 2015; Lee et al., 2020). However, rather few studies have examined self-efficacy as a specific, theory-driven outcome of coordinated theatre activities. This difference is important because self-efficacy is strongly associated with mental health, scholastic tenacity, and adaptive functioning across domains of life (Bandura, 1997; Schunk & DiBenedetto, 2021). Young adulthood is a particularly important stage for examining the development of self-efficacy. During this transitional period, individuals manage educational responsibilities, career decisions, and identity exploration, all of which require confidence in their abilities (Arnett, 2015). Experiences that provide mastery, emotional expression, and caring peer engagement may therefore play a valuable part in strengthening efficacy beliefs during this phase. Considering the close theoretical link between theatre training and the processes driving self-efficacy growth, it is crucial to investigate if long-term involvement in a well-organized drama program is linked with quantifiable variations in self-efficacy. The current study examines this question by examining young adults who completed a three-month theatre education course and assessing how confident they felt before and after the course. It also looks at how the participants described their experiences of growth in this creative, group environment.

LITERATURE REVIEW

Self-efficacy influences how people think, feel, and behave in the face of obstacles—that is one basic psychological concept (Bandura, 1997; Schunk & DiBenedetto, 2021). Strong efficacy beliefs help people approach challenging tasks with perseverance, regulate emotional responses under duress, and heal more effectively from failure (Usher & Pajares, 2008). Strong connections between self-efficacy and motivation, resiliency, and well-being have been established across educational, clinical, and social contexts; hence, self-efficacy has been extensively investigated (Artino, 2012). Four main sources—mastery experiences, vicarious learning, spoken persuasion, and interpretation about physical and emotional conditions—according to Bandura's (1997) social cognitive theory, develop self-efficacy. These sources highlight how crucial learning environments providing active participation, social modeling, positive criticism, and opportunities to control emotional arousal are (Usher & Pajares, 2008). Thus, experiential learning environments that combine performance, cooperation, and reflection are especially suited to promoting efficacy beliefs (Schunk & DiBenedetto, 2021). One such experimental setting is drama-based education. Unlike conventional lecture-based education, theatre learning is physically, socially, and emotionally expressive, enabling students to learn through action and engagement (McArdle & Wright, 2014; Lee et al., 2020). Participating in drama calls for practicing performances, conveying emotions, collaborating with others, and delivering performances to audiences—all of which could help individuals achieve mastery experiences and reinterpret performance-related arousal (Feniger-Schaal & Lotan, 2017).

Meta-analytic research indicates that drama-based instruction improves social ability, empathy, and communication skills—results closely related to confidence and perceived competence (Lee et al., 2020). Moreover enhancing emotional awareness and self-identity study are theatrical activities. Role-play and character embodiment enable people to examine feelings and perspectives different from their daily lives (Snow et al., 2017). By creating a



**Arunkumar et al.,**

systematically and psychologically safe environment, this imaginative engagement lets participants externalize interior occurrences, hence reducing criticism, worry, and increasing expressive confidence (Feniger-Schaal & Lotan, 2017). By increasing people's faith in their capacity to manage emotional circumstances, such processes may indirectly help the growth of self-efficacy (Gaiha et al., 2021). And (Creative and healthy through improv: Effects of training improvisational theatre on creative and work-related self-efficacy and self-esteem, 2025). Use of symbolic and creative methods, including anthropomorphic portrayal, is a fundamental component of theatrical training. In these activities, participants could present non-human entities, such as natural items, abstract notions, or environmental forces, as characters with human characteristics. Encouraging this anthropomorphic approach promotes perspective-taking, emotional projection, and imaginative problem-solving, thereby enhancing emotional involvement and widening expressive breadth. People may experience greater self-expression and a stronger sense of personal agency when processing difficult affective topics by adopting symbolic roles (Snow et al., 2017). Although the psychological benefits of drama are increasingly documented, empirical studies directly linking organized theatre instruction to changes in self-efficacy remain sparse. (Manorothkul, n.d.)

Self-discovery, professional and school decisions, and growing societal responsibilities define young adulthood—a time of development (Arnett, 2015). Regularly encountering performance expectations and social assessment during this stage can test people's coping skills and confidence (Schunk & DiBenedetto, 2021). As such, interventions that provide structured mastery experiences, supportive peer interaction, and opportunities for emotional expression may be useful in enhancing self-efficacy during this transition (Bandura, 1997; Usher & Pajares, 2008). While studies on the theoretical concordance between drama-based learning and self-efficacy development have been conducted, targeted research on this relationship in young adults remains scarce. (Impact, practicality, and acceptability of CREATORS: An arts-based pilot intervention to lower mental-health-related stigma among youngsters in Hyderabad, India, 2024). Social cognitive theory holds that self-efficacy grows from four main sources: mastery experiences, vicarious learning, verbal persuasion, and the interpretation of physical and emotional states (Bandura, 1997; Usher & Pajares, 2008). Structured theatre education provides an experiential setting in which performance, collaboration, feedback, and emotional engagement enable these sources to work in concert (Schunk & DiBenedetto, 2021). Drama-based instruction serves as the primary experiential setting within this framework. Rehearsal, role enactment, and public presentation provide regular mastery experiences, therefore enabling participants to achieve success via effort and practice.

While encouragement from facilitators and group members provides verbal reinforcement that strengthens perceptions of competence (Bandura, 1997), observing peers execute and develop inspires vicarious learning. Furthermore, repeated exposure to performance-related anxiety in a supportive environment can help individuals view physiological arousal as controllable, thereby improving their adaptive emotional control (Usher & Pajares, 2008). One unique technique in theatre education is anthropomorphic role-play, in which actors portray characters with human emotions and intentions, such as natural elements, objects, or abstract concepts. Beyond personal identity, this creative process expands expressive possibilities and encourages deeper emotional exploration and perspective-taking. Assuming symbolic roles allows individuals to indirectly access and express their inner experiences, which can reduce self-consciousness and enhance their communication confidence. Anthropomorphic engagement helps improve emotional engagement and creative agency, enrich mastery experiences, and support emotional reinterpretation within performance scenarios. Theatre training is viewed as enhancing self-efficacy through the interplay of these processes, as evidenced by greater confidence in handling difficulties, more expressive emotional expression, and improved performance before audiences. In turn, strengthened self-efficacy is linked with more general adaptive results, including better affective control, social confidence, resilience, and willingness to participate in new experiences (Bandura, 1997; Schunk & DiBenedetto, 2021). The conceptual path underpinning the current study so suggests that theatre-based experiential education, boosted by anthropomorphic imaginative involvement, triggers the key sources of self-efficacy, therefore promoting greater adaptive self-beliefs and psychological development.





Arunkumar et al.,

Need for the Study

Self-efficacy is a vital psychological construct that helps individuals operate adaptively across academic, social, and emotional spheres (Bandura, 1997; Schunk & DiBenedetto, 2021). Strengthening efficacy beliefs during young adulthood may help individuals be resilient, motivated, and capable of coping with new life difficulties (Arnett, 2015). Although experiential and arts-based methods are increasingly recognized for fostering whole-person development, empirical research on their influence on core psychological factors, such as self-efficacy, remains limited (Lee et al., 2020). Drama-based education provides a distinctive framework in which mastery experiences, social modeling, affective regulation, and constructive feedback naturally unfold (McArdle & Wright, 2014; Feniger-Schaal & Lotan, 2017). Additionally, creative methods such as anthropomorphic role acting might improve emotional engagement and confidence in expressiveness. Most current research emphasize general results like empathy or communication abilities rather than theory-based assessments of self-efficacy (Schunk & DiBenedetto, 2021). Therefore, a methodical research is needed on whether continuous involvement in organised theatre training correlates with noticeable changes in self-efficacy among young adults. Filling this vacuum will support a more thorough understanding of the cognitive advantages of arts-based educational strategies and inform the design of programs to foster confidence, emotional maturity, and adaptive self-beliefs.

Intervention

The intervention investigated in this research was a planned three-month Theatre Education Certificate Course given by Rangayana Shivamogga in partnership with Kateel Ashok Pai Memorial College, Shivamogga. Designed to foster expressive ability, self-awareness, and group creativity, the program meld classic Indian theatrical conventions with current performance techniques. Training was carried out alongside participants' normal academic timetables in rigorous daily morning and evening sessions. The theoretical teaching was interwoven with hands-on performing activities in the curriculum. Principles drawn from Bharata's *Natyashastra*, including *Angika* (body language), *Vachika* (voice and debate), and *Aharya* (costume and theatrical performance), were presented to students. Body conditioning, voice modulation, stage movement, emotive expression, improvisation, character development, and makeup were all covered in the lessons. The performance of anthropomorphic parts sets the training apart. Encouragement was given to pupils to picture and portray non-human or symbolic beings such as trees, discarded items, or abstract powers—as characters with human emotions, objectives, and voices.

Participants may investigate inner emotions indirectly through symbolic expression using this anthropomorphic approach, thereby broadening their emotional range and imaginative perspective-taking. Participants engaged in creative exploration that facilitated the expression of freedom and emotional processing in a secure, cooperative environment by adopting roles outside their normal identities. In addition to group improvisations and ensemble composition, the program included folk performance features such as *Janapada*, *Geethe* and *Kolata*. Students performed socially relevant street theatre plays addressing topics such as cybercrime and plastic contamination. These public shows offered chances for audience engagement, peer modeling, mastery experiences, and good criticism. Shared circles and reflective group discussions helped participants express personal insights and recognize their own development over the course. Combining physical training, symbolic imagination, affective exploration, group creativity, and live performance produced a holistic experiential setting consistent with processes known to foster the development of self-efficacy (Bandura, 1997; Usher & Pajares, 2008).

METHODOLOGY

Research Design

Changes in self-efficacy following attendance in a structured theatre training program were investigated in the current study using a one-group pretest-posttest quasi-experimental approach. This design enables evaluation of change over time inside the same group when random allocation or a control group is not practical (Creswell & Creswell, 2018; Shadish et al., 2002). Although causal inferences are constrained, this strategy is well-suited to



**Arunkumar et al.,**

assessing experiential educational programs conducted in naturalistic contexts. A mixed-methods strategy was used to provide a fuller understanding of the results. Qualitative data investigated participants' lived experiences of the theatre training process (Creswell & Creswell, 2018), whereas quantitative data measured measurable changes in self-efficacy.

Participants

Twenty young adults enrolled in a three-month Theatre Education Certificate Course held in Shivamogga, Karnataka, comprised the sample. Participants were undergraduate and postgraduate students who attended the instruction alongside their regular academic programs. Because all participants belonged to the same training cohort and met the research inclusion criteria (Etikan et al., 2016), purposive sampling was employed. The ultimate sample size of $N = 20$ mirrors the entire cohort enrolled in the certificate program during the study period. (Moore et al., 2016)

Inclusion Criteria

- Age between 18 and 25 years
- Enrollment in the three-month theatre training program
- Willingness to participate and provide informed consent
- Ability to comprehend and react to study instruments

Exclusion Criteria

- Severe physical or psychological conditions that could prevent active participation in theatre activities

Young adults were selected because this developmental stage involves self-identity exploration, performance demands, and increasing personal responsibility, all of which make self-efficacy particularly relevant (Arnett, 2015).

Tool General Self-Efficacy Scale (GSE)

Self-efficacy was measured using the General Self-Efficacy Scale developed by Schwarzer and Jerusalem (1995). The GSE is a widely used 10-item self-report instrument designed to assess individuals' general belief in their ability to cope with a variety of challenging situations. Responses are recorded on a Likert-type scale, and higher scores indicate stronger perceived self-efficacy. The GSE has demonstrated good psychometric properties across cultures, with internal consistency coefficients frequently ranging from .76 to .90 (Luszczynska et al., 2005; Schwarzer & Jerusalem, 1995). The scale has been used extensively in research on coping, resilience, and mental health (Schunk & DiBenedetto, 2021).

Procedure

Pre-Intervention Phase

At the beginning of the program, participants completed the GSE to establish baseline self-efficacy levels. The purpose of this phase proved to be to measure participants' perceived capability before exposure to structured theatre training.

Intervention Phase

Participants underwent a three-month structured theatre education program involving daily training sessions conducted in the morning and evening alongside their academic schedules. The program integrated theoretical instruction with practical performance training.

Components included:

- Body and voice training based on principles of **Angika** (physical expression) and **Vachika** (verbal expression) from classical Indian theatre traditions
- Stagecraft and visual presentation (**Aharya**), including costume, makeup, and staging
- Improvisation, role-play, and character development exercises
- Group performance projects and ensemble theatre creation
- Folk forms such as JanapadaGeethe and Kolata
- Public performances, including socially themed street plays



**Arunkumar et al.,**

One unique feature of the intervention was its use of anthropomorphic role-play. Participants were inspired to represent non-human and metaphorical entities, such as trees, discarded objects, or abstract powers, as characters with human emotions, speech, and purpose. Through symbolic expression, this anthropomorphization process allows students to examine internal feelings and points of view covertly. Participants explored emotionally expressive confidence and perspective-taking in a supportive group setting by adopting roles beyond their own identities. Students engaged in reflective group discussions that promoted the sharing of personal experiences and emotional insights and that facilitated the observation of development throughout the training. These sessions provided verbal reinforcement, peer modeling, and emotional processing, experiential aspects of self-efficacy development (Bandura, 1997; Usher & Pajares, 2008).

Post-Intervention Phase

At the conclusion of the three-month program, participants completed the GSE again as a posttest measure. This enabled comparison of self-efficacy scores before and after participation in the theatre training.

Qualitative Component

Qualitative data were collected through:

- Reflective group discussions
- Participant sharing sessions
- Observational notes from facilitators

These data were analyzed using **thematic analysis** following Braun and Clarke's (2006) framework, including familiarization, coding, theme identification, review, and definition. This approach permitted the organized exploration of participants' experiences related to confidence, emotional expression, and self-improvement.

Ethical Issues

Participants provided informed consent prior to participation. Confidentiality was maintained by assigning identification codes rather than names on all data forms. Participation was voluntary, and participants were informed of their right to cease participation at any time without penalty, in accordance with established ethical protocols for human research (American Psychological Association, 2017).

RESULTS

Quantitative Findings

Descriptive statistics were calculated to examine changes in self-efficacy scores from pretest to posttest. Assumptions of normality were assessed before conducting inferential analysis. A paired-samples *t*-test was performed to determine whether participation in the theatre training program was associated with significant changes in self-efficacy.

Data Analysis

Descriptive statistics (M, SD) were computed for pretest and posttest scores. Normality of difference scores was assessed using the Shapiro-Wilk test, appropriate for small samples (Field, 2018). A paired-samples *t*-test evaluated pre-post change. Cohen's *d* was computed to describe effect size (Cohen, 1988). Qualitative data were analyzed using thematic analysis procedures (Braun & Clarke, 2006).

DISCUSSION

The present study examined whether participation in a structured theatre-based training program was associated with changes in self-efficacy among young adults. Quantitative findings showed a statistically significant increase in



**Arunkumar et al.,**

self-efficacy from pretest to posttest, with a large effect size, indicating meaningful improvement in participants' perceived capability to manage challenges. Qualitative findings further supported these results by revealing increased confidence, improved emotional expression, learning through peer observation, and the importance of a helpful group environment. Together, these findings correspond closely with the conceptual framework underlying the study and with established theory on the development of self-efficacy (Bandura, 1997; Schunk & DiBenedetto, 2021). According to the conceptual model proposed for this study, theatre training provides an experiential context that activates the four primary sources of self-efficacy: mastery experiences, vicarious learning, verbal persuasion, and interpretation of emotional arousal (Bandura, 1997; Usher & Pajares, 2008). The significant increase in self-efficacy observed in the quantitative analysis may be understood as the cumulative effect of repeated mastery experiences embedded within the training. Rehearsals, character development, and public performances required participants to engage in challenging tasks, practice skills, and witness their own improvement over time. Successfully navigating performance demands, particularly in front of an audience, likely strengthened participants' beliefs in their ability to handle difficult situations, consistent with the central role of mastery experiences in efficacy development (Bandura, 1997)

The qualitative results on peer learning provide further evidence for the role of vicarious experiences within the conceptual framework. Participants reported that observing others perform, grow, and overcome performance anxiety helped them feel more confident. Such modeling effects are particularly potent when individuals perceive parallels between themselves and others, thereby reinforcing the idea that they, too, might be successful (Schunk & Di Benedetto, 2021). Theatre training's collaborative character appears to have created an environment in which social comparison worked positively, thereby boosting the development of efficacy. Important parts of the training experience also proved to be support and useful input from group members and facilitators. Particularly when combined with obvious progress in performance and expression, these forms of words may have strengthened participants' impressions of competence (Artino, 2012; Bandura, 1997). Participants' favorable group environment probably increased their inclination to engage more completely in expressive tasks and take creative risks, therefore boosting positive efficacy beliefs. The conceptual framework emphasized that the use of anthropomorphic role play was a unique aspect of the intervention. Participants were challenged to show trees, objects, or abstract forces—as characters with human characteristics—as non-human or symbolic creatures. By letting people express emotions indirectly via symbolic roles, this creative process might have increased emotional involvement and lowered self-consciousness. Participants might have had more expressive freedom and perspective-taking by pretending to be people other than who they were on a daily basis. This might have led to a feeling of creative agency and confidence. Anthropomorphic interaction might then have served as a mechanism to enhance mastery experiences and promote more adaptive interpretation of emotional response during performance contexts.

Improved emotional expression and greater comfort with stage-related anxiety that participants noted support the theoretical connection between theatre participation and reinterpretation of physical and emotional states. Regular exposure to performance-related arousal in a supportive environment may have enabled participants to view anxiety as a tolerable or even inspiring experience instead of a sign of disability (Usher & Pajares, 2008). Those changes in emotional interpretation are accompanied by improved self-efficacy beliefs. The evidence points to theatre-based experiential learning, particularly when it combines creative and anthropomorphic elements, as potentially offering several interlinked pathways through which self-efficacy develops. These results build on earlier studies on the psychological advantages of drama instruction, particularly by highlighting self-efficacy as a conceptually grounded outcome (Lee et al., 2020; Snow et al., 2017). Such treatments can help foster confidence, emotional competence, and adaptive functioning in young adulthood, a developmental period characterized by increasing performance demands and the formation of self-identity (Arnett, 2015; Schunk & DiBenedetto, 2021). However, the findings should be interpreted with caution. The absence of a control group limits the ability to attribute changes solely to the intervention (Shadish et al., 2002). Improvements in self-efficacy may also reflect general maturation, increased social familiarity, or other concurrent experiences. Nevertheless, the consistency among quantitative improvements, qualitative themes, and the conceptual framework strengthens confidence in the interpretation that theatre training was meaningfully associated with increased efficacy beliefs.





To summarize, the discussion of findings in relation to the conceptual framework indicates that theatre training, particularly when enriched by anthropomorphic imagination and joint performance, can activate the core psychological processes through which self-efficacy develops. These results support the view that arts-based instructional environments may contribute not only to creative skill development but also to the strengthening of adaptive self-beliefs and psychological toughness.

Applied Implications

According to the results of the current research, organised theatre-based training courses may be useful instruments for promoting psychological development in young people. Theatre education can help develop self-efficacy, a key psychological resource linked to resilience, drive, and adaptive functioning (Bandura, 1997; Schunk & Di Benedetto, 2021), by offering experiential learning environments that combine performance, teamwork, emotional involvement, and reflection. Including theatre-based or drama-integrated courses in undergraduate and graduate programs can help educational institutions foster pupils' social and personal growth as well as their academic success. The development of efficacy beliefs is correlated with role-play, improvisation, and group performance projects, as these activities offer opportunities for mastery experiences, peer modeling, and constructive criticism, all of which help shape them (Usher & Pajares, 2008). Such programs may be notably beneficial for students who experience performance anxiety, low confidence in communication, or difficulty expressing emotions. The study additionally reveals the potential value of anthropomorphic and symbolic role enactment as a pedagogical strategy. Motivating students to portray non-human or conceptual entities allows for indirect emotional expression and creative perspective-taking, which may reduce self-consciousness and enhance expressive confidence. Educators and facilitators can intentionally use these imaginative techniques to create psychologically safe environments in which students become more comfortable exploring emotions and experimenting with new forms of expression.

Theatre-based activities can provide readily accessible and culturally flexible ways to foster emotional competence and social confidence in youth development and community programs. Group performances and socially focused street dramas can help people to believe in their capacity to speak and make a major contribution to their society, therefore encouraging civic involvement and social awareness, and so enhance participants' belief. Young people's engagement and motivation could be raised by a mix of creative expression and social relevance. Drama-based exercises can be used as adjunctive treatments in counseling and psychosocial support contexts to help individuals build self-assurance in emotional communication and interpersonal interaction. The experiential and physical nature of theatre activities may help regulate emotion and reduce avoidance behavior, potentially enhancing adaptive functioning and coping. The findings ultimately reveal the importance of training facilitators in encouraging comments and performance methods. Whether theatre-based treatments work depends not only on the activities themselves but also on establishing a supportive group environment in which participants feel free to try new things. Organized reflection sessions and peer debates can help internalize efficacy-enhancing experiences, thereby enhancing learning and support. Overall, the present findings support the integration of theatre-based experiential learning approaches inside educational and developmental contexts as a means of promoting self-efficacy and related adaptive outcomes in young adults.

Strengths of the Study

This research has several especially great qualities. It first employed a mixed-methods approach, combining quantitative and qualitative data to provide both measurable evidence of change and a thorough understanding of how participants lived their lives. Linking statistical results with empirical activities helped to clarify the meaning of the data. Second, the intervention was ecologically sound and culturally relevant since it took place in a real theatre education program instead of a simulated laboratory environment. This made the findings more relevant to the real world. Third, the study looked at a three-month structured intervention that was sustained, which let researchers see significant changes in development instead of just short-term effects. Ultimately, the inclusion of anthropomorphic and symbolic performance elements offers fresh conceptual originality by presenting a unique expressive device by





Arunkumar et al.,

which theatre training may affect psychological development, therefore providing a different viewpoint on studies on self-efficacy and arts-based interventions.

Limitations

The study has certain drawbacks that should be taken into account while evaluating the results even if it has some benefits. A one-group pretest-posttest design without a control group limits the power to reach strong causal judgments regarding the consequences of the theater intervention (Shadish et al., 2002). Enhancements in self-efficacy may have been influenced by factors such as growth, greater peer familiarity, or other concurrent activities over the three-month period. The sample size was rather tiny and taken from a single training cohort, the applicability of the results to other groups or cultural contexts may be limited (Creswell & Creswell, 2018). The study was also largely based on self-report questionnaires, which may be subject to response bias or social desirability effects (Podsakoff et al., 2003). Lastly, self-efficacy was measured only immediately after the intervention; the long-term viability of the observed improvements remains uncertain. Future investigations, including bigger samples, control groups, multi-method evaluations, and long-term follow-up, would help to build the evidence base.

CONCLUSION

Young people who participated in a structured theatre-based training program showed changes in their self-efficacy, according to the current research. Quantitative data showed a notable increase in self-efficacy after the three-month program, whereas qualitative results emphasized experiential components including performance practice, emotional expression, peer learning, and group support as important elements of participants' development. These results support social cognitive theory, which holds that theatre training can activate important sources of self-efficacy, such as mastery experiences, vicarious learning, verbal encouragement, and adaptive interpretation of emotional arousal (Bandura, 1997; Usher & Pajares, 2008). Adding anthropomorphic and symbolic role-playing increased opportunities for emotional exploration and expressive confidence, thereby offering a unique means by which theater can support psychological growth. Although the study design precludes causal inferences, the findings support mounting evidence that arts-based experiential learning environments may foster adaptive self-beliefs and creative talent. The results generally highlight the potential of theatre education as a whole to promote psychological resilience and self-efficacy across young adulthood, a developmental stage characterized by increasing performance demands and exploration of self-identity (Arnett, 2015; Schunk & DiBenedetto, 2021). The long-term effects and fundamental processes of drama-based treatments on self-efficacy and associated outcomes will be clarified by future studies employing controlled, long-term designs.

Authors Declaration

- All authors declare that they have no conflicts of interest for authorship regarding this research and have agreed to publish it in the specified order.
- **Authors' Contribution to this paper**
 - Arunkumar and Dr. Beena G conceptualized the research idea and structure of the paper.
 - Vinay and Gayathri V contributed by collecting the primary resources and data for drafting the paper.
 - Dr. Archana Bhat Kallahalla organized the data and proofread the paper.
- **Declaration on funding**
 - This research did not receive any kind of financial support or funding from any source, and the authors of the paper do not have any conflict regarding the financial interest.





REFERENCES

1. American Psychological Association. (2017). *Ethical principles of psychologists and code of conduct*. American Psychological Association.
2. Armesto Arias, M., Neira-Piñeiro, M. del R., Pasarín-Lavín, T., & Rodríguez, C. (2024). A drama-based intervention to improve emotional intelligence in early childhood education. *European Journal of Psychology of Education*, 40(1), 13. <https://doi.org/10.1007/s10212-024-00906-6>
3. Arnett, J. J. (2015). *Emerging adulthood: The winding road from the late teens through the twenties* (2nd ed.). Oxford University Press.
4. Artino, A. R. (2012). Academic self-efficacy: From educational theory to instructional practice. *Perspectives on Medical Education*, 1(2), 76-85. <https://doi.org/10.1007/s40037-012-0012-5>
5. Bandura, A. (1997). *Self-efficacy: The exercise of control*. W. H. Freeman.
6. Berkemeyer, L., Binnewies, C., Hilbert, M., & Maunz, L. (2025). Creative and healthy through improv: Effects of training improvisational theatre on creative and work-related self-efficacy and self-esteem. *Thinking Skills and Creativity*, 56, 101757. <https://doi.org/10.1016/j.tsc.2025.101757>
7. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101. <https://doi.org/10.1191/1478088706qp063oa>
8. Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Erlbaum.
9. Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE.
10. Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, 5(1), 1-4. <https://doi.org/10.11648/j.ajtas.20160501.11>
11. Feniger-Schaal, R., & Lotan, N. (2017). The use of drama therapy in fostering emotional resilience. *The Arts in Psychotherapy*, 54, 1-8. <https://doi.org/10.1016/j.aip.2017.02.003>
12. Field, A. (2018). *Discovering statistics using IBM SPSS Statistics* (5th ed.). SAGE.
13. Gaiha, S. M., Salisbury, T. T., Usmani, S. & Raman, U. (2021). Effectiveness of arts interventions to reduce mental-health-related stigma among youth: a systematic review and meta-analysis. *BMC Psychiatry* 21. <https://doi.org/10.1186/s12888-021-03350-8>
14. Gaiha, S. M., Gasparrini, A., Koschorke, M., Raman, U., Petticrew, M., & Salisbury, T. T. (2024). Impact, feasibility, and acceptability of CREATORS: An arts-based pilot intervention to reduce mental-health-related stigma among youth in Hyderabad, India. *SSM - Mental Health*, 6, 100339. <https://doi.org/10.1016/j.ssmmh.2024.100339>
15. Goldstein, T. R., & Winner, E. (2012). Enhancing empathy and theory of mind through drama. *Psychology of Aesthetics, Creativity, and the Arts*, 6(1), 19-30. <https://doi.org/10.1037/a0024374>
16. Goldstein, T. R., Wu, K., & Winner, E. (2015). Actors are skilled in theory of mind but not empathy. *Imagination, Cognition and Personality*, 35(2), 164-176. <https://doi.org/10.1177/0276236615627124>
17. Lee, B. K., Patall, E. A., Cawthon, S. W., & Steingut, R. R. (2020). The effect of drama-based pedagogy on student outcomes: A meta-analysis. *Review of Educational Research*, 90(1), 32-63. <https://doi.org/10.3102/0034654319892927>
18. Lorenz, T., Frischling, C., Cuadros, R., & Heinitz, K. (2016). Autism and Overcoming Job Barriers: Comparing Job-Related Barriers and Possible Solutions in and outside of Autism-Specific Employment. *PLoS One*, 11(1), e0147040.
19. Luszczynska, A., Scholz, U., & Schwarzer, R. (2005). The general self-efficacy scale: Multicultural validation studies. *The Journal of Psychology*, 139(5), 439-457. <https://doi.org/10.3200/JRLP.139.5.439-457>





20. Manorothkul, N. (n.d.). Performing Arts Education for University Students: Does Training in the Performing Arts Improve Self-Esteem and Self-Efficacy?. <https://nrs.harvard.edu/URN-3:HUL.INSTREPOS:37367597>
21. McArdle, F., & Wright, S. (2014). *Teaching and learning through the arts: Changing schools through arts integration*. Routledge.
22. McEwan, D., Ruissen, G. R., Eys, M. A., Zumbo, B. D. & Beauchamp, M. R. (2017). The Effectiveness of Teamwork Training on Teamwork Behaviors and Team Performance: A Systematic Review and Meta-Analysis of Controlled Interventions. PLoS ONE 12(1). <https://doi.org/10.1371/journal.pone.0169604>
23. Moore, R. C., Straus, E., Dev, S. I., Parish, S. M., Sueko, S. & Eyler, L. T. (2016). Development and Pilot Randomized Control Trial of a Drama Program to Enhance Well-being Among Older Adults. *Arts in Psychotherapy* 52. <https://doi.org/10.1016/j.aip.2016.09.007>
24. Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review. *Journal of Applied Psychology*, 88(5), 879-903. <https://doi.org/10.1037/0021-9010.88.5.879>
25. Thomas, M. K. K. (2013). PREDICTING STUDENTS' CONFIDENCE: HOW TEACHER FEEDBACK AND OTHER SOURCES INFLUENCE SELF-EFFICACY IN MATHEMATICS CLASSROOMS. <https://core.ac.uk/download/232561734.pdf>
26. Schunk, D. H., & DiBenedetto, M. K. (2021). Self-efficacy and human motivation. In A. J. Elliot (Ed.), *Advances in Motivation Science* (Vol. 8, pp. 153-179). Elsevier. <https://doi.org/10.1016/bs.adms.2020.10.001>
27. Schwarzer, R., & Jerusalem, M. (1995). Generalized self-efficacy scale. In J. Weinman, S. Wright, & M. Johnston (Eds.), *Measures in health psychology: A user's portfolio* (pp. 35-37). NFER-NELSON.
28. Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). *Experimental and quasi-experimental designs for generalized causal inference*. Houghton Mifflin.
29. Snow, S., D'Amico, M., & Tanguay, D. (2017). Therapeutic theatre and well-being. *The Arts in Psychotherapy*, 55, 11-18. <https://doi.org/10.1016/j.aip.2017.04.002>
30. Smithner, N. (2025). Embodied Learning in Educational Theatre: Perspectives on Kinesthetic Change and Social Transformation from Urban Classrooms and Prison Settings. Routledge. <https://www.routledge.com/Embodied-Learning-in-Educational-Theatre-Perspectives-on-Kinesthetic-Change-and-Social-Transformation-from-Urban-Classrooms-and-Prison-Settings/Smithner/p/book/9780367651558>
31. Usher, E. L., & Pajares, F. (2008). Sources of self-efficacy in school: A critical review. *Review of Educational Research*, 78(4), 751-796. <https://doi.org/10.3102/0034654308321456>

Table 1: Descriptive Statistics for Pretest and Posttest Self-Efficacy Scores (N = 20)

Measure	N	M	SD
Pretest self-efficacy	20	27.60	5.75
Posttest self-efficacy	20	33.50	4.66

Note. Higher scores indicate stronger perceived self-efficacy (Bandura, 1997).

Table 2: Shapiro-Wilk Test of Normality for Self-Efficacy Difference Scores

Variable	W	p
Pretest-posttest difference	0.921	.105

Note. Difference scores did not significantly deviate from normality ($p > .05$); parametric testing was appropriate (Field, 2018).





Arunkumar et al.,

Table 3: Paired-Samples t Test Comparing Pretest and Posttest Self-Efficacy Scores

Comparison	t	df	p
Pretest vs. posttest	-3.91	19	< .001

A paired-samples t test showed that posttest self-efficacy scores were significantly higher than pretest scores, $t(19) = -3.91$, $p < .001$.

Table 4: Effect Size for Change in Self-Efficacy Scores

Comparison	Cohen's d
Pretest-posttest	0.87

Note. $d \approx 0.87$ indicates a large effect (Cohen, 1988).

Table 5: Qualitative Themes Identified From Participant Reflections

Theme	Description
Increased confidence through performance	Greater confidence speaking, performing, and expressing emotions.
Improved emotional expression	Role-play supported comfort with expressing a range of emotions.
Learning through peer observation	Watching peers improve contributed to belief in one's own capability.
Supportive group environment	Encouragement and collaboration increased psychological safety and willingness to take risks.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Techniques for using MATLAB to Estimate the Weibull Distribution's Parameters for Customer Transaction Data

Mouriya D^{1*} and Mohomed Harif B²

¹Research Scholar, Department of Mathematics, Government Arts College, (Affiliated to Bharathidasan University) Tiruchirappalli, Tamil Nadu, India

²Assistant Professor, Department of Mathematics, Government Arts College, (Affiliated to Bharathidasan University) Tiruchirappalli, Tamil Nadu, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 15 May 2026

*Address for Correspondence

Mouriya D

Research Scholar,

Department of Mathematics,

Government Arts College,

(Affiliated to Bharathidasan University)

Tiruchirappalli, Tamil Nadu, India

E.Mail: remoraj811@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This shape parameter (b) and scale parameter (h) are two techniques for estimating Weibull parameters that we present in this study. For reliability and maintainability analysis in particular, the Weibull distribution is a crucial distribution. The methods that have been given can be divided into two groups: analytical methods and graphical methods. The approaches offered are tested computationally and the results are reported. The usefulness of the Weibull distribution is illustrated using customer transaction data sets. The results show that the Weibull distribution provides a better parametric fit than the competing distributions using MATLAB.

Keywords: Maximum likelihood, Weibull Probability Plotting, predictive analysis.

Mathematics Subject Classification (2020): 00A71, 60G25.

INTRODUCTION

A common The Weibull distribution is frequently used to describe lifetime data and phenomena with monotone failure rates. The Weibull distribution with two parameters, which is frequently used as a model in life testing, In order to estimate the distribution parameters from (i) full data, (ii) singly censored samples, and (iii) progressively (many) censored samples, maximum likelihood equations are generated [1]. For each of these sample types, asymptotic variance-covariance matrices are provided. Included is an example to illustrate the point.



**Mouriya and Mohamed Harif**

Maximum likelihood estimators based on different left and right censored data scenarios for the three parameter Weibull distribution. the developed estimation procedure involves the simultaneous solution of two iterative equations for the case of single censoring from the left and progressive censoring from the right. The aforementioned scenario leads to an estimating process with a single iterative equation for the two parameter Weibull distributions [2]. The estimators' asymptotic variance-covariance matrix is provided. There exist pivot functions whose distributions can be utilized for hypothesis testing and estimating confidence intervals. The estimate process using left-censored samples is demonstrated with an example. Examines and contrasts various approaches to estimating the parameters of the two-parameter Weibull distribution using complete, type II, and massively time censored samples. The performance of various estimators is compared in a comprehensive simulation exercise [3].

The goal of [4] to determine the best approach for calculating the wind power density at four stations, Edmonton City Center Awos, Grande Prairie A, Lethbridge A, and Waterton Park Gate located throughout the Canadian state of Alberta. Both daily and monthly scales are used for the evaluations in order to provide a thorough analysis. The findings show that using alternative parameter estimating techniques to derive the k and c parameters alters the accuracy of calculated wind power density values. While the GP approach has poor ability for all stations, the four EMJ, EML, EPF, and ML methods present extremely favorable efficiency. However, because the wind parameters vary from station to station, it is discovered that the more effective way is not the same.

A linear mixture of Fréchet densities can be used to represent the new density function. The model parameters are estimated using the greatest likelihood method. The flexibility of the new distribution is empirically demonstrated by applying it to two real data sets [5]. In many fields, it can be used as a substitute model for other lifespan distributions found in the literature to model positive real data. The Lindley Weibull distribution is a novel three-parameter lifetime model that accounts for a wide range of monotone failure rates as well as unimodal and bathtub failures. Given thorough explanation of several of its mathematical characteristics, such as order statistics, quantile and generating functions, and ordinary and incomplete moments, a linear combination of exponentiated Weibull densities can be used to represent the new density function. The subject distribution's several mathematical characteristics are examined. Quantile function, expansion of density and distribution functions, moments, generating function, incomplete moments, conditional moments, residual life function, mean deviation, inequality measures, Rényi and q -entropies, probability weighted moments, and order statistics are all given general explicit expressions. The maximum likelihood approach is used to estimate the model parameters [6]. Lastly, three actual data sets are used to analyze the suggested distribution's practical significance. It has been determined that the new distribution outperforms the rival models. The model parameters are estimated using the greatest likelihood method [7]. To evaluate the effectiveness of the maximum likelihood estimation, we report simulated results. We provide empirical evidence for the new distribution's significance and adaptability in modeling two data sets. Equations that enable the representative volume to be computed from strength data are generated using the distribution's exact form, without the assumptions that result in its usual exponential form, as long as enough specimens and sizes are examined. The newly derived equations are applied to the analysis of graphene and polysilicon data [8], yielding representative elements that are in good agreement with the observed flaws.

The main objective of this study is to introduce and examine a novel lifetime model called the Exponentiated Generalized Weibull Exponential Distribution [10], which is based on mathematical techniques. Using the EGWD, we assessed consumer transaction data [11]. The main objective of the new model is to introduce a parameter that will allow for greater flexibility in the shape of the density and hazard functions, among many other desired characteristics. In this paper, Based on the mathematical technique, the primary goal of this research is to present and investigate a novel lifetime model known as the Weibull Distribution [9]. We evaluated customer transaction data using the WD [10]. The primary goal of the new model is to provide more flexibility in the shape of the density and hazard functions, along with many other desired qualities, by adding a parameter.





Mouriya and Mohamed Harif

Weibull distribution

Weibull Probability Plotting

The Weibull distribution density function is given by:

$$f(x) = \frac{\beta}{\eta} \left(\frac{x - \gamma}{\eta} \right)^{\beta-1} e^{-\left(\frac{x - \gamma}{\eta} \right)^\beta}, \beta > 0, \eta > 0, x \geq \gamma \geq 0$$

The cumulative Weibull distribution function is given by:

$$F(x) = 1 - e^{-\left(\frac{x - \gamma}{\eta} \right)^\beta}$$

Where the form, scale, and position parameters are denoted by β , η , and γ , respectively.

We use the double logarithmic transformation of the CDF to determine the relationship between it and the two parameters (β, η).

Let $\gamma = 0$, we have

$$1 - F(x) = e^{-\left(\frac{x}{\eta} \right)^\beta}$$

$$\frac{1}{1 - F(x)} = e^{\left(\frac{x}{\eta} \right)^\beta}$$

$$\ln \left[\frac{1}{1 - F(x)} \right] = \left(\frac{x}{\eta} \right)^\beta$$

$$\ln \ln \left[\frac{1}{1 - F(x)} \right] = \beta \ln \eta - \beta \ln x$$

The final equation is a straight line equation. The process below is used to plot (x) vs x :

- Rank failure times in ascending order.
- Estimate $F(x_i)$ of the i^{th} failure.
- Plot $F(x_i)$ vs. x in the Weibull probability paper.

To estimate $F(x_i)$ in (2 and 3) above, we may use one of the following methods presented in Table 1 where n is number of data points. Using one of the techniques listed in below Table, where n is the number of data points; we can $F(x_i)$ in the aforementioned equations (2 and 3).

Hazard Plotting Technique

The Weibull parameters can be estimated using the hazard plotting technique. Plotting the cumulative hazard function $H(x)$ versus failure times on a hazard paper or a straightforward log-log paper is how this is accomplished.

The following is the hazard function:

$$h(x) = \frac{\beta}{\eta} \left(\frac{x}{\eta} \right)^{\beta-1}$$

The cumulative hazard function is given below:

$$H(x) = \int h(x) = \left(\frac{x}{\eta} \right)^\beta$$

We can transform by taking the logarithm as follows

$$\ln H(x) = \beta \{\ln x - \ln \eta\}$$

From above equation, we can then plot $\ln H(x)$ versus $\ln x$ using the following procedure:

Plotting $\ln H(x)$ against $\ln x$ can then be done by following these steps:

- Rank the failure times in ascending order.
- For each failure, calculate $\Delta H_i = \frac{1}{(n+1)-1}$
- For each failure, calculate $H = \Delta H_1 + \Delta H_2 + \dots + \Delta H_i$





Mouriya and Mohamed Harif

- Plot $\ln H$ vs. $\ln x$.
- Fit a straight line.

The estimated parameters after the plotting is finished will be as follows:

$$\beta = \frac{x}{y} = \frac{1}{\text{slope}}$$

at $H = 1, \eta = x$

Maximum Likelihood Estimator (MLE)

Due to its very desirable characteristics, the maximum likelihood technique is a frequently employed process. Given a probability density function $f_X(x; \theta)$, where θ is an unknown parameter, let $x_1, x_2, \dots, x_n$ be a random sample of size n . The joint density of the n random variables, which depends on the unknown parameter, is the probability function of this random sample. So

$$L = \prod_{i=1}^n f_{X_i}(x_i, \theta)$$

Is the function of likelihood, the value of θ that maximizes L , or the logarithm of L , is the maximal likelihood estimator (MLE) of θ , let's say $\hat{\theta}$. The MLE of θ is frequently, but not always, a solution of

$$\frac{d \log L}{d\theta} = 0$$

Where neither solutions that are not in the parameter space nor those that are not functions of the sample values $x_1, x_2, \dots, x_n$ are admissible, the shape and scale parameters are the Weibull parameters that we will now estimate using the MLE the likelihood function of the WD will be

$$L(x_1, \dots, x_n; \beta, \eta) = \prod_{i=1}^n \left(\frac{\beta}{\eta} \right) \left(\frac{x_i}{\eta} \right)^{\beta-1} e^{-\left(\frac{x_i}{\eta} \right)^\beta}$$

We derive the estimating equations by first differentiating with regard to β and η , then equating to zero.

$$\frac{\partial \ln L}{\partial \beta} = \frac{n}{\beta} + \sum_{i=1}^n \ln x_i - \frac{1}{\eta} \sum_{i=1}^n x_i^\beta \ln x_i = 0$$

$$\frac{\partial \ln L}{\partial \eta} = \frac{n}{\eta} + \sum_{i=1}^n \ln x_i - \frac{1}{\eta} \sum_{i=1}^n x_i^\beta \ln x_i = 0$$

After simplifying and removing η between these two equations, we have

$$\frac{\sum_{i=1}^n x_i^\beta \ln x_i}{\sum_{i=1}^n x_i^\beta} - \frac{1}{\beta} - \frac{1}{n} \sum_{i=1}^n \ln x_i = 0$$

Whose solution yields the estimate of $\hat{\mu}_k = \beta$. Standard iterative processes, such as the Newton-Raphson method, can be used to achieve this. Using above Equation can be used to estimate η once β has been established.

$$\eta = \frac{\sum_{i=1}^n x_i^\beta}{n}$$

Method of Moments (MOM)

Another popular method in the field of parameter estimate is the method of moments. If a set of data is represented by the numbers $x_1, x_2, \dots, x_n$, then an unbiased estimator for the k^{th} origin moment is

$$\hat{m}_k = \frac{1}{n} \sum_{i=1}^n x_i^k$$

$$\mu_k = \left(\frac{1}{\eta^\beta} \right)^{\frac{-k}{\beta}} \Gamma \left(1 + \frac{k}{\beta} \right)$$





where Γ signifies the gamma function

$$\Gamma(s) = \int_0^{\infty} x^{s-1} e^{-x} dx, (s > 0)$$

we can find the first and the second moment as follows

$$m_1 \& = \mu_k = \left(\frac{1}{\eta}\right)^{\frac{1}{\beta}} \Gamma\left(1 + \frac{1}{\beta}\right) \quad (13)$$

$$m_2 \& = \mu_k^2 + \sigma_k^2 = \left[\frac{1}{\eta}\right]^{\frac{2}{\beta}} \left\{ \Gamma\left(1 + \frac{2}{\beta}\right) - \left[\Gamma\left(1 + \frac{1}{\beta}\right) \right]^2 \right\}$$

The formula that results from dividing m_2 by the square of m_1 , is solely a function of β .

$$\frac{\hat{\sigma}_k^2}{\hat{\mu}_k^2} = \frac{\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)}{\Gamma^2\left(1 + \frac{1}{\beta}\right)}$$

we have the coefficient of variation

$$CV = \frac{\sqrt{\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)}}{\Gamma\left(1 + \frac{1}{\beta}\right)}$$

The calculated $(\hat{\beta})$ is the equivalent β . The following can then be used to estimate the scaling parameter (n).

$$\hat{\eta} = \{\bar{x} / \Gamma[(1/\hat{\beta}) + 1]\}^{\hat{\beta}}$$

where $\bar{x}$ is the mean of the data.

Least Squares Method (LSM)

We use the method of least squares,

$$\ln \ln \left[\frac{1}{1 - F(x)} \right] = \beta \ln x - \beta \ln \eta$$

$$\bar{x} \& = \frac{1}{n} \sum_{i=1}^n \ln \left\{ \ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right\}$$

$$\bar{Y} \& = \frac{1}{n} \sum_{i=1}^n \ln x_i$$

$$\hat{\beta} \& = \frac{n \cdot \sum_{i=1}^n (\ln x_i) \cdot \left(\ln \left\{ \ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right\} \right) - \sum_{i=1}^n \ln \left(\ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right) \cdot \sum_{i=1}^n \ln x_i}{n \cdot \sum_{i=1}^n (\ln x_i)^2 - \sum_{i=1}^n (\ln x_i)^2}$$

$$\hat{\eta} \& = e^{\left(\bar{Y} - \frac{\bar{x}}{\hat{\beta}} \right)}$$

Real time Data

This section analyzes an actual data set to show the advantages of the Weibull distribution. The model parameters' MLE and associated standard errors (in parenthesis) are obtained. We present the estimated PDF of the Weibull distribution model together with the histogram for every data set. Additionally, the following figures show the respective plots of the PDF, CDF, and Hazard rate of the data set Using MLE's. Further, fitted CDF and empirical CDF of the Weibull distribution and difference of these both are given. The information which was taken from Kaggle.com [10], shows real-time customer transactions on Kaggle.com. The following is the data set: transaction amounts 35.47, 2552.72, 115.97, 11.31, 62.21, 99.14, 145.94, 161.39, 77.73, 142.85, 928.68, 387.78, 142.07, 107.44, 54.31, 79.57, 441.18, 475.82, 106.26, 1468.14, 40.08, 39.87, 151.73, 17.05, 108.3, 366.56, 924.23





RESULTS AND DISCUSSION

A popular method for modeling lifetime data is a flexible version of the Weibull distribution. A larger class of hazard rate and density functions is produced by this extension. The new distribution is treated mathematically, with extensions for the density and cumulative functions. For a broader spectrum of statistical study, we anticipate that the suggested model will be an intriguing alternative paradigm. With the aid of the MATLAB application, we illustrate the outcomes of all the dependability functions of the adjusted distribution using real-time client amount transaction data from kaggle.com [10]. In Section 4, graphical representations of histogram PDF, CDF, Hazard rate for Estimated Weibull distribution are given. Where, shape parameter α is 280.3304 and β is 0.76063. Furthermore, difference of Difference of Empirical CDF and Fitted CDF of Weibull distribution for customer amount transaction data also given. Hence, MLE to estimating the parameters β and α of the Weibull distribution's from the given transaction data. When the transaction values increases, the shape parameter α of WD shows whether the event occurs more frequently. A Most failure rate is indicated by $\alpha > 1$. When $\alpha < 1$, the failure rate is degenerated. A constant failure rate, unique of an exponential distribution, is indicated by $\alpha = 1$. The cumulative and opportunity that the transaction amount will fall below or equal a specific value has been given by the CDF. With an increase in the transaction amount, it rises from 0 to 1. The Hazard Rate offers information on the instantaneous rate at which an event (such as a high-value transaction) occurs at any particular moment. If the shape parameter $\alpha > 1$, the hazard rate is higher for larger transaction amounts, indicating that larger transaction amounts are more likely to occur over time.

CONCLUSION

We have provided both mathematical and graphical approaches for estimating the Weibull distribution parameters in this study. The computational findings have demonstrated that the method of moments provides the best estimations. Following the model's fit to the transaction amount data set, all of the figures show that the proposed model provides a superior fit to the provided data set than any of the competing models.

REFERENCES

1. Hallinan Jr, A. J. (1993). A review of the Weibull distribution. *Journal of quality technology*, 25(2), 85-93.
2. Cohen, A. C. (1965). Maximum likelihood estimation in the Weibull distribution based on complete and on censored samples. *Technometrics*, 7(4), 579-588.
3. Lemon, G. H. (1975). Maximum likelihood estimation for the three parameter Weibull distribution based on censored samples. *Technometrics*, 17(2), 247-254.
4. Hossain, A., & Zimmer, W. (2003). Comparison of estimation methods for Weibull parameters: complete and censored samples. *Journal of statistical computation and simulation*, 73(2), 145-153.
5. Mohammadi, K., Alavi, O., Mostafaeipour, A., Goudarzi, N., & Jalilvand, M. (2016). Assessing different parameters estimation methods of Weibull distribution to compute wind power density. *Energy Conversion and Management*, 108, 322-335.
6. Afify, A. Z., Yousof, H. M., Cordeiro, G. M., M. Ortega, E. M., & Nofal, Z. M. (2016). The Weibull Fréchet distribution and its applications. *Journal of Applied Statistics*, 43(14), 2608-2626.
7. Hassan, A. S., & Assar, S. M. (2017). The exponentiated Weibull power function distribution. *Journal of data science*, 16(2), 589-614.
8. Cordeiro, G. M., Afify, A. Z., Yousof, H. M., Cakmakyapan, S., & Ozel, G. (2018). The Lindley Weibull distribution: properties and applications. *Anais da Academia Brasileira de Ciências*, 90, 2579-2598.
9. Bernal, R. A. (2021). On the application of Weibull statistics for describing strength of micro and nanostructures. *Mechanics of Materials*, 162, 104057.





Mouriya and Mohomed Harif

10. Al-Fawzan, M. A. (2000). Methods for estimating the parameters of the Weibull distribution. King Abdulaziz City for Science and Technology, Saudi Arabia.
11. <https://www.kaggle.com/datasets/bkcoban/customertransactions/suggestions?status=pending&yourSuggestions=true>.

Table 1. Methods for estimating $F(x_i)$.

Method	$F(x_i)$
Mean Rank	$\frac{i}{n+1}$
Median Rank	$\frac{i-0.3}{n+0.4}$
Symmetrical CDF	$\frac{i-0.5}{n}$

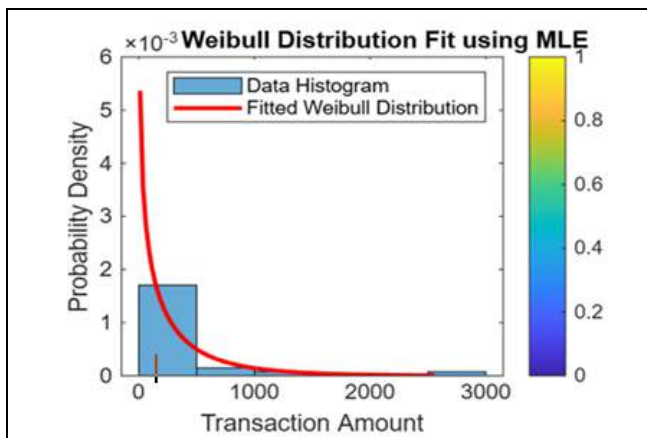


Fig 1: PDF of Weibull distribution.

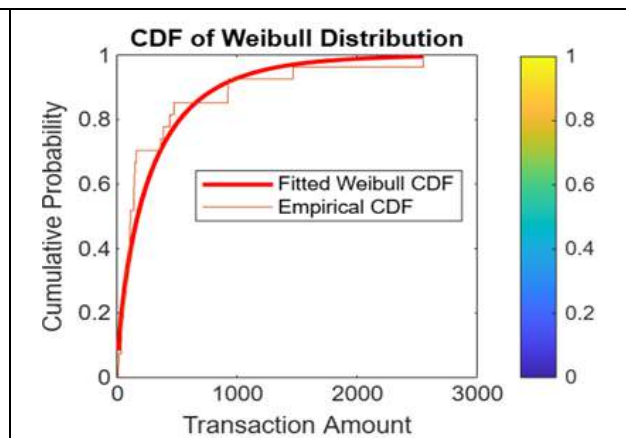


Fig 2: CDF of Weibull distribution for customer amount transaction data.

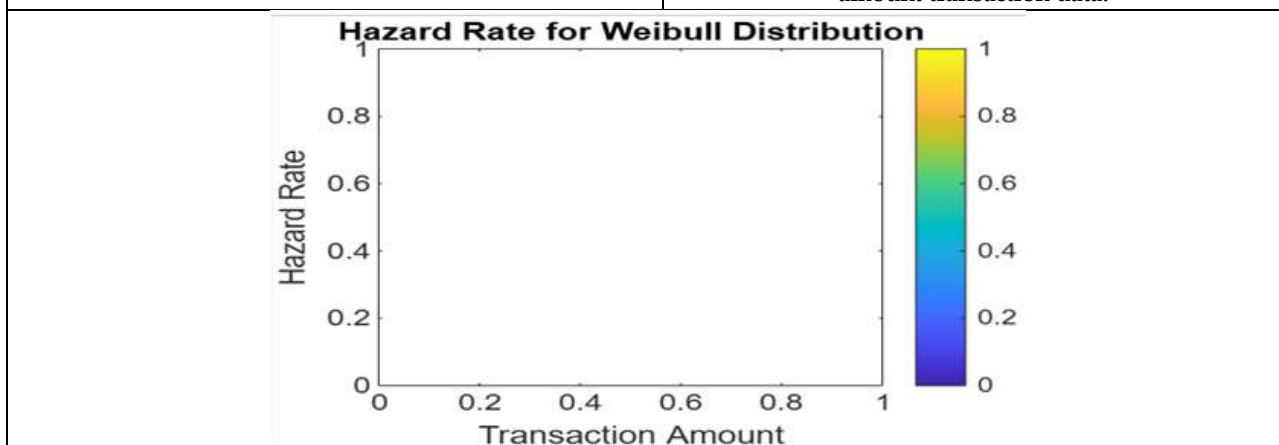


Fig 3: Hazard rate function of Weibull distribution for customer amount transaction data.



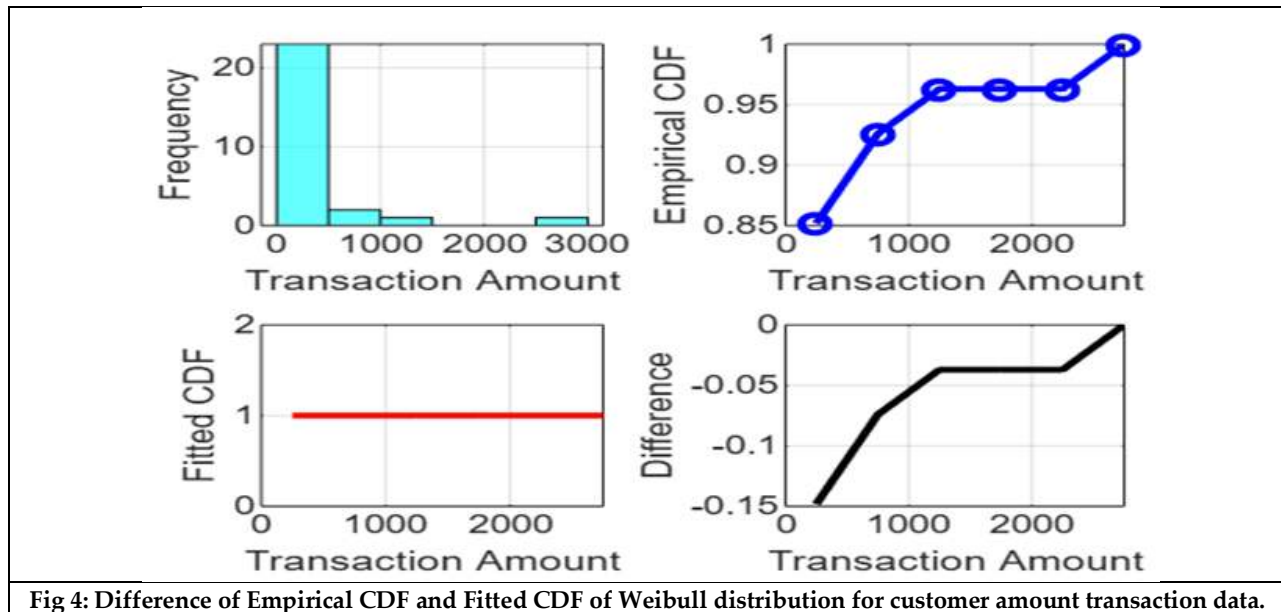


Fig 4: Difference of Empirical CDF and Fitted CDF of Weibull distribution for customer amount transaction data.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Determination of Related Compounds by RP - HPLC Method for the Estimation of Metformin and Alogliptin in Bulk and its Dosage Form

Radhakrishnaveni Vadlamudi*

Lecturer, Department of Pharmaceutical Analysis, Chebrolu Hanumaiah Institute of Pharmaceutical Sciences, (Affiliate to Acharya Nagarjuna University), Guntur, Andhra Pradesh, India

Received: 09 Mar 2026

Revised: 10 Apr 2026

Accepted: 15 May 2026

*Address for Correspondence

Radhakrishnaveni Vadlamudi

Lecturer,

Department of Pharmaceutical Analysis,

Chebrolu Hanumaiah Institute of Pharmaceutical Sciences

(Affiliate to Acharya Nagarjuna University),

Guntur, Andhra Pradesh, India

E.Mail: krishna.vadlamudi8712@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

A new, simple stability-indicating RP-HPLC and UV method for simultaneous estimation of Metformin and Alogliptin in bulk and dosage form was developed. Chromatography was carried out using Phenomenex Synergi polar column with a flow rate of 1.5mL/minute. The mobile phase consisted of 0 Prepare a degassed mixture of buffer, Acetonitrile and methanol in the ratio of 60:28:12 % v/v/v. at 224nm for Alogliptin, 232nm for Metformin. Strict control of impurities is necessary for the manufacturing of drug products. These impurities may be present in the materials, formed as by-products during the process of production or appear as degradation products during storage. Both actual and potential impurities should be studied and detected by a reliable and convenient method. Metformin impurities Related compound A (RCA), Related compound B (RCB) and Related compound C (RCC) are chemically known as 1- Cyanoguanidine (RCA), 1- methyl biguanidine hydrochloride (RCB) and N, N dimethyl (1, 3, 5) triazine 2, 4, 6 triamine (RCC). The impurities of AGLT-BZ studied in this paper were named as compounds RC-01, RC-02, RC-03 & RC-04.

Keywords: Metformin, Alogliptin, RP-HPLC and Related compounds, Impurities

INTRODUCTION

Metformin Hydrochloride is an oral antidiabetic drug in the biguanide class. It is the first-line drug of choice for the treatment of type 2 diabetes, in particular, in overweight and obese people and those with normal kidney function. Its use in gestational diabetes has been limited by safety concerns. It is also used in the treatment of polycystic ovary

115624



**Radhakrishnaveni Vadlamudi**

syndrome, and has been investigated for other diseases where insulin resistance may be an important factor. Metformin Hydrochloride works by suppressing glucose production by the liver. Alogliptin works by increasing levels of natural substances called incretins. Incretins help to control blood sugar by increasing release, especially after a meal. They also decrease the amount of sugar your liver makes. Increased concentrations of the incretin hormones such as glucagon-like peptide-1 (GLP-1) and glucose-dependent insulinotropic polypeptide (GIP) are released into the bloodstream from the small intestine in response to meals. These hormones cause insulin release from the pancreatic beta cells in a glucose-dependent manner but are inactivated by the dipeptidyl peptidase-4 (DPP-4) enzyme within minutes.

MATERIALS AND METHODS:**Instrumentation**

All HPLC experiments were carried out on a Waters Alliance 2695 separation module, with waters uv detector in gradient mode using Auto sampler. The analytical column used for the separation was Phenomenex Synergi polar (250× 4.6 mm I.D., 4µm particle size) Analytical balance (contech balance), pH meter (DIGITAL pH METER 802, Systronics), sonicator (SONIC, VIBRA CELL).

Chemicals and reagents

- A working standards Metformin (99.7%) and Alogliptin (99.5%) were procured from HETERO, Hyderabad, India. Acetonitrile (HPLC Grade; MERCK), Sodium dodecyl sulphate SIGMA-ALDRICH (part no 71725-100G), Orthophosphoric acid (88%) (AR Grade, MERCK), HCl (AR Grade, Qualigens), Related compounds metformin hydrochloride and Related compounds Alogliptin are obtained from HETERO Hyderabad, Methanol (HPLC Grade) and milli Q grade water was used for entrained study

Preparation of solutions**Buffer**

Transfer 1mL of orthophosphoric acid into a beaker containing 1000 ml water, add 1g of sodium dodecyl sulfate and dissolve. Filter the solution through 0.45µm membrane filter.

Mobile phase

Prepare a degassed mixture of buffer, Acetonitrile and methanol in the ratio of 60:28:12 % v/v/v.

0.01N HCl

Dilute 0.85 ml of HCl to 1000mL of water and mix.

Diluent

prepare a degassed mixture of 0.01N HCl and Acetonitrile in the ratio of 90:10%v/v

Determination of Related Compounds

Strict control of impurities is necessary for the manufacturing of drug products. These impurities may be present in the materials, formed as by-products during the process of production or appear as degradation products during storage. Both actual and potential impurities should be studied and detected by a reliable and convenient method. Metformin impurities Related compound A (RCA), Related compound B (RCB) and Related compound C (RCC) are chemically known as 1- Cyanoguanidine (RCA), 1- methyl biguanidine hydrochloride (RCB) and N, N dimethyl (1, 3, 5) triazine 2, 4, 6 triamine (RCC). The impurities of AGLT-BZ studied in this paper were named as compounds RC-01, RC-02 & RC-03.



**Radhakrishnaveni Vadlamudi****Preparation of Standard****Solution A**

Metformin: Accurately weigh and transfer about 40mg of Metformin Hydrochloride working standard into 100ml volumetric flask. Add about 60ml of diluent and sonicate to dissolve. Dilute to volume with diluent and mix.

Solution B

Alogliptin: Accurately weigh and transfer about 57mg of Alogliptin benzoate working standard into 100ml volumetric flask. Add about 60ml of diluent and sonicate to dissolve. Dilute to volume with diluent and mix.

Impurity stock solution was prepared by dissolving each 1mg of related compounds (A, B, C) in 100ml of diluents to obtain a solution having a concentration of each related compounds (0.5mg/ml). Resolution solution of Metformin HCL, Alogliptin Benzoate and its related compounds were prepared by adding 5ml of impurity stock solution in 20ml of diluents. Samples of formulated metformin HCL (tablet) were prepared by dissolving a quantity of tablet equivalent to metformin HCL and Alogliptin Benzoate in 100ml of diluents. A portion of sample solution was centrifuged at 3500rpm for 10 minutes. 5ml of supernatant liquid was transferred to 50 ml volumetric flask and add diluents up to the mark in order to detect impurities and degradants which may be present in the samples of Metformin HCL and Alogliptin Benzoate tablets.

CONCLUSION

Only 1 or 2 Related Compounds are determined in literature survey. There is no method to determine all Related Compounds of Metformin HCL and Alogliptin Benzoate. My method was good because All Related Compounds separated within 15 minutes. The RP-HPLC method was proved to be more sensitive, the validated parameters were found to be within the acceptance criteria and hence the developed methods were proved to be precise, accurate and robust. A simple, accurate and precision stability indicating HPLC analytical method was developed and validated for the analysis of Metformin HCL and Alogliptin Benzoate in tablet formulation.

ACKNOWLEDGMENTS

The authors wish to thank the Department of Pharmaceutical Analysis, Chebrolu Hanumaiah Institute of Pharmaceutical Sciences, Guntur for their constant support in completing this work. The authors wish to acknowledge the management of Spectrum Pharma Ltd. Hyderabad for providing the samples for their research. They would also like to thank colleagues in bulk manufacturers for providing chemicals and standards for research work.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Wanjari M M, There AW, Tajne M R, Chopde C T, Umathe S N. Rapid and simple RPHPLC method for the estimation of Metformin in rat plasma. Indian J Pharm Sci, Mar-Apr 2008; 70(2): 198-202.
2. CPMP, Note for Guidance on Stability Testing of Existing Active Substances and Related Finished Products. Committee for Proprietary Medicinal Products, EMEA, London, 1998.
3. Kolte BL, Raut BB, Deo AA, Bagool MA, Shinde DB. Simultaneous HPLC determination of Pioglitazone and Metformin in pharmaceutical dosage form. J Chromatogr Sci 2004; 42: 27.





Radhakrishnaveni Vadlamudi

4. Jiang JJ, Feng F, Ma M, Zhang ZX. Study on a new precolumn derivatization method in the determination of metformin hydrochloride. J Chromatogr Sci 2006; 44:193
5. Sripalakit P, Neamhom P, Saraphanchotiwitthaya A. J. Chromatogr. B Analyt Technol Biomed Life Sci 2006; 843: 164-169.
6. Porta V, Schramm SG, Koono EE, Armando YP, Fukuda K, Serra CH. Determination of metformin in human plasma for application in pharmacokinetics and bioequivalence studies. Pharm Biomed Anal 2008; 46:143

Table 1: Peak 1 Result:

S.No	Name	RT	AREA	% AREA	PURITY ANGLE	PURITY THRESHOLD	PURITY FLAG
1	MFN RC-A	1.31	8823	0.34			
2	SODIUM BENZOATE	4.66	164379	17.44			
3	MFN RC-C	5.17	25433	2.69			
4	METFORMIN	5.56	344675	36.50			
5	MFN RC-B	6.03	55636	5.90			
6	PEAK-5	6.33	7711	0.82			
7	ALO RC-03	7.34	38283	4.06	0.571	1.072	No
8	ALO RC-01	7.67	69216	7.34	1.336	1.316	Yes
9	ALO	10.50	229159	24.31	0.089	0.422	No
Sum			942615				

Table 2: Peak 2 Results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	2.79	10592	0.73
2	SODIUM BENZOATE	6.24	245443	17.03
3	MFN RC-C	6.68	39784	2.76
4	METFORMIN	6.81	523021	36.29
5	MFN RC-B	7.40	14619	1.01
6	PEAK-5	7.97	90538	6.28
7	ALO RC-03	9.53	59577	4.13
8	ALO RC-01	10.36	107433	7.45
9	ALO	11.61	350380	24.31
Sum			1441385	

Table 3: peak 2 results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	1.31	8823	0.34
2	SODIUM BENZOATE	4.66	164379	17.44
3	MFN RC-C	5.17	25433	2.69
4	METFORMIN	5.56	344675	36.50
5	MFN RC-B	6.03	55636	5.90
6	PEAK-5	6.33	7711	0.82
7	ALO RC-03	7.34	38283	4.06
8	ALO RC-01	7.67	69216	7.34
9	ALO	10.50	229159	24.31
Sum			942615	





Radhakrishnaveni Vadlamudi

Table 4: peak 2 results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	3.10	21855	01.59
2	METFORMIN	5.79	506410	36.94
3	PEAK	6.41	232821	16.98
4	MFN RC-B	7.10		
5	MFN RC-C	7.63		
6	ALO RC-02	8.18	91341	6.66
7	ALO RC-03	9.71	61401	4.48
8	ALO RC-01	10.76	109259	7.97
9	ALO	11.71	229159	25.38
10	ALO RC-04	13.32		
Sum			1370993	

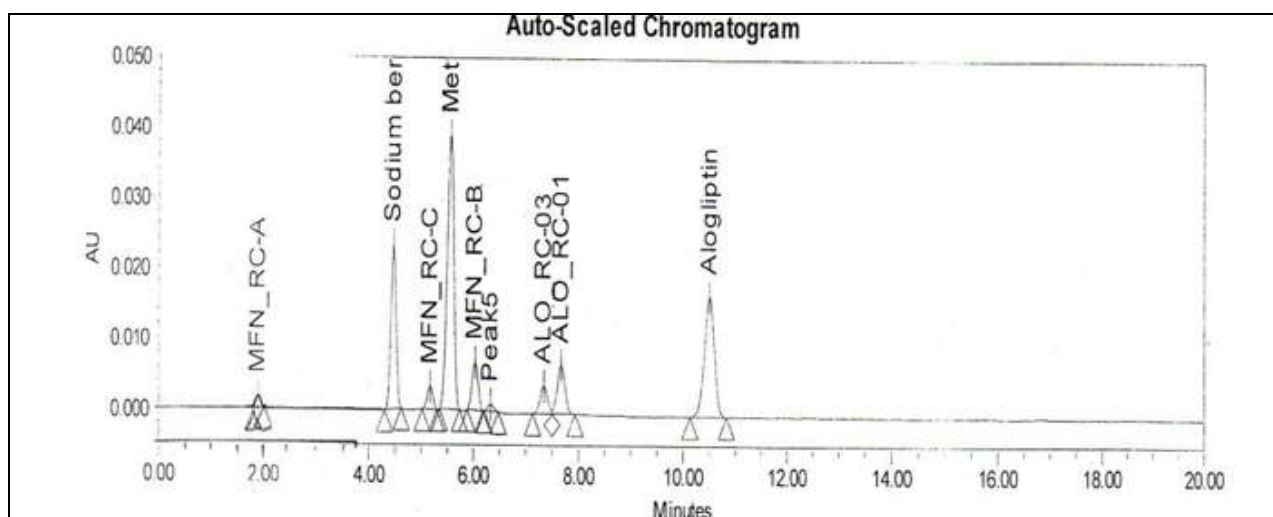


Fig 1: Peak 1

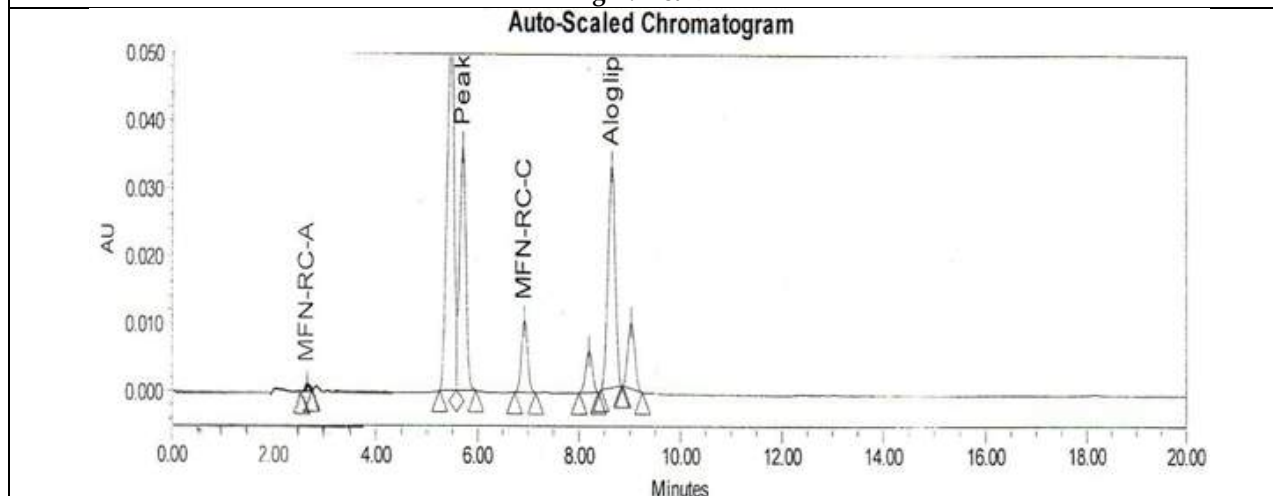
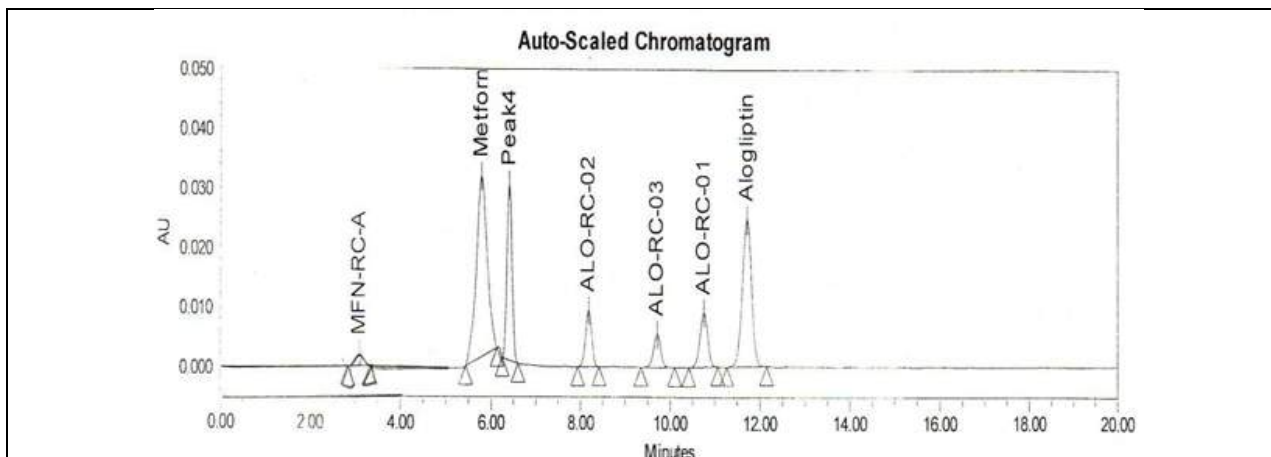
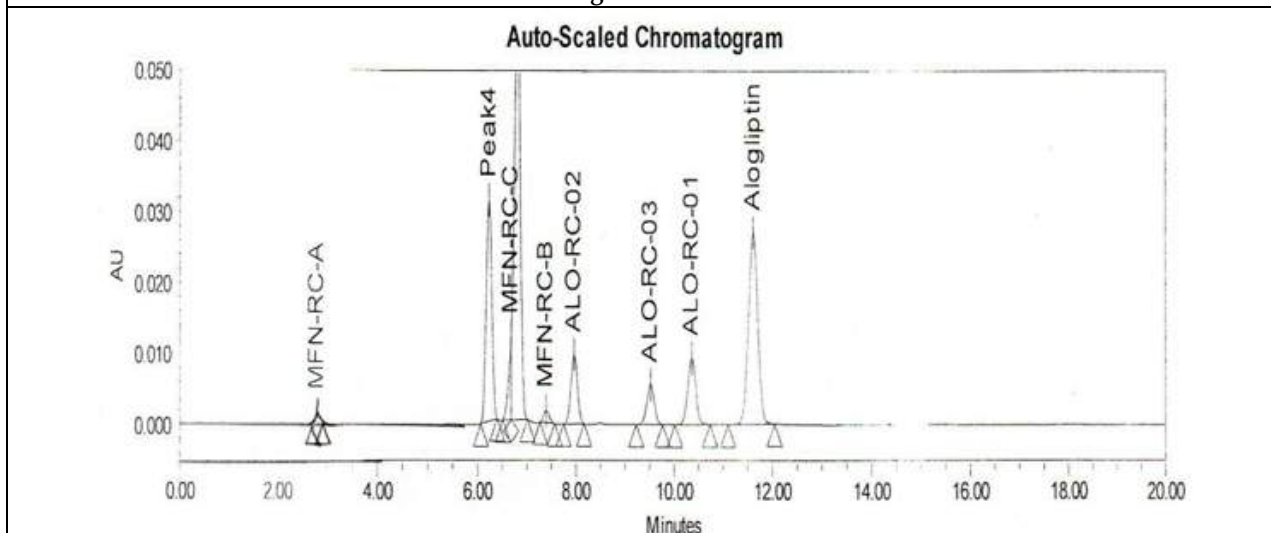


Fig 1: Peak 2



**Radhakrishnaveni Vadlamudi****Fig 1: Peak 3****Fig 1: Peak 4**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Fenugreek (*Trigonella foenum graecum*) in the Management of Polycystic Ovarian Syndrome: Nutritional, Biochemical and Therapeutic Perspectives

Shelly Garg^{1*}, Hardik Dalal² and Sakshi Garg³

¹Assistant Professor, Department of Nutrition and Dietetics, School of Allied Health Sciences, SGT University, Haryana, India

²PG Student, Department of Dietetics and Nutrition, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

³DNB First Year, Department of General Medicine, Maharaja Agrasen Hospital, New Delhi, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 18 May 2026

*Address for Correspondence

Shelly Garg

Assistant Professor,

Department of Nutrition and Dietetics,

School of Allied Health Sciences,

SGT University, Haryana, India

E.Mail: gargshelly8795@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Polycystic Ovarian Syndrome (PCOS) is a prevalent endocrine and metabolic disorder affecting women of reproductive age, characterized by hyperandrogenism, insulin resistance, and chronic anovulation. It is associated with multiple complications including infertility, obesity, type II diabetes, hormonal imbalance and cardiovascular disorders. Conventional management primarily involves lifestyle modification and pharmacological interventions; however, increasing attention has been directed towards functional foods and herbal therapies as alternative therapy. Fenugreek (*Trigonella foenum graecum*), a widely used medicinal plant, exhibits significant nutritional and therapeutic potential due to its rich composition of dietary fiber, steroidal saponins (diosgenin), alkaloids, and polyphenolic compounds. These bioactive compounds contribute to its hypoglycemic, hypolipidemic, immunomodulatory, and antioxidant properties. Diabetes, one of the most common concerns in PCOS, and Fenugreek aids in diabetes or insulin resistance by delaying carbohydrate absorption and enhancing insulin secretion as well as insulin sensitivity. Further, its effects on lipid metabolism and oxidative stress further support its role in managing associated metabolic disturbances. This review highlights the nutritional composition, biochemical properties, and therapeutic relevance of fenugreek in PCOS management, emphasizing its potential as a functional food and alternate therapy. Further clinical investigations are required to validate its efficacy and establish standardized therapeutic applications.

Keywords: Polycystic Ovarian Syndrome; PCOS; Fenugreek (*Trigonella foenum graecum*); Insulin Resistance; Hyperandrogenism; Functional food; Bioactive compounds; Hypoglycemic effect; Antioxidant activity; Nutritional therapy





Shelly Garg et al.,

INTRODUCTION

As humans approach puberty, both sexes start producing sex hormones that differentiate them from one another. Females release Progesterone, Estrogen, Follicle Stimulating Hormone, Gonadotropin Releasing Hormone and Luteinizing Hormone. A small amount of male hormone is additionally present in females, called Androgen. When androgen levels in women rise to greater extents, it leads to PCOS, known as Polycystic Ovarian Syndrome [1]. The global prevalence of PCOS ranges between 2.2 to 26%, it is around 2 to 7.5% in Asia. In India, the PCOS affects around 9-22% of all women [2]. Signs and symptoms of PCOS include infertility, chronic anovulation, obesity, and insulin resistance. Common symptoms include hirsutism and acne. However, some cases may exhibit hypermenorrhea (prolonged, heavy menstrual periods) as well as alopecia (thinning or loss of hair) among other symptoms [3]. Nearly 80% of PCOS cases are found in women with obesity, the other 20% are lean, or non- obese women [4]. Diagnosis of PCOS comes with the increased risk of the associated conditions including insulin resistance and type II diabetes, endometrial cancer, depression and anxiety, high blood pressure, dyslipidemia, sleep apnea, patchy skin, fatty liver disease, strokes, miscarriage, and even weight gain [3]. A pelvic ultrasound is a major diagnostic tool for PCOS [5]. The management of PCOS includes changes in lifestyle along with medical treatment..

Fenugreek Seeds:

Botanical Description and Culinary Uses:

Fenugreek, scientifically named *Trigonella foenum graecum*, is a plant belonging to the family of Leguminosae, which is the most famous spice of human food. Fenugreek seeds and leaves are widely used in food and medicinal applications. Flavor and color are increased by adding the leaves and seeds of fenugreek, along with altering the texture of food materials. Seeds have medicinal properties like lactational aid, hypercholesterolemic, gastric stimulant, antibacterial, anti-anorexic, galactagogue and antidiabetic effects. These beneficial effects are due to intrinsic dietary fiber constituent that promises nutraceutical value [6]. Fenugreek is known largely for the taste of its slightly sweet and bitter seeds, which are available in any form, either whole or ground, used to flavor many foods, mostly curry powders, spices and teas. Fenugreek seeds have yellow and hard central embryo surrounded by corneous and comparative large layers of semi-transparent, white endosperm [7].

Chemical Composition and Bioactive Compounds

Diosgenin, present as 0.1-0.9% in fenugreek, is extracted from it commercially. As much as 2% diosgenin was found from plant tissue cultures of fenugreek when grown under optimal conditions. Smaller amounts of gitogenin and trigogenin were found too. Saponin fenugrin B was also found in the seeds. Fenugreek seeds are known to contain several coumarin compounds and numerous alkaloids, such as trigonelline, carpaine and gentianine. Trigonelline, present in large amounts, is degraded to nicotinic acid and pyridines during the process of roasting [8]. Fenugreek's chemical composition shows that the endosperm has the highest saponin (4.63g/100 g) and protein (43.8g/100 g). Husk, however, contains higher total polyphenols. The extracts of the husk and fenugreek seed at about a concentration of 200 mcg exhibited an antioxidant activity of 72%, 64% and 56% respectively, using the method of free radical scavenging [9]. Majority of the bioactive compounds in fenugreek seeds are polyphenols, like isovitexin and rhaponticin [10]. From studies, it was reported that fenugreek seeds are a rich source of protein and dietary fiber. About 4.8% of saponins are found in whole fenugreek seeds. Fenugreek seed saponins are steroidal, type furostanol saponins with diosgenin as the primary steroidal saponin. Alkaloids, including gentianine, trigonelline and carpaine compounds are found in fenugreek seeds. The seeds contain fenugreekine fiber that may have hypoglycaemic activity. Crude fibre is composed of cellulose, a complex carbohydrate made up of glucose molecules. Hemicellulose is related to cellulose, while pectin is a type of hemicellulose. Another form of crude fibre, lignin, is not a carbohydrate but is of plant origin and is indigestible as well. This arrests the rapid uptake of glucose in the small intestine and slows gastric emptying, which in turn retains blood sugar in diabetes patients and may be effective in the treatment of hypercholesterolemia [11]. High proportion of protein between 20 to 30% of amino acids, especially



**Shelly Garg et al.,**

4-hydroxy isoleucine are found in fenugreek [12]. From another comparative study, fenugreek protein fraction is comparable with soybean protein because of its richness of lysine [13].

Metabolic and Nutritional Effects:

Glucose can be blunted by the consumption of dietary fiber after the meal and fenugreek does an excellent job at that. Mechanisms for these effects haven't thoroughly been explained. A 45.5% content of dietary fiber ensures that fenugreek works well in that aspect, with 32% insoluble and 13.3% soluble fibre; and the gum being composed of mannose and galactose. These latter compounds are responsible for the reduction in the glycemic effect. Hypoglycemic effect of fenugreek has been documented in animals as well as humans with type 1 and type 2 diabetes mellitus [14]. The digestion is delayed by soluble fibre of fenugreek and absorption of carbohydrate is delayed, which improves the homeostasis of glucose. Researchers accounted for this behavior to gel formation and low viscosity of the gels that result in the small intestine that delay gastric emptying and decrease the transit time of the food mass in the intestine [15]. From studies it has been observed that adding 100 g of fenugreek with 50% dietary fibre for 10 days decreased blood sugar levels among type II diabetes patients by 25% [16]. An investigation of the effects of fenugreek on blood lipids has been carried out too, using rats with diabetes. The rats were induced with streptozotocin and administered by oral intragastric intubation with low, middle and high doses of fenugreek extracts along with metformin HCl for six weeks. When compared to the diabetic rats control group, fenugreek treated rats showed lower levels of triglycerides and total cholesterol and higher levels of HDL cholesterol in a manner dependent on the dosage of the extract [17].

Antioxidant Activity:

Antioxidant activity is exhibited by fenugreek due to the presence of polyphenols and flavonoids [18]. They have also been reported to show protective effects against oxidation induced by hydrogen peroxide by protecting red blood cells from hemolysis and peroxidation of lipids [19]. Studies conducted suggested of fenugreek being powerful as an antioxidant with positive effects on the pancreas as well as liver [20]. It was reported that fenugreek seeds have a radical scavenging activity with ethanol, methanol, acetone, dichloromethane, hexane and ethyl acetate [21]. A positive effect of fenugreek on lipid peroxidation and enzymatic antioxidants [22]. Another report showed the proximate composition of fenugreek seeds having cotyledons and husk with the highest protein and saponin content. Husk contains higher content of total polyphenols [23]. At a concentration of 200 mcg, extracts of husk, seeds and endosperm of fenugreek showed 64%, 72% and 56% antioxidant activity by scavenging activity of free radicals [24].

Immunomodulatory Activity:

An agent by which the immune system or immune responses are diminished is called an immunomodulator, with its effect being known as immunomodulatory effect. Research has studied the immunomodulatory effect of fenugreek on stimulation as seen from relative thymus weight, body weight, quantitative hemolytic assay, hemagglutination titer, cellularity of lymphoid organs, phagocytosis, plaque forming cell assay, hypersensitivity response of late type, increase in phagocytic index and capacity and a lymph proliferation significantly. The research was conducted in aqueous extracts at three doses, namely 200, 100 and 50 mg per kg of body weight. They were done on albino mice's immune system for 10 days [13].

Functional Food Applications:

Fenugreek is also known well for its gum, fibre and other components of chemical importance as well as volatile components. The 25% constitution of dietary fiber in fenugreek seeds changes the texture of foods when used in ample quantity. Use of fenugreek is also done as a dietary stabilizer, emulsifier and adhesive due to the high gum, fibre and protein content. Protein found in fenugreek is considered alkaline and more soluble [13]. Fenugreek is used in many foods throughout different cuisines, especially those of Asian origin. It has established itself as a functional food in recent times due to the high fibre content. Fenugreek gum, a hydrocolloid, gives thickening, appeal, textural, stabilizing, emulsifying, encapsulating and gelling effect to the food item in which it is added. Soluble fiber can thus find its way into many products like nutritional beverages, yogurts, bars and dairy products. Soluble fibre powder



**Shelly Garg et al.,**

can be used for mixing with seasonings, spice mixes and for juices. It can be used directly in the form of tablets along with other supplements which are needed. Milk shakes, dressings, candies, soups and sweets can also utilize the same. Fortification of pizza, cake mixes, flour, bagels, breads, muffins, tortilla and noodles is also done with fenugreek. Unwanted fat intake can also be taken care of using fenugreek extract by adding it to fried snacks. It decreases oil absorption by 8-15 % [25]. Urinary sugar and glycosylated Hb were reported to reduce by 13% and 12.2% in an examination of 40 patients after consumption of fenugreek seed for 8 weeks [26].

Traditional Therapeutic Uses:

Cleansing the blood and acting as a diaphoretic are other beneficial effects of fenugreek, which help to detoxify the body by sweating. The pungent aroma of fenugreek is smellable in the underarm and on skin perspiration. Lymphatic cleansing activities are also brought about by fenugreek, and it irrigates the cells with nutrients, removing toxic wastes, trapped proteins and dead cells in the process. Poor circulation of fluid, pain, fluid retention, disease and energy loss are also brought about by the blockages in the lymphatic system. Congestion in the lungs is also cleaned using fenugreek, which in turn helps in the maintenance of mucosal balance in the body. Fenugreek is used as a throat cleaner as well, as it eases the urge to cough. Consumption of water in which fenugreek seeds were soaked helps in dissolving and softening, accumulating and hardening the mass of dead cell's leftovers. Fenugreek is also used in relieving bronchial complaints, asthma, influenza, colds, constipation, catarrh, pleurisy, sinusitis, sore throat, pneumonia, hay fever, emphysema and laryngitis [27].

Fenugreek in PCOS Management:

It was indicated with the study that process viability advantage can be availed by separating fenugreek into seed, husk and endosperm with respect to the selective fractionation of bioactive compounds for the effective isolation of the same. Prophylaxis effect of fenugreek seeds on the renal stone formation was also studied in rats [24]. Calcic urolithiasis patients can be treated with the use of fenugreek also reported an anti-inflammatory potential [28]. Another investigation showed treatment by fenugreek as having inhibitory effect on the growth of breast, prostate and pancreatic cancer; however primary and immortalized cells remained unaffected. Trigonella inhibiting the cell growth in cancer is attributed to the ability to induce phagocytosis, i.e., the death of the cell, while promoting growth stimulating pathways in healthy cells [29]. Women with PCOS, obesity, lipid disorders and insulin resistance as well as infertility can be bettered with the use of fenugreek. Hyperinsulinemia can cause increase in abnormal androgen secretion and follicle development, which leads to dysfunctional ovarian cyclicity and menstrual cycle [30].

The first choice of treatment in such cases is metformin of reproductive disorders that stem from PCOS. It inhibits gluconeogenesis from the liver and has a direct effect on steroid production in the ovaries in granulosa cell structures [31]. Insulin resistance and ovarian hyperandrogenism in women with PCOS can be bettered with the use of metformin [32]. Glucose tolerance curve was significantly improved along with glucose induced insulin response using water extract of the fenugreek seed. According to a study, the hypoglycemic effect may be intermediated by stimulation of synthesis of insulin and secretion from beta cells [33]. From another study, similar results were found, where fenugreek seeds extract showed hypoglycemic effect by inhibition of sucrose, alpha-amylase and two other enzymes involved in metabolism of carbohydrates [34]. It also reduces insulin resistance [35]. From another study, the subgroup that had raised insulin showed less changes [36]. As opposed to the studies metformin was shown to reduce the markers of insulin resistance [37, 38].

CONCLUSION

PCOS (Polycystic Ovarian Syndrome) is an endocrine disorder characterized by hyperandrogenism, insulin resistance, and metabolic dysregulation, contributing to significant metabolic and reproductive complications. The growing prevalence of PCOS highlights the need for exploring therapeutic strategies apart from conventional interventions. Fenugreek (*Trigonella foenum graecum*) is one of the promising functional foods with substantial



**Shelly Garg et al.,**

therapeutic and nutraceutical potential in the management of PCOS. The bioactive constituents of fenugreek, including steroidal saponins such as diosgenin, alkaloids like trigonelline, and polyphenolic compounds, contribute to its diverse therapeutic activities. High fibre content in fenugreek has a critical role in modulating glucose metabolism pathways by delaying carbohydrate absorption and enhancing insulin sensitivity. Additionally, fenugreek has hypoglycemic, hypolipidemic, immunomodulatory and antioxidant activity, which in turn has positive impact on metabolic disruptions caused because of PCOS. The hypoglycemic, and enhanced insulin sensitivity action attributed by fenugreek is considered comparable to metformin. Furthermore, its functional food applications enhance its feasibility as a potential dietary intervention agent. While traditional usage highlights its broader therapeutic relevance, modern scientific findings support its role in mitigating insulin resistance and hormonal imbalance in PCOS. Overall, fenugreek represents a viable adjunct in the dietary and therapeutic management of PCOS. However, further clinical studies are required to establish standardized dosages, long-term safety, and mechanistic pathways to fully validate its efficiency in clinical practice.

REFERENCES

1. Hardik Dalal, Shelly Garg, Sakshi Garg. Polycystic Ovarian Disease and Effect of Lifestyle Modification- A Systematic review of RCTs. Adv. Biores., Vol 14 (2) March 2023: 154-161.
2. National Health Portal. Polycystic ovarian disease. Available from: <https://www.nhp.gov.in/disease/endocrinal/ovaries/polycystic-ovary-syndrome-pcos> [Accessed October 25, 2023]
3. Teede H, Deeks A, Moran L. Polycystic ovary syndrome: a complex condition with psychological, reproductive and metabolic manifestations that impacts on health across the lifespan. BMC Medicine. 2010; 8 (1): 41.
4. Goyal M, Dawood AS. Debates Regarding Lean Patients with Polycystic Ovary Syndrome: A Narrative Review. Journal of Human Reproductive Sciences. 2017; 10 (3): 154-161.
5. González F, Rote NS, Minium J, Kirwan JP. Reactive oxygen species-induced oxidative stress in the development of insulin resistance and hyperandrogenism in polycystic ovary syndrome. The Journal of Clinical Endocrinology and Metabolism. 2006; 91 (1): 336-340.
6. K. Srinivasan. Fenugreek (*Trigonella foenum-graecum*): A review of health beneficial physiological effects. Food Rev. Int. 2006; 22 (2): 203-224.
7. Ahmad A, Alghamdi SS, Mahmood K, Afzal M. Fenugreek a multipurpose crop: Potentialities and improvements. Saudi J Biol Sci. 2016 Mar;23(2):300-10. doi: 10.1016/j.sjbs.2015.09.015.
8. S. Acharya, A. Srichamroen, S. Basu, B. Ooraikul, T. Basu Improvement in the nutraceutical properties of fenugreek (*Trigonella foenum-graecum* L.) SJST. 2006; 28:1-9.
9. M.M. Naidu, B.N. Shyamala, P.J. Naik, G. Sulochanamma, P. Srinivas. Chemical composition and antioxidant activity of the husk and endosperm of fenugreek seeds. Food Sci. Technol. 2010; 44:451-456.
10. He C, Lin Z, Robb SW, Ezeamama AE. Serum Vitamin D Levels and Polycystic Ovary syndrome: A Systematic Review and Meta-Analysis. Nutrients (Meta-analysis). 2015; 7 (6): 4555– 4577.
11. Mullaicharam AR, Geetali D, Uma MR. Medicinal Values of Fenugreek – A Review. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 2013; 4(1):1304-1313.
12. Işıklı ND, Karababa E. Rheological characterization of fenugreek paste (çemen). J Food Eng. 2005; 69(2):185- 190.
13. Meghwal M, Goswami TK. A Review on the Functional Properties, Nutritional Content, Medicinal Utilization and Potential Application of Fenugreek. J Food Process Technol, 2012; 3(9).
14. Roberts KT, Cui SW, Chang YK, Ng PKW, Graham T. The influence of fenugreek gum and extrusion modified fenugreek gum on bread. Food Hydrocolloid. 2012; 26:350-358.
15. Hannan J, Ali L, Rokeya B, Khaleque J, Akhter M, Flatt P. Soluble dietary fibre fraction of *Trigonella foenum-graecum* (fenugreek) seed improves glucose homeostasis in animal models of type 1 and type 2 diabetes by delaying carbohydrate digestion and absorption, and enhancing insulin action. Brit J Nutr. 2007; 97(03):514-21.





Shelly Garg et al.,

16. Nasim Khorshidian, Mojtaba Yousefi Asli, Masoumeh Arab, Abolfazl Adeli Mirzaie, Amir Mohammad Mortazavian. Fenugreek: potential applications as a functional food and nutraceutical Nutrition and Food Sciences Research. Jan-Mar 2016; 3(1): 5-16.
17. Xue WL, Li XS, Zhang J, Liu YH, Wang ZL, Zhang RJ. Effect of Trigonella foenum- graecum (fenugreek) extract on blood glucose, blood lipid and hemorheological properties in streptozotocin-induced diabetic rats. Asia Pac. J. Clin. Nutr. 2007; 1: 422-426.
18. Dixit P, Ghaskadbi S, Mohan H, Devasagayam TPA. Antioxidant properties of germinated fenugreek seeds. Phytother Res. 2005; 19:977-983.
19. Kaviarasan S, Vijayalakshmi K, Anuradha C. Polyphenol-rich extract of fenugreek seeds protect erythrocytes from oxidative damage. Plant Food Hum Nutr. 2004; 59(4):143-7.
20. Balch PA. Prescription for dietary wellness (2nd edn). Penguin group, New York. 2003.
21. Syeda BB, Muhammad IB, & Shahabuddin M. Antioxidant activity from the extract of fenugreek seeds. Pak. J. Anal. Environ. Chem. 2008; 9(2), 78-83.
22. Bhatia K, Kaur M, Atif F, Ali M, Rehman H, Rahman S. Aqueous extract of ameliorates additive urotoxicity of buthionine sulfoximine and cyclophosphamide in mice. Food Chem. Toxicol. 2006; 44: 1744-50.
23. Naidu MM, Shyamala BN, Naik JP, Sulochanamma G, & Srinivas P. Chemical composition and antioxidant activity of the husk and endosperm of fenugreek seeds. LWT-Food Science and technology, 2011; 44(2), 451-456.
24. Laroubi A, Touhami M, Farouk L, Zrara I, Aboufatima R, Benharref A. Prophylaxis effect of Trigonella foenum graecum L. seeds on renal stone formation in rats. Phytother. Res. 2007; 21(10):921-925.
25. Im KK, Maliakel B. Fenugreek dietary fibre a novel class of functional food ingredient. Agro Food Ind. Hi-Tech. 2008;19: 18-21.
26. Khorshidian N, Mojtaba YA, Masoumeh A, Mirzaie AA, Amir MM. Fenugreek: potential applications as a functional food and nutraceutical. Nutrition and Food Sciences Research. 2016; 3(1):5-16.
27. Dixit P, Ghaskadbi S, Mohan H, Devasagayam TPA. Antioxidant properties of germinated fenugreek seeds. Phytother Res. 2005; 19:977-983.
28. Chauhan G, Sharma M, Varma A, Khanrkwal H. Phytochemical analysis and anti-inflammatory potential of fenugreek, Medicinal plants. Int. J. Phytomedicine. Rel. Ind. 2010; 2 (1): 39-44.
29. Shabbeer S, Sobolewski M, Anchoori RK, Kachhap S, Hidalgo M, Jimeno A, Davidson N, Carducci MA, Khan SR. Fenugreek: a naturally occurring edible spice as an anticancer agent. Cancer Biol. Ther. 2009;8: 272-278.
30. Galluzzo A, Calogero Amato M, Giordano C. Insulin resistance and polycystic ovarysyndrome. Nutr. Metab. Cardiovas Dis. 2008; 18:511–518.
31. Eisenhardt S, Schwarzmam N, Henschel V, Germeyer A, Von Wolf M, Hamann A, Strowitzki T. Early effects of Metformin in women with polycystic ovary syndrome: A prospective randomized, double-blind, placebo-controlled trial. J. Clin. Endocrinol. Metab. 2006; 91:946– 952.
32. Diamanti Kandarakis E, Kourli C, Tsianateli T, Bergiele A. Therapeutic effects of metformin on insulin resistance and hyperandrogenism in polycystic ovary syndrome. Eur. J. Endocrinol. 1998; 138:269–294.
33. Puri D, Prabhy KM, Murthy PS. Mechanism of action of a hypoglycemic principle isolated from fenugreek seeds. Indian J. Physiol. Pharmacol. 2002; 46:457–62.
34. Basch E, Ulbricht C, Kuo G, Szapary P, Smith M. Therapeutic applications of fenugreek. Altern. Med. Rev. 2003; 8 :20–27.
35. Patti G, Shane –Mc Whorter L. Dietary supplements in the management of diabetes: potential risks and benefits. J. Am. Diet. Assoc. 2008;108: S59–S65.





Shelly Garg et al.,

36. Pirwany IR, Yates RWS, Cameron IT, & Fleming R. Effects of the insulin sensitizing drug metformin on ovarian function, follicular growth and ovulation rate in obese women with oligomenorrhoea. Human reproduction. 1999; 14(12): 2963-2968.
37. Eisenhardt S, Schwarzmann N, Henschel V, Germeyer A, Von Wolff M, Hamann A, & Strowitzki T. Early effects of metformin in women with polycystic ovary syndrome: a prospective randomized, double-blind, placebo-controlled trial. The Journal of Clinical Endocrinology & Metabolism. 2006; 91(3): 946-952.
38. Harborne L, Fleming R, Lyall H, Sattar N, Norman J. Metformin or antiandrogen in the treatment of hirsutism in polycystic ovary syndrome. J. Clin. Endocrinol. Metab. 2003; 88:4116–4123.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Nanotechnology in Periodontics: Current Advances, Clinical Applications and Future Perspectives

Amit Mani¹, Shivani Sachdeva², Gayatri Magar^{3*}, Sakshi Takale³ and Prabhavati Dive³

¹Professor and HOD, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

²Professor, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

³PG Student, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

Received: 04 Mar 2026

Revised: 16 Apr 2026

Accepted: 18 May 2026

*Address for Correspondence

Gayatri Magar

PG Student,

Department of Periodontology,

Rural Dental College,

Pravara Institute of Medical Sciences,

Loni, Maharashtra, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Nanotechnology has emerged as a transformative domain in modern biomedical sciences, significantly influencing the diagnosis, prevention, and treatment of periodontal diseases. Periodontitis is a multifactorial chronic inflammatory disease characterized by progressive destruction of the supporting structures of teeth, driven by complex interactions between pathogenic biofilms and host immune responses. Conventional periodontal therapies, although effective in reducing microbial load, are often limited by inadequate drug delivery, inability to completely eradicate biofilms, and insufficient regenerative outcomes. Nanotechnology, defined as the manipulation of materials at the nanoscale (1–100 nm), provides unique physicochemical properties such as enhanced surface area, improved bioavailability, and superior cellular interaction, which can be harnessed for targeted periodontal therapy. Applications of nanotechnology in periodontics include nanoparticle-based drug delivery systems, antimicrobial nanomaterials, nanodiagnosics, and nanostructured scaffolds for tissue regeneration. These innovations enable site-specific drug delivery, sustained release kinetics, enhanced antimicrobial efficacy, and improved regenerative potential. Despite its promising benefits, challenges such as cytotoxicity, high production costs, and limited clinical validation persist. This review comprehensively discusses the role of nanotechnology in periodontics, emphasizing its applications, biological mechanisms, clinical relevance, and future prospects.

Keywords: nanomaterials, drug delivery systems, Periodontal regeneration, Nano dentistry.



Amit *et al.*,

INTRODUCTION

Periodontal diseases represent one of the most prevalent chronic inflammatory conditions affecting humans and are a major cause of tooth loss worldwide. The disease process is initiated by the accumulation of microbial biofilms on tooth surfaces, which trigger a host-mediated inflammatory response leading to destruction of the periodontal ligament, alveolar bone, and cementum. The complexity of periodontal disease lies in its multifactorial etiology, involving microbial, environmental, genetic, and immunological factors. Although conventional treatment modalities such as scaling and root planing, systemic and local antimicrobial therapy, and surgical interventions are effective in controlling disease progression, they often fail to completely eliminate pathogenic biofilms or achieve predictable regeneration of lost tissues (1,2).

One of the major limitations of traditional periodontal therapy is the inability to deliver therapeutic agents at effective concentrations directly to the site of infection for prolonged periods. Additionally, biofilms exhibit significant resistance to antibiotics due to their structural complexity and protective extracellular matrix. These challenges necessitate the development of advanced therapeutic strategies that can overcome these limitations. Nanotechnology has emerged as a promising solution by enabling precise manipulation of materials at the molecular level, thereby enhancing their interaction with biological systems. The application of nanotechnology in periodontics, often termed nanoperiodontics, has opened new avenues for improving diagnostic accuracy, therapeutic efficacy, and regenerative outcomes (3,4).

Fundamentals of Nanotechnology and Its Biological Relevance

Nanotechnology involves the design, synthesis, and application of materials with dimensions in the range of 1 to 100 nanometers. At this scale, materials exhibit unique properties that differ significantly from their bulk counterparts, including increased surface area-to-volume ratio, enhanced chemical reactivity, and improved mechanical strength. These properties enable nanoparticles to interact with biological molecules such as proteins, nucleic acids, and cell membranes in a highly efficient manner. Nanomaterials used in periodontics can be broadly classified into organic and inorganic nanoparticles. Organic nanoparticles, such as polymeric nanoparticles, liposomes, dendrimers, and nanogels, are widely used for drug delivery due to their biocompatibility and ability to encapsulate therapeutic agents. In contrast, inorganic nanoparticles, including silver, gold, zinc oxide, and titanium dioxide nanoparticles, exhibit strong antimicrobial and anti-inflammatory properties. The ability of these nanomaterials to penetrate biological barriers and deliver therapeutic agents in a controlled manner makes them highly suitable for periodontal applications (5,6).

Role of Nanotechnology in Periodontal Pathogenesis and Therapy

The pathogenesis of periodontal disease involves the formation of complex biofilms composed of diverse microbial communities embedded within an extracellular polymeric matrix. This matrix acts as a barrier, preventing the penetration of antimicrobial agents and protecting bacteria from host immune responses. Nanoparticles can overcome these barriers due to their small size and high surface reactivity, enabling them to penetrate biofilms and exert antimicrobial effects directly at the site of infection. In addition to their antimicrobial properties, nanoparticles can modulate host immune responses by reducing inflammation and promoting tissue healing. For instance, certain nanoparticles have been shown to inhibit the production of pro-inflammatory cytokines and enhance the activity of anti-inflammatory mediators. This dual action of antimicrobial and immunomodulatory effects makes nanotechnology a powerful tool in periodontal therapy (7,8).

Nanoparticle-Based Drug Delivery Systems in Periodontics

One of the most significant advancements in nanotechnology is the development of nanoparticle-based drug delivery systems. These systems are designed to deliver therapeutic agents directly to the periodontal pocket, ensuring high



**Amit et al.,**

local concentrations and sustained release over extended periods. This targeted approach minimizes systemic side effects and improves treatment efficacy. Polymeric nanoparticles are among the most commonly used drug delivery systems due to their biodegradability and ability to provide controlled drug release. Liposomes, which are phospholipid vesicles, can encapsulate both hydrophilic and hydrophobic drugs, enhancing their stability and bioavailability. Dendrimers, with their highly branched structure, offer multiple binding sites for drug molecules, allowing for high drug-loading capacity. Nanogels, which are hydrogel-based nanoparticles, provide a three-dimensional network for drug encapsulation and controlled release (9,10). Clinical studies have demonstrated that nanoparticle-based delivery systems significantly enhance the efficacy of antimicrobial agents such as doxycycline and chlorhexidine in the treatment of periodontal diseases. These systems not only improve drug penetration into biofilms but also maintain therapeutic concentrations for longer durations, reducing the frequency of administration (11,12).

Antimicrobial Applications of Nanotechnology

Nanoparticles possess intrinsic antimicrobial properties that make them highly effective against periodontal pathogens. Silver nanoparticles are the most extensively studied due to their broad-spectrum antimicrobial activity. They exert their effects by disrupting bacterial cell membranes, generating reactive oxygen species, and interfering with DNA replication. Similarly, zinc oxide nanoparticles and titanium dioxide nanoparticles have been shown to exhibit strong antibacterial and anti-inflammatory properties. The use of nanoparticles in periodontal therapy offers several advantages over conventional antibiotics, including reduced risk of resistance, enhanced biofilm penetration, and sustained antimicrobial activity. Furthermore, nanoparticles can be incorporated into various dental materials, such as gels, mouthwashes, and implant coatings, to provide long-term antimicrobial protection (13,14).

Nanodiagnostics in Periodontal Disease

Early detection of periodontal disease is essential for preventing disease progression and improving treatment outcomes. Nanotechnology has facilitated the development of advanced diagnostic tools capable of detecting disease biomarkers with high sensitivity and specificity. Nanosensors, quantum dots, and lab-on-a-chip devices are among the most promising technologies in this field. These diagnostic tools can detect specific biomarkers in saliva and gingival crevicular fluid, such as inflammatory cytokines, enzymes, and microbial components. The use of nanodiagnostics allows for real-time monitoring of disease progression and response to therapy, enabling personalized treatment approaches. This represents a significant advancement over traditional diagnostic methods, which are often limited by low sensitivity and delayed detection (15,16).

Nanotechnology in Periodontal Regeneration

Regeneration of periodontal tissues remains a major challenge in clinical practice. Nanotechnology offers innovative solutions by providing nanostructured scaffolds that mimic the natural extracellular matrix. These scaffolds support cell adhesion, proliferation, and differentiation, thereby promoting tissue regeneration. Nanofibers, hydrogels, and nanocomposites are commonly used as scaffolds in periodontal tissue engineering. These materials can be combined with growth factors and stem cells to enhance their regenerative potential. Studies have shown that nanostructured scaffolds significantly improve bone regeneration and periodontal tissue repair, making them a promising approach for achieving predictable clinical outcomes (17,18).

Nanotechnology in Implant Dentistry

Nanotechnology has significantly improved the success of dental implants by enhancing their surface properties. Nanostructured implant surfaces promote better osseointegration by increasing surface roughness and surface energy, which facilitate protein adsorption and cell adhesion. Additionally, the incorporation of antimicrobial nanoparticles into implant surfaces reduces the risk of peri-implant infections, thereby improving long-term implant success (19,20).





Amit et al.,

DISCUSSION

Nanotechnology has emerged as a transformative approach in periodontics, addressing several limitations associated with conventional therapeutic modalities. The complex pathogenesis of periodontal disease, which involves intricate interactions between pathogenic biofilms and host immune responses, necessitates advanced strategies that go beyond mechanical debridement and systemic drug administration. Traditional periodontal therapies often fail to achieve complete eradication of biofilms due to their structural complexity and resistance mechanisms. In this context, nanotechnology offers a promising solution by enabling targeted drug delivery, improved antimicrobial efficacy, and enhanced regenerative potential. The nanoscale size of particles allows for deeper penetration into periodontal pockets and biofilm matrices, thereby increasing the effectiveness of therapeutic agents and improving clinical outcomes (1,5).

One of the most significant contributions of nanotechnology to periodontics lies in the development of nanoparticle-based drug delivery systems. These systems have demonstrated the ability to deliver drugs in a controlled and sustained manner directly to the site of infection, thereby maintaining therapeutic concentrations for extended periods. This localized delivery not only enhances drug efficacy but also minimizes systemic side effects, which are commonly associated with conventional antibiotic therapy. Studies have shown that nanoparticle-based formulations of antimicrobial agents such as doxycycline and chlorhexidine exhibit superior efficacy in reducing periodontal pathogens compared to their conventional counterparts (6,11). Furthermore, the use of biodegradable and biocompatible nanocarriers, such as polymeric nanoparticles and liposomes, has improved the safety profile of these delivery systems, making them suitable for clinical application.

In addition to drug delivery, the intrinsic antimicrobial properties of certain nanoparticles have been extensively explored for periodontal therapy. Silver nanoparticles, for instance, have demonstrated broad-spectrum antibacterial activity against key periodontal pathogens through mechanisms such as disruption of bacterial cell membranes, generation of reactive oxygen species, and interference with DNA replication (13). Similarly, zinc oxide and titanium dioxide nanoparticles have shown promising antibacterial and anti-inflammatory properties. These nanoparticles are particularly effective in disrupting biofilms, which are known to be highly resistant to conventional antimicrobial agents. By targeting both planktonic bacteria and biofilm-associated microorganisms, nanomaterials offer a more comprehensive approach to infection control in periodontics (5,14).

Another important application of nanotechnology in periodontics is in the field of diagnostics. Early detection of periodontal disease is critical for preventing disease progression and improving treatment outcomes. Nanodiagnostic tools, such as nanosensors and lab-on-a-chip devices, have enabled the detection of disease biomarkers with high sensitivity and specificity. These technologies allow for the identification of inflammatory mediators, enzymes, and microbial components in saliva and gingival crevicular fluid, facilitating early diagnosis and real-time monitoring of disease progression (7,16). Compared to traditional diagnostic methods, which are often limited by low sensitivity and delayed detection, nanodiagnostics provide a more accurate and efficient means of disease assessment, thereby supporting personalized treatment approaches. The role of nanotechnology in periodontal regeneration represents another significant advancement in the field. Regeneration of periodontal tissues, including alveolar bone, periodontal ligament, and cementum, remains a major clinical challenge. Nanostructured scaffolds, such as nanofibers and nanocomposites, have been designed to mimic the natural extracellular matrix, thereby providing a conducive environment for cell attachment, proliferation, and differentiation. These scaffolds can be combined with growth factors and stem cells to further enhance their regenerative potential. Studies have demonstrated that nanostructured biomaterials significantly improve bone regeneration and periodontal tissue repair, highlighting their potential in achieving predictable regenerative outcomes (17,18).

Despite these promising advancements, the clinical translation of nanotechnology in periodontics is not without challenges. One of the major concerns is the potential cytotoxicity associated with certain nanoparticles, particularly



**Amit et al.,**

when used in high concentrations or for prolonged periods. The interaction of nanoparticles with biological systems can lead to unintended effects, such as oxidative stress and inflammatory responses, which may compromise tissue health. Therefore, thorough evaluation of the biocompatibility and safety of nanomaterials is essential before their widespread clinical application. Additionally, the high cost of nanotechnology-based materials and the complexity of their manufacturing processes pose significant barriers to their adoption in routine clinical practice (21,22).

Another limitation is the lack of long-term clinical studies evaluating the efficacy and safety of nanotechnology-based therapies in periodontics. While numerous in vitro and animal studies have demonstrated promising results, there is a need for well-designed randomized controlled trials to validate these findings in human populations. Furthermore, regulatory and ethical considerations must be addressed to ensure the safe and effective use of nanotechnology in dentistry. The development of standardized guidelines for the evaluation and approval of nanomaterials is crucial for facilitating their integration into clinical practice (23).

Future research in nanoperiodontics should focus on the development of smart and multifunctional nanocarriers capable of simultaneous diagnosis and therapy, a concept known as nanotheranostics. These advanced systems have the potential to revolutionize periodontal treatment by enabling real-time monitoring of disease and targeted delivery of therapeutic agents. Additionally, the integration of nanotechnology with other emerging fields, such as artificial intelligence and regenerative medicine, may further enhance the precision and effectiveness of periodontal therapy. With continued advancements and rigorous clinical validation, nanotechnology is expected to play a pivotal role in shaping the future of periodontics (24).

CONCLUSION

Nanotechnology has revolutionized the field of periodontics by introducing advanced diagnostic, therapeutic, and regenerative strategies. Its ability to provide targeted drug delivery, enhanced antimicrobial action, and improved tissue regeneration offers significant advantages over conventional approaches. Although challenges remain, ongoing research and technological advancements are expected to further expand the clinical applications of nanotechnology in periodontics. With continued development and validation, nanotechnology holds immense potential to transform periodontal therapy into a more precise, effective, and patient-centered discipline.

REFERENCES

1. Agarwal P, Durge K, Bajaj P, Kale B, Bharate R. Nanotechnology in periodontics: Review. *J Pharm Res Int.* 2021;33(60B):3508–14.
2. Kamble PS, Gandhi AA, Vhanmane P, Vijapure S. Nanotechnology in periodontics revisited. *J Pharm Res Int.* 2021;33(54B):134–43.
3. Agrawal R, Bajaj P, Shirbhate U, Reche A, Pahade A, Barhate A. Clinical implications of nanosciences in dentistry. *Cureus.* 2023;15(11):e48593.
4. Archana B, Rupini N, Vasunthra S, Ravindran N, Sudhakar U. Nanotechnology in periodontics. *IJFMR.* 2026;8(1).
5. Wang D, Li Q, Xiao C, Wang H, Dong S. Nanoparticles in periodontitis therapy. *Int J Nanomedicine.* 2024;19:6857–93.
6. Basudan AM. Nanoparticle-based periodontal drug delivery. *Saudi Dent J.* 2022;34(8):669–80.
7. Steigmann L, Maekawa S, Sima C, Travan S, Wang CW, Giannobile WV. Biosensor technologies in periodontics. *Front Pharmacol.* 2020;11:588480.
8. Dalai DR, Gupta D, Bhaskar DJ, et al. Nanorobotics in dentistry. *J Contemp Dent.* 2014;4:106–12.
9. Cho MI, Garant PR. Development of periodontium. *Periodontol 2000.* 2000;24:9–27.
10. Hajishengallis G, Lamont RJ. Beyond the red complex. *Mol Oral Microbiol.* 2012;27:409–19.
11. Van Dyke TE. Inflammation in periodontitis. *J Periodontol.* 2007;78:1567–73.
12. Piñón-Segundo E, Ganem-Quintanar A. Nanoparticle drug delivery systems. *J Nanobiotechnol.* 2010;8:1–10.
13. Freitas RA Jr. Nanodentistry. *J Am Dent Assoc.* 2000;131:1559–65.



**Amit et al.,**

14. Xu C, Chen Y, Romandini M, Haugen HJ, Ivanovski S. Nanoparticles in periodontology. J Periodontal Res. 2026.
15. Suresh S, et al. Nanomaterials in dentistry. Dent Mater. 2019;35:112–24.
16. Jain KK. Nanotechnology in clinical diagnostics. Clin Chem. 2005;51:1285–6.
17. Emerich DF, Thanos CG. Nanotechnology and medicine. Expert Opin Biol Ther. 2003;3:655–63.
18. Zhang L, Pornpattananangkul D, Hu CMJ, Huang CM. Nanoparticles for antimicrobial therapy. Curr Med Chem. 2010;17:585–94.
19. Goldberg M, Langer R, Jia X. Nanostructured materials in tissue engineering. J Biomater Sci. 2007;18:241–68.
20. Torchilin VP. Multifunctional nanocarriers. Nat Rev Drug Discov. 2014;13:813–27.
21. Peer D, Karp JM, Hong S, Farokhzad OC. Nanocarriers in drug delivery. Nat Nanotechnol. 2007;2:751–60.
22. Park K. Controlled drug delivery systems. J Control Release. 2014;190:3–8.
23. Bawa R. Nanotechnology and regulatory issues. Nanomedicine. 2008;3:1–3.
24. Shi J, Votruba AR, Farokhzad OC, Langer R. Nanotechnology in drug delivery. Nano Lett. 2010;10:3223–30.
25. Ferrari M. Cancer nanotechnology. Nat Rev Cancer. 2005;5:161–71.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Structural Discrimination and Mental Health among Migrant and Native Workers in Kerala's Informal Labour Sectors

Jince George^{1*} and Sheeja B Karalam²

¹Research Scholar, Department of Social Work, Christ (Deemed to be University), Bengaluru Karnataka, India

²Professor, Department of Work, Christ (Deemed to be University), Bengaluru, Karnataka, India

Received: 10 Mar 2026

Revised: 14 Apr 2026

Accepted: 20 May 2026

*Address for Correspondence

Jince George

Research Scholar,

Department of Social Work,

Christ (Deemed to be University),

Bengaluru Karnataka, India

E.Mail: jince.george@res.christuniversity.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Discrimination in informal labor markets is a considerable yet underexplored socioeconomic determinant of mental health, particularly in contexts characterized by employment insecurity and weak institutional protections. This study examines the forms, dimensions, and psychological effects of claimed discrimination among migrant and indigenous laborers in the construction and plantation sectors in Idukki District, Kerala. Utilizing a cross-sectional quantitative approach, primary data were collected from 225 informal laborers through standardized questionnaires administered by interviewers. Standardized instruments were utilized to assess perceived discrimination, melancholy, anxiety, stress, self-esteem, psychological well-being, coping strategies, and awareness and utilization of welfare services. Descriptive statistics, Mann-Whitney U tests, Spearman correlation analysis, and exploratory factor analysis were employed to examine the data. The findings indicate that prejudice is multifaceted, impacting employment, social interactions, and access to resources. Migrant workers encounter much higher levels of social and interpersonal bias and exhibit poorer psychological outcomes compared to native workers. Perceived discrimination is positively associated with depression, worry, and tension, but negatively associated with self-esteem and psychological well-being. Despite the frequent documentation of adaptive coping methods such as acceptance and positive reframing, the use of support systems remains limited, particularly among migrant workers. This study improves understanding of how discrimination and migration status affect mental health outcomes by comparing migrant and native informal workers within a single regional labor market. It emphasizes the need for integrated labor, welfare, and psychosocial policy measures in informal employment settings.

Keywords: Discrimination; Migrants; Natives; Informal Employment; Psychological Well-Being; Coping Strategies; Kerala



**Jince George and Sheeja B Karalam**

INTRODUCTION

Informal work and internal migration have become key components of contemporary labor markets in emerging countries, particularly in India. A significant proportion of individuals in India are employed in the informal sector, characterized by precarious employment, absence of written contracts, restricted access to social security, and inadequate legal protections (National Commission for Enterprises in the Unorganized Sector [NCEUS], 2009; International Labor Organization [ILO], 2023). Informal employment is particularly prevalent in labor-intensive sectors like as construction and agriculture, which depend on manual labor and consistently employ both local and migrant workers. Although these firms are crucial for economic growth and regional development, their workforce remains structurally vulnerable. Kerala possesses a distinctive labor market characterized by an aging population, an increase in individuals attaining higher education, and a declining willingness among local workers to engage in physically strenuous and low-wage manual jobs. India's dependence on labor from adjacent states has increased owing to structural transformations, particularly in the construction and plantation sectors (ILO, 2021; Ministry of Labour and Employment, 2022). A considerable percentage of local workers participates in these firms under informal and precarious conditions marked by employment instability, income fluctuation, and inadequate social protection (Kannan, 2021; Kannan & Papola, 2007). Migrant and native workers both encounter vulnerabilities associated with informality; yet, their labor market experiences are shaped by distinct and intersecting social contexts.

Growing evidence indicates that informal labor markets serve not just as venues for transactions but also as arenas where social inequities and power dynamics persist (Chen & Carré, 2020). Discrimination in informal employment emerges in multiple dimensions, including remuneration, task allocation, work conditions, interpersonal dynamics, and access to social programs and public services. Migrant workers are particularly susceptible to bias concerning language, origin, ethnicity, and cultural identity, often resulting in social marginalization and restricted access to institutional assistance (Srivastava, 2020). Indigenous informal laborers, despite their local integration, face discriminatory practices arising from class hierarchies, contractual instability, and unequal power dynamics between employers and employees (Harriss-White, 2014). Discrimination in informal work sectors is deeply entrenched in socioeconomic disparities. Harriss-White and Gooptu (2021) assert that informality intensifies labor fragmentation, leading to specific vulnerabilities based on worker origin, job role, and industry. Migrant workers frequently occupy the lowest tiers in occupational hierarchies, rendering them more susceptible to exploitative practices and systemic discrimination (Srivastava, 2020). These structural disadvantages are linked to industry-specific traits, especially in the construction and plantation sectors, where labor practices are markedly informal and regulatory oversight is inadequate.

Discrimination is increasingly acknowledged as a crucial social determinant of health within social science and public health domains. A substantial body of empirical research demonstrates that experiences of discrimination are associated with adverse mental health outcomes, including heightened stress, anxiety, depression, and diminished psychological well-being (Kessler et al., 1999; Williams & Mohammed, 2009; Williams et al., 2019). Discrimination functions as a continual stressor that undermines self-esteem, obstructs coping strategies, and results in lasting psychosocial distress. Prejudice exacerbates mental health issues for migrant workers by imposing additional stresses related to cultural adaptation, linguistic barriers, disrupted social networks, and unfamiliarity with institutional frameworks (Berry, 1997; Bhugra et al., 2021). Empirical research demonstrates that migratory workers frequently encounter barriers to healthcare services, social programs, and grievance resolution mechanisms, hence exacerbating psychological vulnerability (ILO, 2023). Indigenous informal workers, despite their understanding of local social and institutional frameworks, experience significant psychosocial distress due to persistent employment instability, income variability, and perceived marginalization within informal labor markets (Benach et al., 2014; Benach et al., 2021). Standing (2021) defines these workers as part of the "precariat," whose daily existence is marked by uncertainty, absence of autonomy, and ongoing psychological suffering. A recent study highlights the importance of coping strategies and institutional support in shaping employees' reactions to prejudice. Adaptive coping strategies,



**Jince George and Sheeja B Karalam**

such as problem-focused and emotion-focused methods, can mitigate the negative mental health effects of discrimination, but avoidance-oriented coping is often associated with poorer psychological outcomes (Benach et al., 2021). The ability of employees to manage is closely linked to the support provided by social networks and welfare agencies. Despite the existence of legislation designed to assist informal and migrant workers, many are unaware of or do not utilize social services. This is particularly applicable to migrant workers, who encounter difficulties with documentation, complex regulations, and insufficient information (ILO, 2021; Ministry of Labour and Employment, 2022).

This study employs a cross-sectional quantitative technique to examine the dynamics of discrimination in informal labor markets and its effects on the psychological well-being of workers in the construction and plantation sectors of Idukki District, Kerala. It outlines the primary aspects of felt discrimination and assesses whether their prevalence and severity differ between migrant and native workers in the same labor market context. The study also explores the relationships between discrimination and psychological outcomes, including depression, anxiety, stress, self-esteem, and psychological well-being, while also analyzing differences based on migratory status. It examines how individuals confront discrimination and their awareness and utilization of help programs. The study aims to formulate policies and psychosocial interventions for informal workplaces by integrating perspectives from labor and public health.

MATERIALS AND METHODS

Study Design and Setting

This study employed a quantitative, cross-sectional descriptive approach to examine reported discrimination, psychological effects, coping strategies, and access to welfare among informal workers in the construction and plantation industries in Idukki District, Kerala. The district is a labor-intensive region that depends significantly on migrant workers from other states and local informal laborers. This renders it an advantageous location for comparative analysis.

Sample and Sampling Procedure

A total of 225 informal workers participated in the study, including both migrant and native workers from construction sites and plantations. Participants were recruited using convenience sampling, an approach frequently utilized in informal labor research owing to the lack of formal worker registries, significant workforce mobility, and limited employer access (Benach et al., 2016; Chen et al., 2020). To mitigate selection bias, data were collected from many worksites and plantations, with recruitment conducted at various times throughout the day. Eligibility criteria comprised: (i) informal employment within the construction or plantation sectors, and (ii) a minimum of six consecutive months of work experience at the current location, guaranteeing enough exposure to workplace and social contexts. The non-probability sampling method limits generalizability at the population level; yet, it is appropriate for exploratory and analytical research focused on hard-to-reach and structurally vulnerable populations.

Data Collection and Instruments

Structured interviewer-administered schedules were employed to collect data, enabling participation from those with low reading levels. The survey employed the following standardized instruments: the 20-item Discrimination Scale to assess discrimination in occupational, social, and service contexts; the Depression, Anxiety, and Stress Scale (DASS-21); the Rosenberg Self-Esteem Scale; the Psychological Well-Being Scale; and the Brief COPE Inventory to evaluate problem-focused, emotion-focused, and avoidance coping strategies. All instruments demonstrated satisfactory internal consistency, with Cronbach's alpha coefficients ranging from 0.84 to 0.89.



**Jince George and Sheeja B Karalam****Statistical Analysis**

We utilized SPSS version 29 to analyze the data. Descriptive statistics encompassed demographic and occupational characteristics. Due to the non-normality of data distributions, Mann–Whitney U tests were employed to compare groups of migrant and native workers. The Spearman correlation study examined the associations between discrimination and psychological consequences. We employed exploratory factor analysis (EFA) with varimax rotation to identify the fundamental dimensions of discrimination and strategies for addressing it. The criterion for statistical significance was set at $p < 0.05$.

Ethical Considerations

Prior to data collection, ethical approval was obtained. Participation was voluntary, informed consent was secured from all participants, and confidentiality and anonymity were strictly maintained throughout the study.

RESULTS

The study comprised 225 informal workers, of whom 56% were migrant workers and 44% were native workers. Construction workers constituted 49.8% of the sample ($n = 112$), while plantation workers comprised 50.2% ($n = 113$). A majority of participants (73.3%) were aged between 26 and 55, and 93.8% reported having ceased their education. All respondents have been employed in their current field for a minimum of six consecutive months. Migrant workers had significantly higher levels of depression ($M = 18.32$) compared to native workers ($M = 14.21$). Migrant workers exhibited elevated anxiety ratings ($M = 12.45$) compared to native workers ($M = 10.16$) and experienced higher stress levels ($M = 20.18$) than native workers ($M = 15.67$). Migrant workers had significantly lower self-esteem ($M = 19.27$) compared to native workers ($M = 22.44$). Migrant workers ($M = 52.11$) exhibited inferior psychological well-being scores compared to native workers ($M = 61.34$). The Mann–Whitney U tests indicated that the group differences were statistically significant across all psychological variables ($p < 0.01$), hence affirming the poorer mental health outcomes among migrant workers. Descriptive statistics revealed that workplace discrimination was the most often reported form, with 44.9% of respondents indicating restricted leave access, 38.2% reporting limited salary progression, and 26.7% noting inequitable compensation for equivalent labor. Migrant workers indicated markedly elevated occurrences of social discrimination markers, such as disrespect, incivility, and adverse stereotyping. The Mann–Whitney U analysis indicated statistically significant differences in social and interpersonal discrimination indicators between migrant and native workers ($p < 0.01$); however, the differences in workplace discrimination were not statistically significant.

Exploratory factor analysis utilizing varimax rotation revealed three factors with eigenvalues greater than 1.0. Collectively, these elements constituted 72.81% of the overall variance. Discrimination at work accounted for 41.28% of the variance, prejudice based on social standing contributed 19.46%, and discrimination based on service represented 12.07%. All maintained items exhibited a loading exceeding 0.60, indicating robust construct validity. Spearman correlation analysis revealed statistically significant positive associations between perceived discrimination and adverse psychological impacts. Discrimination had a positive connection with depression ($r > 0.40$, $p < 0.01$), anxiety ($r > 0.35$, $p < 0.01$), and stress ($r > 0.45$, $p < 0.01$). Negative correlations were seen between discrimination and self-esteem ($r < -0.30$, $p < 0.01$) as well as between discrimination and psychological well-being ($r < -0.40$, $p < 0.01$). A partial correlation analysis, controlling for age, sector, and education level, confirmed the statistical significance of these correlations, indicating that perceived prejudice independently predicts psychological discomfort. A descriptive analysis of the Brief COPE Inventory indicated a notable prevalence of adaptive coping strategies. The predominant strategies employed were acceptance (72.1%), positive reframing (64.4%), and religious coping (58.7%). Substance use was minimal, at 4.3%. A limited number of respondents indicated the use of avoidance-based coping strategies, and no statistically significant differences were observed between migrant and native workers. Although 58.2% of respondents expressed awareness of welfare services, only 23.5% reported actual



**Jince George and Sheeja B Karalam**

utilization. Migrant workers exhibited significantly lower usage rates than native workers ($p < 0.05$), primarily due to documentation issues and administrative constraints.

DISCUSSION

The research examined discrimination, psychological impacts, and coping strategies among migrant and native laborers in the construction and plantation sectors in Idukki District, Kerala. The findings highlight the existence and intricacy of bias, its psychological impacts, and the coping strategies employed by employees, thereby corroborating and enhancing prior research. The demographic characteristics of respondents reflect the structural features of informal labor markets in Kerala, where physically strenuous and low-paying positions are increasingly filled by migrant workers. The density of workers within the economically productive age bracket (26–55 years) and the exceedingly low levels of formal education indicate restricted occupational mobility and reduced bargaining power. Prior research consistently identifies inadequate educational attainment and informal employment as primary factors contributing to job precarity, poor working conditions, and heightened susceptibility to exploitation (Benach et al., 2016; Quinlan et al., 2019). The excessive representation of migrant workers in the sample highlights Kerala's growing dependence on inter-state labor, a trend intensified in the post-pandemic period and associated with increased livelihood insecurity and social vulnerability (Bhagat et al., 2020).

Forms and Dimensions of Discrimination

The prevalence of discriminatory behaviors indicates that discrimination in informal labor markets is mostly structural and institutional, rather than occasional or incidental. Restricted leave access, limited salary advancement, and unequal compensation for identical work illustrate structural inequities present in employment relations. These trends correspond with conceptual frameworks that view prejudice as a systemic issue arising from organizational regulations, power disparities, and policy inadequacies (Krieger, 2014). Moreover, service-related discrimination, particularly exclusion from welfare programs, demonstrates that inequality extends beyond the workplace into governmental and administrative systems, maintaining cumulative disadvantage across several facets of workers' lives (Marmot et al., 2020). The very high discrimination ratings among migrant workers highlight migratory status as a vital factor of stratification in informal labor markets.

The increased exposure of migrants to social and interpersonal prejudice demonstrates that adversity includes not only material deprivation but also symbolic devaluation and habitual exclusion. These findings align with acculturation theory, which posits that migrants experience heightened stress when integration is obstructed by language, cultural, and institutional barriers (Berry, 1997). Empirical evidence indicates that perceived discrimination is more common among migrant groups and is significantly associated with diminished well-being (Jasinskaja-Lahti et al., 2006; Schmitt et al., 2014). The exploratory factor analysis empirically validates the conception of discrimination as a multidimensional phenomena that includes workplace, social, and service-related dimensions. The frequency of workplace discrimination in explaining variance underscores the critical significance of job contacts in shaping inequality within informal labor markets. Nevertheless, the emergence of social and service-related factors confirms that discrimination is sustained in several social contexts. This multifaceted paradigm aligns with life-course and ecosocial perspectives, emphasizing the accumulation and interplay of social inequalities across institutional, interpersonal, and structural domains in shaping health outcomes (Gee et al., 2009; Krieger, 2014).

Discrimination and Psychological Outcomes

The relationship between perceived discrimination and adverse psychological effects strongly suggests that discrimination functions as a chronic psychosocial stressor. Positive associations with depression, anxiety, and stress, alongside negative correlations with self-esteem and psychological well-being, correspond with the stress and coping framework, which asserts that persistent social stressors are pivotal factors influencing mental health (Lazarus & Folkman, 1984). The buffering theory asserts that, without adequate social and institutional support, such stresses



**Jince George and Sheeja B Karalam**

exert direct psychological pressure (Cohen & Wills, 1985). Meta-analytic and longitudinal studies corroborate these findings, demonstrating significant correlations between bias and mental health across diverse populations (Pascoe & Smart Richman, 2009; Schunck et al., 2015). The significant negative psychological impacts encountered by migrant workers indicate a compounded vulnerability arising from the intersection of migration-related stress, job insecurity, and prejudice. Elevated levels of depression, anxiety, and stress among migrants correspond with systematic reviews and empirical studies that demonstrate impaired mental health among migrant workers facing discrimination and unstable employment situations (Chen et al., 2020; Li et al., 2022). Decreased self-esteem and psychological well-being signify the internalization of discriminatory experiences, a phenomena thoroughly established in studies on perceived discrimination and identity threat (Williams & Mohammed, 2009; Schmitt et al., 2014).

Coping Strategies

The widespread use of adaptive coping strategies—such as acceptance, positive reframing, and religious coping—exemplifies resilience among informal workers despite enduring hardship. These strategies align with meaning-making and emotion-focused coping frameworks, which have been effective in reducing distress in situations marked by limited material resources (Park et al., 2020). However, the presence of avoidance-oriented coping among a certain cohort of employees is noteworthy, as avoidance has been linked to detrimental long-term psychological effects when stressors remain unresolved (Thoits, 2011). This suggests that personal coping skills may be insufficient without supportive systemic environments.

Welfare Awareness and Utilization

The considerable gap between awareness and utilization of welfare programs highlights institutional limitations that reduce the effectiveness of social protection initiatives. The significantly low use rates among migrant workers suggest problems with documentation, administrative complexities, and inadequate support, a trend also observed in studies regarding refugee and migrant access to social services (Hynie, 2018). From a stress-buffering perspective, insufficient institutional support may intensify the psychological impacts of discrimination by depriving employees of vital external coping mechanisms (Cohen & Wills, 1985; Marmot et al., 2020).

CONCLUSION

This study demonstrates that discrimination in labor-intensive informal sectors in Idukki District is a complex and systemic problem, stemming from workplace disparities and intensified by pervasive social and institutional exclusion, particularly impacting migrant workers. The findings provide strong evidence that perceived discrimination acts as a chronic psychosocial stressor, significantly impairing mental health by intensifying melancholy, anxiety, and stress, while diminishing self-esteem and psychological well-being. Migrant workers have a compounded disadvantage stemming from their migrant status, employment instability, and limited access to institutional support. Although many workers exhibit resilience through adaptive coping strategies, the persistent limitations on welfare access substantially reduce their protective effectiveness. This study advances existing literature by juxtaposing migrant and native informal workers within a unified regional labor market, elucidating the mechanisms via which bias is sustained throughout occupational, social, and service-related contexts. The findings underscore the necessity for integrated solutions, including improved labor laws, optimized welfare delivery systems, and the integration of mental health services into support structures for informal workers. Future longitudinal studies are crucial for identifying causal pathways and evaluating the effectiveness of policies and psychosocial therapies aimed at reducing discrimination and improving worker well-being in informal labor markets.





REFERENCES

1. J. Benach, A. Vives, M. Amable, C. Vanroelen, G. Tarafa, and C. Muntaner, "Precarious employment: Understanding an emerging social determinant of health," *Annual Review of Public Health*, vol. 37, pp. 229–253, 2016.
2. J. W. Berry, "Immigration, acculturation, and adaptation," *Applied Psychology*, vol. 46, no. 1, pp. 5–34, 1997.
3. J. W. Berry and F. Hou, "Immigrant acculturation and well-being in Canada," *Canadian Psychology*, vol. 57, no. 4, pp. 254–264, 2016.
4. R. B. Bhagat, R. S. Reshmi, H. Sahoo, A. K. Roy, and D. Govil, "The COVID-19, migration and livelihood in India," Aajeevika Bureau and International Institute for Population Sciences, Working Paper, 2020.
5. W. Chen, L. Ling, A. M. N. Renzaho, and Y. Zhong, "Discrimination and mental health among migrant workers: A systematic review," *International Journal of Environmental Research and Public Health*, vol. 17, no. 22, Art. no. 8262, 2020.
6. S. Cohen and T. A. Wills, "Stress, social support, and the buffering hypothesis," *Psychological Bulletin*, vol. 98, no. 2, pp. 310–357, 1985.
7. G. C. Gee, K. M. Walsemann, and E. Brondolo, "A life course perspective on how racism may be related to health inequities," *American Journal of Public Health*, vol. 102, no. 5, pp. 967–974, 2009.
8. M. Hynie, "The social determinants of refugee mental health in the post-migration context: A critical review," *Canadian Journal of Psychiatry*, vol. 63, no. 5, pp. 297–303, 2018.
9. The International Labour Organization's World Employment and Social Outlook: Trends 2021. International Labour Organization, Geneva, 2021.
10. I. Jasinskaja-Lahti, K. Liebkind, and R. Perhoniemi, "Perceived Discrimination and Well-Being: A Victim Study of Different Immigrant Groups," *Journal of Community & Applied Social Psychology*, vol. 16, no. 4, pp. 267–284, 2006.
11. R. C. Kessler, K. D. Mickelson, and D. R. Williams, "The prevalence, distribution, and mental health correlates of perceived discrimination in the United States," *Journal of Health and Social Behavior*, vol. 40, no. 3, pp. 208–230, 1999.
12. N. Krieger, "Discrimination and health inequities," *International Journal of Health Services*, vol. 44, no. 4, pp. 643–710, 2014.
13. R. S. Lazarus and S. Folkman, *Stress, Appraisal, and Coping*. Springer-Verlag, New York, 1984.
14. J. Li, N. Rose, and S. Richardson, "Discrimination, coping, and mental health among migrant workers," *Social Science & Medicine*, vol. 292, Art. no. 114569, 2022.
15. C. Lund, C. Brooke-Sumner, F. Baingana, et al., "Social determinants of mental disorders and the Sustainable Development Goals," *The Lancet Psychiatry*, vol. 5, no. 4, pp. 357–369, 2018.
16. M. Marmot, J. Allen, P. Goldblatt, E. Herd, and J. Morrison, *Build Back Fairer: The COVID-19 Marmot Review*. London: Institute of Health Equity, 2020.
17. C. L. Park, D. Edmondson, J. R. Fenster, and T. O. Blank, "Meaning Making and Psychological Adjustment Following Stressful Life Events," *Journal of Consulting and Clinical Psychology*, vol. 88, no. 6, pp. 570–583, 2020.
18. E. A. Pascoe and L. Smart Richman, "Perceived Discrimination and Health: A Meta-Analytic Review," *Psychological Bulletin*, vol. 135, no. 4, pp. 531–554, 2009.
19. V. Patel, S. Saxena, C. Lund, et al., "The Lancet Commission on Global Mental Health and Sustainable Development," *The Lancet*, vol. 392, no. 10157, pp. 1553–1598, 2020.
20. *Managing Occupational Health and Safety: A Multidisciplinary Approach* by M. Quinlan, P. Bohle, and F. Lamm. Palgrave Macmillan, London, 2019.
21. M. T. Schmitt, N. R. Branscombe, T. Postmes, and A. Garcia, "The consequences of perceived discrimination for psychological well-being," *Psychological Bulletin*, vol. 140, no. 4, pp. 921–948, 2014.
22. R. Schunck, K. Reiss, and O. Razum, "Pathways between perceived discrimination and health among immigrants," *International Journal of Public Health*, vol. 60, no. 6, pp. 711–721, 2015.





Jince George and Sheeja B Karalam

23. P. A. Thoits, "Mechanisms linking social ties and support to physical and mental health," *Journal of Health and Social Behavior*, vol. 52, no. 2, pp. 145–161, 2011.
24. S. O. Utsey, J. N. Hook, N. Fischer, and B. Belvet, "Cultural humility and coping strategies among marginalized populations," *Journal of Counseling Psychology*, vol. 61, no. 3, pp. 353–366, 2014.
25. D. R. Williams and S. A. Mohammed, "Discrimination and Racial Disparities in Health: Evidence and Needed Research," *Journal of Behavioral Medicine*, vol. 32, no. 1, pp. 20–47, 2009.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Adoption Level of Grapevine Cultivation Practices Among the Farmers of Dindigul District of Tamil Nadu

K. Thamim Ansary¹ and R. Jeya^{2*}

¹Ph.D Scholar, Department of Agricultural Extension, Annamalai University, Chidambaram, Cuddalore, Tamil Nadu, India

²Associate Professor, Department of Agricultural Extension, Annamalai University, Chidambaram, Cuddalore, Tamil Nadu, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 20 May 2026

*Address for Correspondence

R. Jeya

Associate Professor,
Department of Agricultural Extension,
Annamalai University,
Chidambaram, Cuddalore,
Tamil Nadu, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The study was conducted in Athoor block of Dindigul district of Tamil Nadu to study the adoption level of grapevine growers on recommended grapevine cultivation practices. A sample size of 120 farmers was selected based on proportionate random sampling procedure. The study revealed that majority of the respondents (50.84 per cent) had high level of adoption about recommended grapevine cultivation practices whereas, low level of adoption was observed on fertilizer application (52.00 per cent). The correlation analysis showed that the adoption level of grapevine growers was positively influenced by the characteristics namely educational status, experience in grapevine cultivation, extension agency contact, training undergone and market perception.

Keywords: Adoption level, Grapevine growers, Grapevine cultivation, Practices.

INTRODUCTION

Grape (*Vitis vinifera* L.) is one of the finest and the healthiest fruit. It is one of the most important subtropical fruit crops. The crop has wide adaptability and it has been taken up under a wide range of soil types. Grapes can be eaten raw which are primary source of red and white wine. Table grapes, Raisin grapes, Wine grapes are the three categories of grapes. They were also used for the preparation of grape jelly, grape seed extract, jam, grape seed oil, vinegar and bread spread. There are no reliable statistics that break down grape production by variety. It is believed that the most widely planted variety is Sultana, also known as Thompson Seedless, with at least 3,600 km² (880,000 acres) dedicated to it. The second most common variety is Airen. Other popular varieties include Cabernet Sauvignon, Sauvignon blanc, Cabernet Franc, Merlot, Grenache, Tempranillo, Riesling, and Chardonnay.



**Thamim Ansary and Jeya**

(www.fao.org – 2019). Grapes are one of the oldest utilized fruit crops in India. In India, among growing commercial fruit crops grapes are most important. It occupies 1.14 percent of the total area of cultivation with 2.56 percent of the total production of fruits. India's share in the global production of grapes is 2.80 percent. In Tamil Nadu, Pacha-drakshai (Thompson Seedless) is the earliest variety to be grown and occupies the leading position due to its unfailing yields season after season, the adaptability to the region and the easy marketability. Hence an attempt was made to study the adoption level of grapevine growers with the following objectives.

- To findout the adoption level of grapevine growers on recommended grapevine cultivation.
- To study the relationship of socio-personal and psychological characteristics of respondents with their adoption level.

MATERIALS AND METHODS

This study was conducted in Dindigul district of Tamil Nadu. Ex-post facto research design was followed. A sample of 120 respondents was selected by proportionate random sampling procedure. The selected villages were Thoppampatti, Yerumanayaakampatti, Panjampatti, Jadhigoundanpatti and Muthampatti from Athoor block. Data were collected by a well structured and pre-tested interview schedule. A test was administered to test the adoption level of grapevine growers. The collected data were analysed by using cumulative frequency method, percentage analysis, simple correlation and multiple regression analysis.

RESULTS AND DISCUSSIONS

In order to study the extent of adoption of grapevine growers a test was administered. The respondents were classified as low, medium and high using cumulative frequent method. The result on overall knowledge level of grapevine growers are presented in Table 1. It could be observed from the Table 1 that half of the respondents (50.84 per cent) were found to have high level of adoption about recommended cultivation practices followed by medium (40.83 per cent) and low (8.33 percent) level of adoption. In general majority of the respondents had high to medium level of adoption about recommended cultivation practices. This may be due to majority of the respondents had quite knowledge about the cultivation practices and often got advices from the State Horticulture Department. This finding is in agreement with the findings of RS Karangami et. al. (2024).

Practice-Wise Adoption Level of Grapevine Growers

The results on practice-wise adoption level of the respondents are presented in Table 2. It could be observed from the Table 2 that all the respondents (100.00 per cent) were adopted the same variety, recommended manure application, pest management and recommended harvesting. Also it was observed that majority of the respondents were adopted recommended special practices (96.60 per cent), field preparation (95.80), spacing (95.00 per cent), ripening (92.50 per cent) and training practices (91.20 per cent). The high level on adoption rate was due to the respondents had high farming experience in grapevine cultivation and also well training programme conducted by State Horticultural department in recommended cultivation practices. The majority of the respondents were adopted recommended shoot cutting practices (87.50 per cent), pruning (85.80 per cent), herbicide application (84.20 per cent), irrigation practices (80.80 per cent) and disease management (78.30 per cent) respectively. The low level of extent of adoption was on micro-nutrient application (69.70 per cent) and fertilizer application (52.00 per cent) of the respondents. This finding is in accordance with the findings of Jayasankar (2020).

Association and Contribution of Characteristics of Respondents With Their Adoption Level

It could be seen from the Table 3 that out of sixteen variables training attended was found to be significant at one per cent level of probability, whereas the remaining variables such as educational status, experience in grapevine cultivation, innovativeness and market perception had significant at five per cent level of probability. The correlation values for the other variables showed non-significant association with knowledge level of respondents. In order to find out which of the variables explained the variation in extent of adoption and also to know the extent of contribution made by these variables, multiple regression analysis was carried out and the results are presented in Table 3. The results revealed that the extent of adoption of growers could be positively influenced by their





Thamim Ansary and Jeya

educational status, experience in grapevine cultivation, extension agency contact, training attended and market perception. All the other variables were found to be non-significant.

CONCLUSION

Majority of the respondents were found to have high level of adoption about the recommended grapevine cultivation practices. To enhance the extent of adoption of recommended cultivation practices, the extension personnel may organize intensive training programmes and adopt innovative teaching methods to enhance the adoption level of grapevine growers on other grapevine cultivation practices. Regarding the characteristics educational status, experience in grapevine cultivation, innovativeness, extension agency contact, training attended and market perception shown positive and significant relationship with extent of adoption of the respondents. Hence these characteristics may be taken into account while formulating extension strategies for dissemination of grapevine technologies at farm level.

REFERENCES

1. Jayasankar,R., Sneha,V., and R. Muthukumar. 2020. Technological and cultivation knowledge of the PMKSY beneficiaries about grape cultivation with drip irrigation in Tamil Nadu. Plant Archives, Vol. 20(1): 1589-1592.
2. Dasharath Dodamani, G.R. Pennobalishwamy, S. Mahantesh and Gajanand, P. 2018. Knowledge and Adoption Level of Thompson Seedless Grape Growers of Bijapur District of Karnataka, India. Int.J.Curr.Microbiol.App.Sci. 7(01): 2202-2209.
3. Doi: <https://doi.org/10.20546/ijcmas.2018.701.265>
4. Alex Lalramdinthara and Dipak Kumar Bose. 2023. Knowledge of Farmers towards Adoption of Grape Cultivation for Wine Making in Champhai District, Mizoram. Asian Journal of Agricultural Extension, Economics and Sociology. Vol. 41(9): 647 – 651.
5. RS Karangami, SB Bhange and Deepali S K Kokate.2024. The constraints faced and obtain suggestions of grape growers towards utilization pattern of pesticides. International Journal of Agriculture Extension and Social Development. Vol. 7(4):115-117.

Table 1: Distribution of respondents based on their overall adoption level: (n=120)

Sl. No.	Category	Number	Percent
1.	Low	10	8.33
2.	Medium	49	40.83
3.	High	61	50.84
	Total	120	100.00

Table-2: Practice-wise adoption level of grapevine growers (n=120)

Sl. No	Items	No. of respondents	Per cent
1.	Variety	120	100.00
2.	Field preparation	115	95.80
3.	Shoot cuttings	105	87.50
4.	Spacing	114	95.00
5.	Irrigation	97	80.80
6.	Herbicide application	101	84.20
7.	Manures	120	100.00
8.	Fertilizer application	62	52.00
9.	Micronutrient application	84	69.70
10.	Training	109	91.20





Thamim Ansary and Jeya

11.	Pruning	103	85.80
12.	Special practices	116	96.60
13.	Pest management	120	100.00
14.	Disease management	94	78.30
15.	Ripening	111	92.50
16.	Harvesting	120	100.00

Table-3. Zero-order correlation and multiple regression analysis of socio-personal and psychological characteristics of respondents with their knowledge level

Sl. No.	Variables	'r' value	Regression co-efficient	Standard error	't' value
1.	Age	0.233NS	1.712	1.549	1.457NS
2.	Educational status	0.214*	0.496	0.312	2.248**
3.	Occupational status	0.113NS	-0.317	0.876	1.248NS
4.	Annual income	0.105NS	0.474	0.274	1.468NS
5.	Farm size	0.108NS	1.176	0.699	1.876NS
6.	Area under grapevine cultivation	0.083NS	0.818	0.486	1.422NS
7.	Experience in grapevine cultivation	0.355*	0.365	0.115	1.366*
8.	Social participation	0.118NS	-1.116	0.426	1.734NS
9.	Innovativeness	0.382*	0.414	0.564	1.326NS
10.	Extension agency contact	0.108NS	0.382	0.217	2.486**
11.	Scientific orientation	0.048NS	0.848	0.474	1.222NS
12.	Risk orientation	0.093NS	0.794	0.195	1.177NS
13.	Economic motivation	0.088NS	0.954	0.787	1.114NS
14.	Credit orientation	0.072NS	0.725	0.875	1.368NS
15.	Training attended	0.311**	0.903	1.188	1.251*
16.	Market perception	0.219*	0.682	0.368	1.455*

R² = 0.526

F = 7.142**

a = 9.304

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Ancient Wisdom for Future Trends: The Art of Natural Dyeing Techniques among the Karbi Community of Northeast India

Ronjit Hanse¹ and Ramie H. Begum^{2*}

¹Assistant Professor, Department of Zoology, Diphu Government College (Affiliated to Assam University Diphu Campus), Assam, India

²Associate Professor and HOD, Department of Life Science and Bioinformatics, (Assam University Diphu Campus), Assam, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Ramie H. Begum

Associate Professor and HOD,

Department of Life Science and Bioinformatics,

Assam University, Diphu Campus, Assam, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Natural dyes and pigments used in traditional attires enhance the vibrancy and cultural expression of tribal communities, reflecting both ecological harmony and biological richness. The Karbi communities traditionally extract these dyes and apply them to clothes, fabrics and crafts using age-old techniques. Textile serves as a livelihood of many Karbi women living in both rural and urban areas. It was revealed that, 23 dye-yielding plants species belong to various botanical families are used by Karbi tribe as sources of dye. Among these, 5 species are known for their medicinal properties, while 11 are considered edible. Pre and post dyeing treatment adopt to improve the quality of the textile product. Unfortunately, this valuable traditional knowledge of dye sources and techniques is not widely practiced among the younger generation, posing a high risk of its permanent loss in the near future. Additionally, the natural plant sources used for dyeing are increasingly threatened by ongoing massive deforestation. So, in light of these concerns, there is a pressing need to conduct systematic research through qualitative ethnographic methods, including semi-structured interviews with local dyeing experts, traditional herbalists, and community elders. In addition, direct observation was employed to document the complete dyeing process.

Keywords: Natural dye, colour, conservation, Karbi tribe, traditional knowledge

INTRODUCTION

Natural dyes are colorant derived from various biological sources including plants, insects and minerals. Indigenous communities traditionally have been using dye extract from biological sources to impart colour and apply on fabrics,

115655



**Ronjit Hanse and Ramie H. Begum**

clothing, craft etc since time immemorial. Different parts of the plants were used for the extraction of dyes such as leaves, flowers, vegetables, etc.^[1]. Many traditional dyes require traditional mordant prepared from various natural sources to bind the dye to textile fibres and retain colour fastness. The absorption of light depends on the structure or constituents of the colouring pigment/molecules that contain various chromophores present in the dye yielding plant to display the plethora of colours^[2]. Colours obtained from natural dyes depend on the concentration of the chemicals in the plants, the plant part used, the season in which the material was collected, the growth stage of the plant, and the use of mordants^[3]. The plant material that is used in textile dyeing can be fresh, dried or fermented^[4]. Normally, the colour of newly dyed textiles is lighter and not always pure but when mordant is added to make the binding tight and help fix the colours to the fibre and lighten the fabric to produce brighter colours^[5]. The discovery of natural dye and its uses has contributed to the continuation of the age old bond between human kind and nature^[6]. But traditional natural plant dyes for silk, wool and cotton fibres have over time been replaced by synthetic dyes^[7] because they were cheaper, more easily available, of consistent quality, with greater colour fastness and more stable^[8]. Unfortunately, synthetic dyes may have negative side effects for human and environment, including health and safety risks such as cancer, caused by the toxic mordants^[8].

Therefore, recently, interest in the use of natural dyes has been growing rapidly due to the result of stringent environmental standards imposed by many countries in response to toxic and allergic reaction associated with synthetic dyes. As a result with a distinct lowering in synthetic dyestuff costs, the natural dyes were virtually unused at the beginning of twentieth century^[9]. And they are useful for human health because they have antibacterial, insecticidal and healthy properties, which are due to their natural origin^[6]. Natural dyes/colorants derived from flora and fauna are believed to be safe because of its nontoxic, non-carcinogenic and biodegradable in nature^[10]. Natural dyes are now a days in demand not only in textile industry but in cosmetics, leather, food and pharmaceuticals. Organic pigments are large and often complex organic molecules responsible for the different colours of plants and foods. Besides giving the vegetable their characteristics colour, they are also responsible for critical plant functions^[11]. The rich biodiversity of our country has provided us plenty of raw materials, yet sustainable linkage much be developed between cultivation, collection and their use^[12].

Indigenous handloom textile is intrinsically associated with social and cultural life of ethnic groups of Assam. Every community of the state has their own dresses dyed with indigenous herbal dyes. Although, use of herbal dye is no longer practiced but preparation of dye from locally available plants to dye their silk, cotton and woollen yarns and garments was only option in the absence of chemical dyes a decade back^[13]. Karbi Anglong, the largest district of Assam is blessed with gigantic biodiversity. The Karbi tribe has long relied on forest resources for food and medicine. Their knowledge of dye has been acquired through long years of observation, possibly through trial and error^[14]. This Karbi tribe continues to practice traditional dyeing techniques to color fabrics, clothing, and handicrafts. Textile production serves as a vital source of livelihood for many Karbi women in both rural and urban areas. Interestingly, some of the plants used for natural dyes are also known for their edible and medicinal properties. But unfortunately, traditional dye sources and their associated knowledge are being threatened due to massive destruction of forest, changing of life style, the growing generation gap wherein knowledge transmission between the older and the younger folks is threatened. So, the need is felt to undertake scientific research on various biological sources of dye and document for future references. This research made an attempt to bridge the gap between older and younger folks regarding the empirical understanding and practical application of these historically significant dyeing processes, thereby promoting their preservation and potential sustainable integration.

MATERIALS AND METHODS

Study Area

The Karbi communities predominantly living in Karbi Anglong and West Karbi Anglong districts of Assam (Figure 1 & Figure 2), the largest district (before division) with a geographical area of 10,434 Sq Km. A home for tribal



**Ronjit Hanse and Ramie H. Begum**

communities such as Karbi, Dimasa, Rengma, Kuki, Hmar, Tiwa, Bodo, Assamese, Garo, Chakma etc. However, the Karbis are major tribe in this district. The district lies between 25° 33' to 26° 35' North latitude and from 92° 10' to 93° 50' East longitude. The general status of Mikir Hills (Present Karbi Anglong) of wild flora and fauna is quite rich which could well be gauged from the fact that this district is considered one of the mega biodiversity of the north-eastern region ^[15]. The forest area of the hill regions of Assam covers about 34% of the total geographical area of the region against the regulated forest coverage of 60% as fixed by the National Forestry Policy, 1952. So, the Karbi depend on forest product for food, shelter, medicine and clothes. It is believed that, the rich traditional and its practice is highly prevalent among this tribe in the past. Ethnically, they belong to the Indo-Mangoloid race and linguistically to the Tibeto-Burman family of language. The Karbis have distinctive language, culture, identity and tradition. They have their distinct traditional dress and ornaments which vary according to the age of the wearer ^[16]. Numerous traditional attires including, *Poho* (turban), *choi hongthor* (sleeveless jacket), *pilu* (shawl), *jiso* (wrapper at the chest), *pini* (lower garment), *pekok* (upper garment), *vam'kok* (belt), *chepan*, *pesarpi* (shawl) at different occasion by different age group. They spin yarn and weave through conventional method and used natural dye for colouring their clothes and fabric. It is worth mentioning that some Karbi women traditionally tattooed their faces from the forehead to the chin using natural dye—a practice known as *duk kachiduk*, with the tattoo itself called *duk*. Similarly, both men and women have a strong fondness for wearing ornaments.

Interview method

Preliminary information and data were systematically recorded in a research diary, based on inputs collected randomly across different seasons from traditional dye experts, weavers, elders, priests, and forest department personnel.

Field visit method

Frequent visits were made to the local micro textile industry/weaving centre as and when situation warrants. The process involved in dyeing techniques were observed and learned the every step of dyeing process including grinding/crushing/chopping of natural dyes yielding plant leaves/barks, extract preparation, mordant preparation etc. And all the processes both pre and post dyed treatment were recorded in the research diary in serial.

RESULT AND DISCUSSION

The Karbis use 23 plants species along with other biological sources of dye such as insect and mineral for dyeing fabrics and clothes that revealed during the course of study. All these natural dye yielding plants species are tabulated in vernacular name, common name, scientific name, family, habit followed by part of used (Table 1). Out of 23 natural dye yielding plants, 6 species reported medicinal and 11 are edible (Table 2). 19 different families of plants species belong to phyllanthaceae (01), pubanaceae (01), zingiberaceae (01), lynththraceae (01), acanthaceae (02), apocynaceae (01), theaceae (01), amryllidaceae (01), combretaceae (01), malvaceae (01), bixaceae (01), rhamnaceae (01), myrtaceae (02), burseraceae (02), arecaceae (01), bombaceae (01), combretaceae (01) Euphorbiaceae (01), bignoniaceae (01) and asteraceae (1). Natural dye yielding plants produce different colour pigments and the amount of pigment production is varied in different seasons. It has been reported that pigment quality is better during the winter season compared to summer. It is also believed that, exposition of sunlight and orientation of the plant can affect pigment quality. Plants facing north and east tend to produce inferior pigments, likely due to higher water accumulation on those sides. In contrast, plants facing south and west yield pigments with richer and thicker content. Therefore, traditional dye experts always prefer to collect from south and west facing plant parts. Generally, young dye yielding plants (below 40 years) are avoided for pigment extraction. The distribution of pigment within the plant is uneven, with the highest concentration typically found in the nodes of the trunk compared to other parts. The Karbi people extract dyes from various plant parts including leaves, fruits, bark, and seeds using both hot and cold water extraction methods. However, hot extract maintain colour fastness and lustre while cool extract colour become fade very soon. To increase colour fastness they use mordants like salt (NaCl) and Soda (prepare from ash).



**Ronjit Hanse and Ramie H. Begum**

Fermentation is involved only in some dyeing techniques. It has also been reported that besides plants other sources are used as colorant including iron ore, cow dung, mud etc. now and then.

In Malaysia 51 plant species were identified as sources of natural dyes used mostly for body paints by the Orang Ulu, an informal collective name for several ethnic groups on the Island of Borneo ^[17]. In India, nearly 450 plant taxa are known to yield dyes for a variety of purposes including dyeing of textiles ^[18]. Dyes have been widely used by communities for various purposes, such as a compositional ingredient in food, customs or traditional activities and crafts ^[19]. Colour carries valuable information in Karbi society. It gives elegance to garments, garments dyed with specific colours reflect cultural identity, fibres to specific colour are used during religious and certain colours and garments are considered taboo. Several terms reflect the role of dyes in the cultural life of the Karbis such as *amen ki'ir*, *honjeng kekok* (naming ceremony), *melur* (a ritual lamp), *Rongker* (community festival), *ahop* (a natural physiological change in infants characterised by sticky-greenish stool that lasts for a few days), *Duikhrari* (ritual to appease a deity), *Karjong kikur* (a ritual to reunite body and soul), *Jambili athon* (traditional Karbis wood crafts), *Pi sarpi* (elderly women's cloth) and *Pini* (Women's lower garment) ^[14].

Preparation of extracts: The method of extract preparation varies depending on the plant part used. Parameters such as boiling temperature, duration, and technique differ — for example, some parts require decoction (boiling), while others are better suited for cold extraction or fermentation to preserve bioactive compounds.

Bark extract: Dye yielding plants' bark crushed with pestle and boiled for 40-60 min at 100 °C in an aluminium utensil. Allow the extract to get cool and then filter with the help of thin cloth. Filtrate is ready to use.

Leaves extract: For certain plants, leaves are crushed into a paste using a pestle and then boiled with soda (alkaline solution) at 80–90°C for 40–60 minutes. After boiling, the extract is allowed to cool and is then filtered through a fine cloth to remove solid residues. In contrast, for plants like indigo species (*Strobilanthes cusia*, *Marsdenia tinctoria*), the preparation process differs. The leaves are first chopped, crushed into a paste, and shade-dried. The dried paste is then soaked in soda water and left to ferment for 3–4 days. Following fermentation, the mixture is filtered using a thin cloth to obtain the extract, which is then ready for use. This fermented extract can be reused multiple times over several days, depending on its stability and effectiveness."

Peel extract

Onion peels (*Allium cepa*) are directly boiled in water at 100°C for 40–60 minutes to extract water-soluble compounds. After boiling, the mixture is allowed to cool to room temperature and then filtered through a fine mesh or cloth to obtain the clear extract.

Rhizome extract

Turmeric rhizomes (*Curcuma longa*) are commonly used as a natural dye source. The rhizomes are crushed to increase surface area and then boiled in water at 90–100°C for 40–90 minutes to extract the curcuminoid pigments. This process yields a dye-rich extract suitable for various applications.

Lac extract

Lac resin is boiled in water at 100°C for 40–60 minutes to soften and release the soluble components. After boiling, the mixture is squeezed to separate the extract from solid debris. The clarified extract is then ready for use.

Cow dung/mud extract

Cow dung or mud is thoroughly mixed with water to form uniform slurry. The liquid portion of this mixture is then used as the extract, typically without the need for further processing.



**Ronjit Hanse and Ramie H. Begum****Mordant preparation**

Phelo a traditional mordant used to enhance color fastness in dyeing, is made by burning dried banana sheaths, sesame stalks, or bamboo. About 500 grams of the resulting ash is mixed with 1000 ml of water, then filtered through a traditional bamboo strainer known as the *Phelo bisir* (Figure 3) The resulting filtrate is ready for use as a natural mordant.

Dyeing process

Cotton or eri silk fabrics/clothes are soaked in clean water thoroughly before dyeing and the water squeezed out or material is left to drip off excess water. Cotton or Eri fabrics are boiled in water for 30-40 minutes to remove wax and debris and allow to dry under shade. Sometime, cotton fabrics are boiled in soda to increase absorbing capacity of dye. If not, the fabric is directly soaked in warm water for 30 minutes and squeezed. The wet fabrics and clothes immersed in dye bath for 30-60 min at 80° C and stirred every after 10 min to make dyeing uniform (figure 4). After that fabrics or clothes taken out from the dye bath and dried in the shade with the help of bamboo pole. Again and over again, immersed until achieving the desired level of colouration.

Shade

The attractive colours and fragrance of natural dyes are influenced by several factors, including the concentration of bioactive compounds in the source plants, the specific plant part utilized, the season and stage of plant growth at the time of harvest, and the application of mordants, which can alter dye uptake and colour fastness (figure: 5).

CONCLUSION

Natural dyes are colorants derived from naturally available sources. They have a wide range of applications in textiles, crafts, cosmetics, tattoos, and medicine. Typically, natural dyes are eco-friendly, non-toxic, non-carcinogenic, and biodegradable. As a result, interest in their use has been growing rapidly. This rising demand is further driven by increasingly stringent environmental regulations in many countries, aimed at reducing the toxic and allergic effects linked to synthetic dyes. Moreover, due to their antibacterial, insecticidal, and health-promoting properties, natural dyes gain more attention. It is reported that, textile products that develop through natural dye techniques give beauty results such as lustre, soft and shadow gives much pleasure to the eyes. Some edible natural dye can be applied in food industry for colouring various confectionery food items. The Karbi tribe primarily relies on the forest and its resources for food, medicine, and shelter. They also possess a rich heritage of culture, traditions, customs, and indigenous knowledge. The indigenous Karbi tribe of Karbi Anglong and West Karbi Anglong has been practicing traditional dyeing techniques sustainably for generations to color their fabrics, clothing, and crafts. Notably, they spin natural yarns, primarily cotton and eri silk. However, the use of natural dyes in textiles and crafts is gradually being replaced by synthetic dyes due to cheap and obtainable. Moreover, traditional dyeing technique is being threatened due growing generation gap wherein knowledge transmission between older and younger folks is menaced. Massive destruction of forest in regular mode lead the biological sources of dye to perish day after day and subsequently the laudable traditional knowledge of Karbi tribe may poses risk of its permanent loss in the near future. This research initiative aimed to systematically and facilitate the revitalization of traditional dyeing techniques among the contemporary populations. The objective is to bridge the gap between older and younger folks regarding the empirical understanding and practical application of these historically significant dyeing processes, thereby promoting their preservation and potential sustainable integration.

ACKNOWLEDGEMENT

The authors greatly indebted to Bura Hanse, Kareng Beypi and Bina Ronghangpi for their significant contribution towards the articulation of data and information. Authors also thanks to all the traditional dye experts, herbalists, weavers for their consistent helps and supports throughout the research in all possible ways





REFERENCES

1. Geetha B, Sumathy V J H. Extraction of Natural dye from plants. International Journal of Chemistry and Pharmaceutical Sciences 2013; 502-509
2. Khandelwal K R. Practical Pharmacognosy, Nirali Prakashan 1995; 149-155
3. Lambare D A, Hilgert N I, Ramos R S. Dyeing plants and knowledge transfer in the Yungas communities of Northwest Argentina. Economic Botany 2011; 65 (3): 315-328
4. Meesin P. Traditional knowledge of silk dyeing processes from natural materials in Northeastern Bangkok. The Queen Sirikit Department of Sericulture; Ministry of Agriculture and Cooperatives 2010.
5. Junsongduang A, Sirithip K, Inta A, Nachai R, Onputtha B, Tanming W, Balslev H. Diversity and Traditional Knowledge of Textile Dyeing Plants in North-eastern Thailand. Economic Botany 2017; XX (X): 1-15
6. Chungkrang L, Phukon A R, Barman S. The indigenous techniques of natural dye in Jorhat District, Assam. International Journal of Research in applied, Natural and Social Science 2007; 95-100
7. Hartl A, Vogel C R. The potential use of organically grown dye plants in the organic textile industry. Experiences and results on the cultivation and yields of Dyer's Chamomile (*Anthemis tinctoria* L), Dyer's Knotweed (*Polygonum tinctoria* Ait) and Weld (*Reseda luteola* L), J. Sustain. Agric 2003; 23 (2): 17-40
8. MacFoy C. Ethnobotany and sustainable utilization of natural dye plants in Sierra Leone. Economic Botany 2004; 58 (Supplement): S66-S76
9. Kumarresan M, Palanisamy P N, Kumar P E. Application of natural dye obtained from flower of *Spathodea campanulata* on silk using combination of mordants, Eur J Sci Res, 2011; 52 (3): 306-312
10. Cristea G Y and Vilarem S J. Ultrasound assisted enhancement in natural dye extraction from beetroot for industrial applications and natural dyeing of leather, Ultrason. Sonochem 2003; 16 (6): 782-789
11. Gupta M, Thakur S, Sharma A, Gupta S. Qualitative and Quantitative Analysis of Phytochemicals and Pharmacological Values of some Dye yielding Medicinal Plants. Oriental journal Chemistry 2013; 29 (2): 475-481
12. Gukhale S B, Tatiya A U, Bakliwal S R, Fursule R A. Natural dye yielding plants in India. Nat Prod Rad 2004; 3 (4): 228-234
13. Kar A, Borthakur SK. Dye yielding plants of Assam for dyeing handloom textile products. Indian Journal of Traditional Knowledge 2008; 7 (1): 166-171
14. Teron R, Borthakur SK. Traditional Knowledge of Herbal Dyes and Cultural Significance of Colors among the Karbis Ethnic tribe in Northeast India. Ethnobotany Research & Applications 2012; 10: 593-603
15. Dhanaraju V. The Colonial Foundation of Scientific Forest Management in Mikir Hills: Some Observations. Phurkimo 2022; 87-104
16. Phangcho P C. The Karbis of North-East India 2003.
17. Rosli N, Ismail Z, Lepun P. Plant used as natural dye by the Orang Ulu ethnic in Asap Koyan Belaga Sarawak, Malasia. International Journal of Current Research 2015; 7 (8): 19770-19775
18. Siva R. Status of natural dyes and dye yielding plants in India. Current Science 2007; 92 (7): 916-925
19. Fatubun A, Susanti C M E, Sinaga N I, Wanma J F, Lea M M. Natural dyes used by the byak tribe and its prospects as raw materials for the natural dyes industry. Earth and Environmental Science 2022; 1-11

Table 1: Biological sources of natural dye

Vernacular name	Common Name	Scientific Name	Family	Habit	Origin	Part of used	Colour Shade	Fabric/garment
Tamsir	Indo-China Alder	<i>Aporosa octandra</i> Buch. Hem.ex D.Don	Phyllanthaceae	Tree	South China to tropica Asia including Queensland and	Leaves	Blue	Cotton, Eri silk and garment




Ronjit Hanse and Ramie H. Begum

					New Guinea			
Sugun	Teak	<i>Tectona grandis</i> L.	Perbenaceae	Tree	South and Southeast Asia, India, Myanmar, Laos and Thailand	Shoot	Redish - brown	Cotton, Eri silk
Tharmit	Turmeric	<i>Curcuma longa</i> L.	Zingiberaceae	Herb	Southeast Asia particularly India	Rhizome	Yellow	Cotton, Eri silk
Jetuka	Henna	<i>Lawsonia inermis</i> L.	Lythraceae	Herb	Northern Africa, Asia and Australia	Leaves	Maroon	Cotton, Eri silk
Sibu	Assam indigo or Chinese rain bell	<i>Strobilantes cusia</i> (Nees) Kuntze	Acanthaceae	Herb	South Asia, China and Indochina	Whole part except root	Blue	Cotton, Eri silk, face tattoo and garment
Bujir	Climbing-indigo	<i>Marsdenia tinctoria</i>	Apocynaceae	Creep er	Southeast Asia including India, China and Malaysia	Whole part except root	Blue	Cotton, Eri silk, face tattoo and garment
Sa	Tea	<i>Camellia sinensis</i> L.	Theaceae	Tree	It is native to East Asia and Indian subcontinent	Leaves	Light brown	Cotton, Eri silk
Harsun ke'er	Onion	<i>Allium cepa</i> L.	Amaryllidaceae	Herb	Central Asia basically Northwest India, Afghanistan, Pakistan and Soviet Republic of Tajikistan and Uzbekistan	Peel	Greenish	Cotton, Eri silk




Ronjit Hanse and Ramie H. Begum

Siluka	Myrobalan/Harad	<i>Terminallia chebula</i> Retz.	Combretaceae	Tree	South and Southeast Asia	Fruit	Black	Cotton, Eri silk
Hansering	Roselle	<i>Hibiscus sabdariffa</i> L.	Malvaceae	Herb	West Africa, particularly Sudan region.	Fruit	Pink	Cotton, Eri silk
Lipstick tree/Annatto	Annatto	<i>Bixa orellana</i> L.	Bixaceae	Tree	Central and South Africa, specially the area between Mexico and Brazil	Seed	Red	Cotton, Eri silk
Bogori	Jujube	<i>Ziziphus jujube</i> Mill.	Rhamnaceae	Tree	China	Bark	Brown	Cotton, Eri silk
Jangmi	Black berry	<i>Syzygium cumini</i> L.	Myrtaceae	Tree	North America, Europe and part of Asia	Fruits	Pink	Cotton, Eri silk
Timur	Grey Down Balsam Tree	<i>Garuga pinnata</i>	Burseraceae	Tree	Indian subcontinent, southern China and Southeast Asia	Bark	Light brown	Cotton, Eri silk
Soprim	Guava	<i>Psidium guajava</i> L.	Myrtaceae	Tree	Southern Mexico through Central America and northern South America	Bark/Leaves	Black	Cotton, Eri silk
Kove	Betel nut	<i>Areca catechu</i> L.	Arecaceae	Tree	Philippines and other parts of Southeast Asia	Seed	Red	Cotton, Eri silk
Tiji	Garuga	<i>Garuga floribunda</i>	Burseraceae	Tree	Asia including India,	Bark	Red	Cotton, Eri silk




Ronjit Hanse and Ramie H. Begum

					Southeast Asia and part of Australia			
Pharkong	Red-silk cotton tree	<i>Bombax ceiba</i> L.	Bombacaceae	Tree	South and Southeast Asia, including India, Sri Lanka and Malaysia	Bark	Red	Cotton, Eri silk
Kuru	Bahera	<i>Terminalia bellirica</i>	Combretaceae	Tree	Indian subcontinent, Sri Lanka and Southeast Asia	Bark	Yellow	Cotton, Eri silk
Nopakban	Indian trumpet tree	<i>Oroxylum indicum</i> L.	Bignoniaceae	Tree	Native to Indian subcontinent basically Himalayan foothills.	Bark	Green	Cotton, Eri silk
So'ik	Climbing croton	<i>Croton caudatus</i>	Euphorbiaceae	Creepers	Asia mostly in China, Indian subcontinent and southeast Asia	Sap of twigs	Black	Teeth
Mirve	Marsh water-willow	<i>Justicia comata</i> (L.) Lam	Acanthaceae	Herb	Tropical America	Leaves and shoots	Pink	Bamboo craft
Bapbongnai	Siam weed or bitter Bush	<i>Chromolaena odorata</i> (L)	Asteraceae	Herb	Native to Americas	Leaves	Light green	Cotton, Eri silk

Table 2: List of edible dye yielding plants

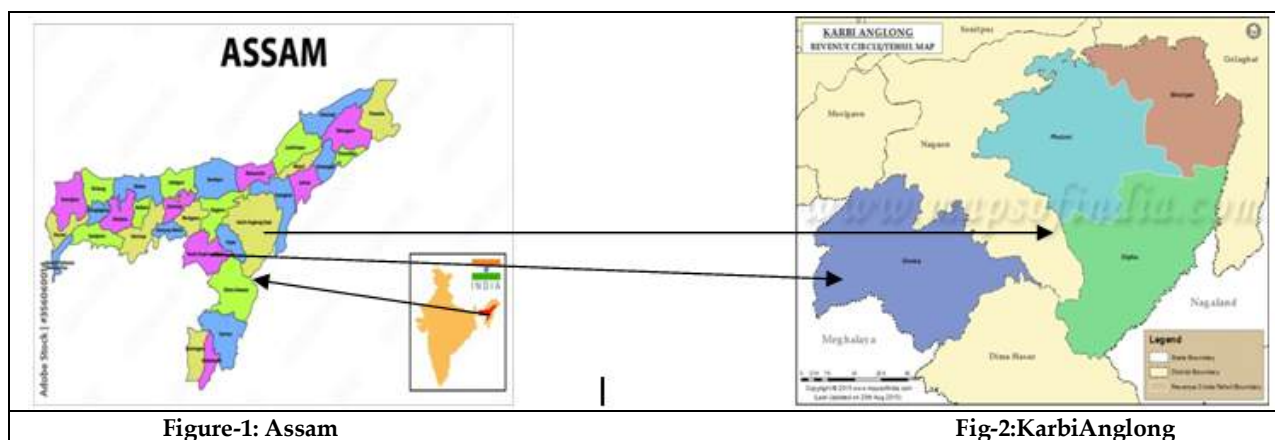
Scientific Name	Part of used	Source of plant material	Mode of preparation
<i>Curcuma longa</i> L.	Rhizome	Cultivated	A paste made from rhizomes, fermented dry fish, salt, and raw chilies is wrapped in banana leaves and placed in hot ash for 30–45 minutes. The cooked mixture is then consumed as chutney. Sometimes, raw rhizomes are crushed and added to boiled curries—especially pork, chicken, or fish—as a spice. Turmeric powder is typically used in





Ronjit Hanse and Ramie H. Begum

			vegetable curries or fried dishes.
<i>Camellia sinensis</i> L.	Leaves	Cultivated	Leaves are chopped and dried into sunlight. Dried leaves are boiled and prepare a drink.
<i>Allium cepa</i> L.	Bulb and leaves	Cultivated	Bulb and leaves are chopped and put into different curries as spices. Raw onion also prefers to eat.
<i>Terminallia chebula</i> Retz.	Fruits	Wild	Both raw and dry fruits are used as mouth freshener. It is also used as digestive.
<i>Hibiscus sabdariffa</i> L.	Leaves and fruits	Cultivated	The buds and immature fruits are cooked for 40-60 min with various ingredients including sesame powder, garlic, salt etc. In order to minimise the source taste fermented dry fish put into it.
<i>Ziziphus jujube</i> Mill.	Fruits	Wild	Fruits are consumed. Sometime ripen fruits are dried and prepare pickles for future use.
<i>Syzygium cumini</i> L.	Fruits	Wild	It is one the delicious and popular fruit among the Karbi. Ripe fruits are consumed.
<i>Psidium guajava</i> L.	Fruits	Wild	It is one of the common fruits among the Karbi people, who consume it both raw and ripe. It has been reported that the buds are crushed to prepare a drink used as a remedy for dysentery.
<i>Areca catechu</i> L.	Seed	Cultivated	Areca is consumed with beetle leaves
<i>Terminalia bellirica</i>	Seed	Wild	Seeds are directly consumed after removing the seed coat. The taste is similar to almond.
<i>Oroxylum indicum</i> L	Bud	Wild	The buds are traditionally consumed by baking—wrapped in banana leaves and placed in hot ash. It is also reported that the bark is crushed and mixed with water to prepare a medicinal drink used to treat dysentery





Ronjit Hanse and Ramie H. Begum

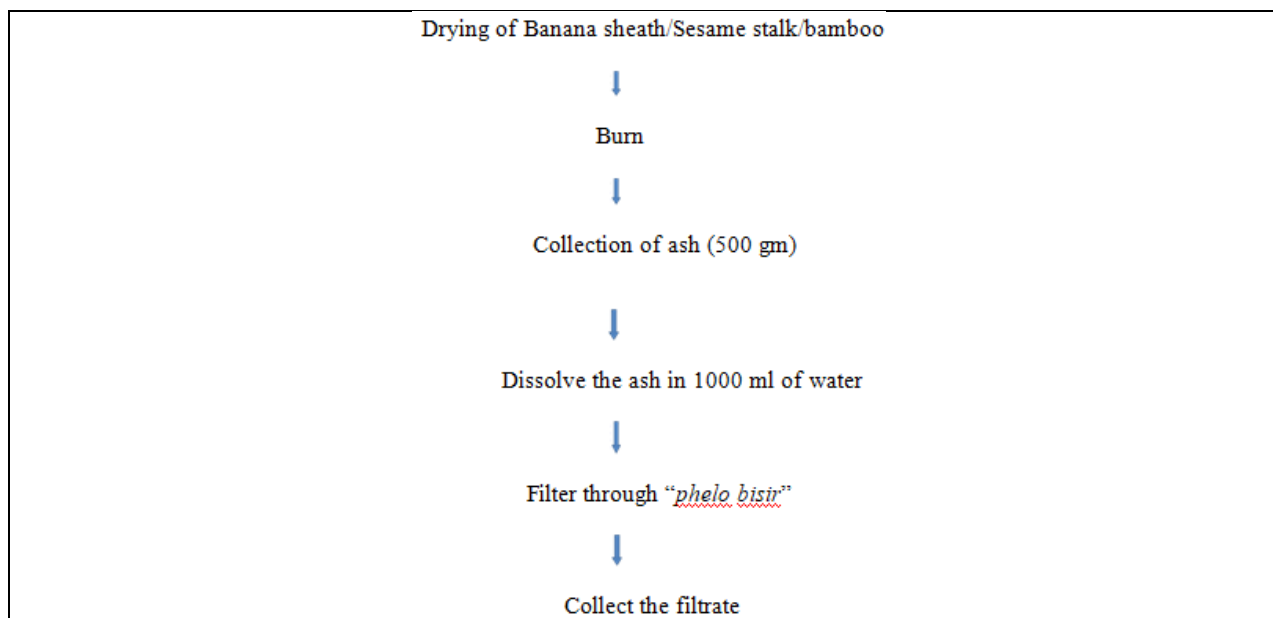


Figure 3: Flowchart of traditional mordant (*phelo*) preparation

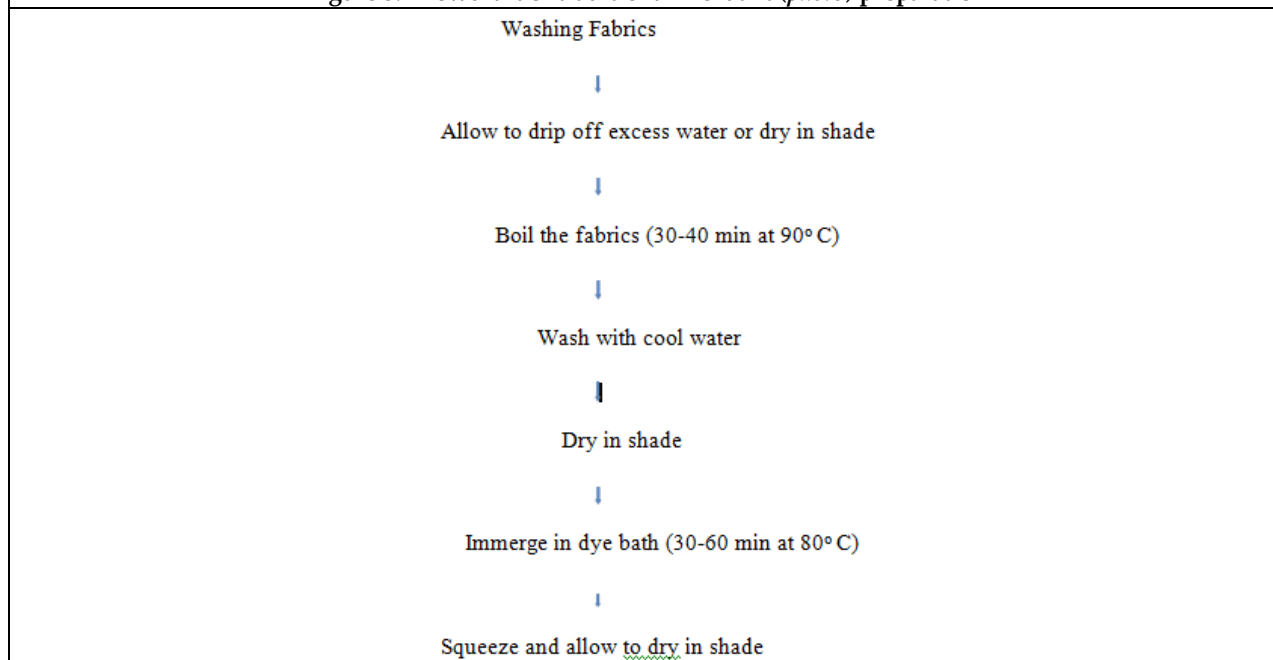


Figure 4: Flow chart of traditional dyeing process



**Ronjit Hanse and Ramie H. Begum**

Plat1: Indigo dye



Plat2: Jammu dye



Plate3: Teadye



Plat 4: Lac dye



Plat 5: Onion peel dye



Plat 6: Termeric dye

Plat 7: *Chromolaena odorata*Plat 8: *Garuga floribunda*plat 9: *Oxoxylum indicum***Figure 5: Dyed fabric with natural dyes**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Nutritional Profiling and Consumer Acceptability of A Plant - Based Milk Alternative

Samiya Mohammedi¹, Sundaravalli A² and Padmashree Kulkarni^{3*}

¹M.Sc Student, Department of Food Science and Nutrition, Mount Carmel College, (Affiliated to Bengaluru City University), Bengaluru, Karnataka, India

²Dean of Natural and Applied Sciences and Associate Professor, Department of Home Science, Mount Carmel College, (Affiliated to Bengaluru City University), Bengaluru, Karnataka, India

³Associate Professor, Department of Life Science, Mount Carmel College, (Affiliated to Bengaluru City University), Bengaluru, Karnataka, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Padmashree Kulkarni

Associate Professor, Department of Life Science,
Mount Carmel College,
(Affiliated to Bengaluru City University),
Bengaluru, Karnataka, India
E.Mail: padmashree.kulkarni@mccbmr.edu.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Plant-based milk alternative is made from water-soluble extracts of grains, nuts, legumes, oilseeds, and pseudo-cereals, which are crucial constituents in traditional Indian culture. They are known for their unique characteristics. Various reasons, such as environmental sustainability, cholesterol levels, lactose intolerance, and a need for nutrient-rich, locally sourced foods like finger millet and coconut, have led to an increased interest in these plant-based milk alternatives. This study investigated the nutritional profiling, consumer acceptability, physicochemical properties, and microbiological analysis of a milk blend developed using finger millet (*Eleusine coracana*) and coconut (*Cocos nucifera*) milk. Three variations with different ratios of finger millet milk to coconut milk blend were analysed. Most suitable ratio of coconut and water was determined based on sensory attributes for the extraction of coconut milk. FiCo3 mix had the least fat. To improve flavor and cultural value, 2% jaggery was added as a sweetening agent and 0.05% xanthan gum as a stabilizer. Nutritional value per serving is packed with 156.4 kCal, 8.7 g of carbohydrates, 5.2 g of protein, 11.2 g of fat, 3.8 mg of iron, and 292.2 mg of calcium. The milk blend showed a strong nutritional profile due to its calcium content per 100 ml. The findings suggest this milk blend could help improve nutritional security by addressing the shortages of macronutrients and micronutrients in the population and avoid dependency on dairy milk.

Keywords: Plant-based milk alternative; finger millet; coconut milk; nutritional profiling; consumer acceptability





INTRODUCTION

Milk obtained from finger millet serves as an excellent plant-based milk alternative to traditional cow's milk, helps control diabetes and supports bone strength. It contains 112 mg of calcium per 100 g, surpassing cow's milk; enzyme treatment can also boost protein and antioxidant activity. Coconut milk is produced from liquid extraction from matured coconut using a 1:3 (w/ v) ratio. Coconut milk, rich in lauric acid, has an energy content of 135.9 kCal for every 100 ml and is high in fat. It serves as a nutritional and highly digestible source of milk alternative. Its elevated levels of phenols and vitamin C provide numerous health benefits due to their remarkable antioxidant properties. It serves as a nutritious and easily digestible alternative to milk [1]. Finger millet milk rich in fibre, calcium, and protein, is blended with coconut milk, abundant in vitamins and healthy fats, to produce a nutritious plant-based milk. This milk blend enhances taste and nutrition by creating a lactose-free, nutrient-rich beverage that supports bone strength, digestive health, and diabetes control [2]. The present study aimed to develop a milk alternative that is nutritious, tasty, and healthier for mindful consumers, thereby enhancing its nutritional value through the blending of finger millet and coconut milk.

MATERIALS AND METHODS

This study was conducted in the Department of Food Science and Nutrition at Mount Carmel College, Autonomous, Bengaluru, Karnataka, India. Mature coconuts sourced from a dealer in Shanti Nagar, Bengaluru, India, were used to prepare coconut milk. The ML 365 variety of finger millet was procured from the Karnataka State Seed Corporation, Beeja Bhavan, located in Bangalore, Karnataka, India to ensure a better quality. Before germination, finger millet was washed and rinsed to remove any contaminants. Followed by the preliminary processing, it was soaked in water for 12 hours [3]. It was then germinated for approximately 48 hours. During the initial 24 to 48 hours of germination, the enzyme activity in the grain increases while its anti-nutritional factors decrease, thereby improving nutrient availability and digestibility [4]. Following germination, finger millet was dried and roasted at 75–80°C for 10–15 minutes to achieve a moisture content of 10–12%. This process reduces antinutritional factors, imparts a unique roasted flavour, and enhances sensory attributes, digestibility and overall palatability [5]. Then milk was extracted from processed finger millet. Milk obtained after a 48-hour germination period of finger millet, characterized by optimal shoot length and color, yielded a lighter liquid with increased α -amylase activity. The coconut milk extracted was stored in a sealed container, under refrigeration at 4°C for further analysis.

Formulation of milk blend

To enhance the extraction process, the optimal balance of finger millet to water must be determined. Finger millet was roasted and germinated at various finger millet-to-water (w/v) ratios such as 1:1, 1:2, 1:3, 1:4, and 1:5. The suitable ratio of finger millet to water was determined based on the sensory profile of millet milk extracted. The extraction process involved blending finger millet and water for 5 minutes were used to combine the finger millet with water, it was filtered using a double-layer muslin cloth and stored at 4 °C in a sterilised glass jar. Preliminary studies on different coconut-to-water ratios, such as 1:1, 1:2, 1:3, 1:4, 1:5, were conducted to optimize the coconut milk extraction. The most suitable ratio of coconut and water was determined based on sensory attributes for the extraction of coconut milk. Three formulations were then prepared- FiCo1, comprising of 60% finger millet milk and 40% coconut milk; FiCo2, containing 70% finger millet milk and 30% coconut milk and FiCo3, consisting of 80% finger millet milk and 20% coconut milk. Then 0.05% of xanthan gum was added to the blends as a stabilizer. They were then homogenized under high pressure. In semi-batch process using high-pressure chambers, the FiCo3 milk blend was subjected to pressures of 600 – 700 MPa. At medium, moderate, or mild temperatures, processing time lasts between 5 and 30 minutes [6].



**Samiya Mohammedi et al.,****Sensory evaluation**

A 9-point hedonic scale was used to conduct a sensory analysis of the milk blends. The evaluation was carried out by thirty panellists with modest experience. The samples were given three-digit codes to eliminate bias. A structured assessment form was used to assess sensory attributes such as color, aroma, texture, mouthfeel, and overall acceptability.

Product evaluation

The physicochemical characteristics and sensory attributes of food products are critical determinants of their quality, stability, and nutritional value. In this study, a comprehensive physicochemical evaluation was conducted on cow's milk, finger millet milk, coconut milk, and milk blend of finger millet and coconut milk.

Determination of physicochemical parameters

Degrees Brix refers to the total soluble solids (TSS) content, which represents the amounts of dissolved solids in a liquid. TSS is an important parameter in food products such as fruit juices, gravies, and plant-based milk alternatives, where sweetness, texture and flavor strength are inter-related [7]. Using the standard AOAC methods, cow's milk, finger millet milk, coconut milk, and milk blends were examined for ash content and pH [8, 9]. The energy content was determined using the following formula [10]. Food energy = (Crude protein × 4) + (Fat content × 9) + (Carbohydrate × 4).

Macronutrient assessment

Carbohydrate content was determined following anthrone method [11]. The Kjeldahl Digester, and Distillation method, a standard practice used in the food industry, was used to determine the nitrogen levels in the samples. The nitrogen content is calculated with a multiplication factor of 6.25, to transform the nitrogen content into crude protein [12]. The fat content of the sample is measured according to AOAC standards [13].

Micronutrient, and Antioxidant activity

Calcium and iron are essential for healthy bones and anemia prevention; hence the focus of micronutrient estimation was on these two elements. Micronutrient assessment was performed according to the AOAC guidelines. Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method [14].

Microbial Analysis

Ensuring the safety and stability of food products relies on shelf-life studies through microbial analysis. In this study, the spread plate technique was used, involving serial dilutions, plating samples onto nutrient agar, and counting the colonies after incubation [15].

Statistical analysis

Using IBM SPSS Statistics for Windows, Version 26.0, a statistical evaluation of the data was conducted through an analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The present study comprehensively examines various milk blend ratios and evaluates them to identify the optimal blend that enhances consumer appeal and nutritive value, considering their physical, chemical, sensory, and proximal characteristics.



**Samiya Mohammedi et al.,**

Yield analysis

The findings of the milk yield for both the milk samples are as illustrated in table 1. The highest yield was recorded for both the samples were recorded at 1:5 (w/v) ratio. For finger millet milk it was 455 ± 0.3 ml followed by 310 ± 0.07 ml at a 1:4 rate. Coconut milk it was 525 ± 0.18 mL. Increasing solubilization and extraction effectiveness contribute to the gradual yield rise as water volume grows. Millet germination enhances nutrient availability and increases milk yield. For instance, in a similar study, yield from sprouted kodo millet was reported to be 475 mL, while the yield from raw grains was 400 mL [16]. Oats yielded 320.4 mL under similar conditions; finger millet yielded 96 ml following 8 hours of soaking and 18 hours of sprouting [17].

Sensory evaluation

Results of the sensory evaluation studies are illustrated in table. 2. Both blends exhibited distinct sensory characteristics, including color (8.5 ± 0.3) and aroma (8.3 ± 0.1). These sensory evaluations differ from previous assessments of millet-based milk blends, which generally received a rating of 7.8 or 7.9 overall [18]. The FiCo3 milk blend which contains 80% finger millet and 20% coconut milk, an overall acceptance score of 7.8, which is closest to sensory score of the top-performing combination, T2 reported in previous studies [3].

Determination of physiochemical parameters

The FiCo3 milk blend, due to its unique attributes, showed the highest moisture content 88.6 ± 0.7 and 0.7 ± 0.1 ash content compared to control sample cow's milk which contained 81.3 ± 0.06 moisture content and the lowest ash content 1.9 ± 0.03 (Table. 3). Initially, the pH levels of all samples ranged from 5.59 to 6.84, reflecting a consistent level of acidity. The FiCo3 milk blend exhibited a total soluble solids content of 4.2 ± 0.1 , suggesting increased mineral residue and humidity retention. Finger millet milk displayed a higher total soluble solids (TSS) content of 3 ± 0.42 due to its greater concentration of soluble minerals and carbohydrates compared to barnyard millet milk. Little millet, kodo millet milk, and barnyard millet milk each recorded TSS values of 2 ± 0.06 [19]. In the present study, finger millet milk, displayed a TSS value of 3.1, which is consistent with previous findings. Variation in total soluble solids (TSS) in finger millet milk can arise due to differences in analytical methods, millet varieties, and processing techniques used [20]. Coconut milk and millet displayed significantly different nutritive and physical characteristics ($p < 0.05$). The dilution resulted in a decrease in the moisture content of coconut milk. Previous studies showed similar findings [21].

Determination of macronutrient content

The results of macronutrient analysis are illustrated in Table.4. Coconut milk is a calorie-dense plant-based milk alternative that surpasses cow's milk in energy and fat content. It contains 272.9 ± 0.01 kCal of energy, 5.6 ± 0.5 g of protein, and 24.9 ± 0.9 g of fat. Containing 46.2 ± 0.04 kCal of energy, 2.3 ± 0.4 g of protein, and 0.3 ± 0.05 g of fat, finger millet milk serves as an excellent low-calorie, low-fat choice. The milk blend, FiCo3, featuring a moderate energy value of 156.4 ± 0.3 kCal, contains a protein content of 5.2 ± 0.8 g and moderate fat content of 11.2 ± 0.3 g. Importantly, these lipids promote heart health as they're mainly unsaturated and free from cholesterol [22]. The coconut milk produced in this present study contained a 5.6g of protein which is similar to the 5.8% protein content reported in domestic coconut milk [23]. However, our results contradict with the findings of Tulasiet al., [2]. which reported approximately 135.94 kCal, 14.12% protein, and 2.2% fat in domestic coconut milk. These significant variations highlight considerable diversity, which may be attributed to differences in coconut species or the analysis method used.

Determination of micronutrients, and antioxidant activity

Compared to cow's and coconut milk, the FiCo3 milk blend contained significantly higher levels of calcium 380.3 mg^{-1} and iron 4.6 mg^{-1} (Table 5). These results suggest that finger millet can enhance the mineral content of plant-based milk alternatives, including the FiCo3 milk blend. Although this milk blend exhibited only mild antioxidant activity ($39.4\% \pm 0.02$) due to presence of flavonoids and polyphenols, but it remains favourable. Earlier findings have indicated that increasing the amount of coconut milk in the mixture boosts the overall mineral content [3]. The





highest antioxidant activity of 46.2% was recorded for finger millet milk followed by coconut milk finger millet and coconut milk of (44.4%) as indicated in Table. 6. However, the blend showed an antioxidant activity of 39.4%. Coconut milk is rich in antioxidant proteins and phenolic compounds, which help sustain balanced antioxidant activity by counteracting free radicals and hence shows an activity.

Microbial analysis

The microbial analysis showed that the total plate count (TPC) of finger millet and coconut milk blend varied during storage. On Day 1, the TPC was $2 \times 10^5 \pm 0.09$ CFU- ml^{-1} indicating a minimum initial microbial load. By Day 5, the TPC increased to $33 \times 10^5 \pm 0.05$ CFU- ml^{-1} , followed by a reduction to $3 \times 10^5 \pm 0.1$ CFU- ml^{-1} on Day 10. Throughout the 10-day storage period, no yeast or mold was detected, suggesting that they were either absent or present at levels below the detection threshold (Table. 7). Early microbial growth remained significant although the decline observed on Day 10 suggests a period of stabilization. The consistent rise in TPC by Day 5 highlights the necessity of using preservatives or refrigeration to prevent bacterial growth. Increasing from 1.2×10^3 to 1.5×10^5 CFU- ml^{-1} , the TPC indicates the sensitivity of milk blends to microbial growth. This significant variation in microbial growth of finger millet-based milk, may result from differences in raw materials, processing, storage conditions, or hygiene practices, emphasizes the need for improved processing methods [24].

CONCLUSION

Plant-based milk alternatives are an excellent option for health-conscious individuals avoiding lactose, as they contain lower saturated fat and calorie content compared to dairy milk. The blend developed holds great potential as an alternate to dairy milk and a lactose-free beverage. Future research could focus on its role in supporting weight loss, preventing diabetes, promoting heart health, and strengthening bones. The FiCo3 milk blend is a nutrition-packed, eco-friendly, and culturally significant plant-derived milk substitute with greater consumer approval and market potential.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the funding support provided by the Centre for Scientific Research and Advanced Learning, Mount Carmel College, Autonomous, Bengaluru, Karnataka, India.

REFERENCES

1. Tulashie, S. K., Amenakpor, J., Atisey, S., Odai, R., & Akpari, E. E. A. Production of coconut milk: A sustainable alternative plant-based milk. *Case Studies in Chemical, and Environmental Engineering*, 2022; 6, 1-8.
2. Sunny, Dhankar, J., Kundu, P., & Mehla, R. *International Journal of Pharmacy, and Biological Sciences*, 2019; 9, 565-572.
3. Pushpa Devi, M., & Narayanasamy Sangeetha. Extraction, and dehydration of millet milk powder for formulation of extruded product. *IOSR Journal of Environmental Science, Toxicology, and Food Technology*, 2013; 7(1), 63-70.
4. Chilkawar, P. M., Salve, R. V., & Hashmi, S. I. Studies on standardization of malting process for finger millet (ragi). *International journal of processing, and post-harvest technology*. 2010; 1(2), 81-86.
5. Dhilwayo, T., Chopera, P., Matsungu, T. M., Chidewe, C., Mukanganyama, S., Nyakudya, E., Mtambanengwe, F., Mapfumo, P., & Nyanga, L. K. Effect of germination, and roasting on the proximate, mineral, and anti-nutritional factors in finger millet (*Eleusine coracana*), cowpeas (*Vigna unguiculata*), cowpeas (*Vigna unguiculata*), and orange maize (*Zea mays*). *African Journal of Food, Agriculture, Nutrition, and Development*. 2023; 23(8), 24346-24362.





Samiya Mohammedi et al.,

6. Bernat N., Cháfer M., Chiralt A., & González-Martínez C. Hazelnut milk fermentation using probiotic *Lactobacillus rhamnosus* GG and inulin. *International Journal of Food Science & Technology*. 2014; 49(12), 2553-2562.
7. Association of Official Analytical Chemists. Official methods of analysis, (12th ed.). Association of Official Analytical Chemists, USA. 1975.
8. Sanjaya, S., & Romulo, A. Study of chemical, physical stabilites, and sensory properties of sorghum-adlay-based milk. *IOP Conference Series Earth and Environmental Science*. 2023; 1252(1).
9. Chanchlani V., Goyal P., Sharma L., Sharma S., & Nathawat H. Review: Digital pH Meter. *International Journal of Creative Research Thoughts*. 2023; (IJCRT),11(12), 861-863.
10. Kassegn, H. H. Determination of proximate composition, and bioactive compounds of the Abyssinian purple wheat. *Cogent Food & Agriculture*. 2018; 4(1), 1-9.
11. Prasanna, K., Narayanamma, N., Satya Sai, L. J. V N. B., Prasad, I., Rajesh, I., & Vinay Teja, K. Estimation of carbohydrates by anthrone method in different juices. *Indo american journal of pharmaceutical sciences*. 2025; 12(3), 137-140.
12. Anurag., & Garg, A. P. Estimation of protein of germinated multi-millet puffs using an advanced Kjeldahl titration method. *The Pharma Innovation Journal*. 2023; 12(6), 2621–2626.
13. Kochneva, M., Butusov, L., Bindukov, S., & Ivlev, V. Soxhlet-randall method modification for rapid lipid extraction on example of rainbow trout. *Engineering For Rural Development*. 2019; 521–522.
14. Baliyan, S., Mukherjee, R., Priyadarshini, A., Vibhuti, A., Gupta, A., Pandey, R. P., & Chang, C. Determination of Antioxidants by DPPH Radical Scavenging Activity and Quantitative Phytochemical Analysis of *Ficus religiosa*. *Molecules*. 2022; 27(4).
15. Sunmonu, M. O., Odewole, M. M., Sanusi, M. S., Ajala, O. E., & Oyediji, H. F. Effect of extracting methods on micro-organisms characterization in orange juice. *Agricultural Engineering International: CIGR Journal*. 2021; 23–23(2), 229–238.
16. Geetha, P., & Preethi, P. Development of kodo millet based functional milk beverage. *International Journal of Chemical Studies*. 2020; 8(6), 1034–1037.
17. Gaikwad, V., Kaur, J., Rasane, P., Kaur, S., Singh, J., Kumar, A., Kumar, A., Sharma, N., Mehta, C. M., & Patel, A. S. Nutritional significance of finger millet, and its potential for using in functional products. *Foods, and Raw Materials*. 2023; 12(1), 110–123.
18. Shunmugapriya, K., Kanchana, S., Maheswari, T. U., Kumar, R. S., & Vanniarajan, C. Standardization, and stabilization of millet milk by enzyme, and its physicochemical evaluation. *European Journal of Nutrition & Food Safety*. 2020; 12(1), 30–38.
19. Karunasiri, A. N., Gunawardane, M., Senanayake, C. M., Jayathilaka, N., & Seneviratne K. N. Antioxidant, and nutritional properties of domestic, and commercial coconut milk preparations. *International Journal of Food Science*. 2020; 1–9.
20. Chethan S, Malleshi N. Finger millet polyphenols: Characterization, and their nutraceutical potential. *American Journal of Food Technology*. 2007; 2(7):582–592.
21. Walther B, Guggisberg D, Badertscher R, Egger L, Portmann R et al., Comparison of nutritional composition between plant-based drinks, and cow's milk. *Frontiers in Nutrition*. 2022; 9:1-17.
22. Hiremath, N., Netravati, H., & Prabhakar, K. Minerals content in finger millet [*Eleusine coracana* (L.) Gaertn]. *International Journal of Current Microbiology, and Applied Sciences, Special Issue-7*. 2018; 3448-3455.
23. Chethan, S., & Malleshi, N. Finger millet polyphenols: Characterization, and their nutraceutical potential. *American Journal of Food Technology*. 2007; 2(7), 582–592.
24. Daryani, D., Pegua, K., & Aryaa, S. S. Review of plant-based milk analogue: its preparation, nutritional, physicochemical, and organoleptic properties. *Journal of Food Safety*. 2024; 1059–1073.



Samiya Mohammedi *et al.*,

Table 1: The milk yield of finger millet milk and coconut milk

Ratios composition	Finger millet milk (mL)	Coconut milk (mL)
1:1 (w/v)	80±0.05	175±0.08
1:2 (w/v)	145±0.04	225±0.17
1:3 (w/v)	270±0.2	330±0.41
1:4 (w/v)	310±0.07	410±0.15
1:5 (w/v)	455±0.3	525±0.18

Mean ± SD; n=3

Table 2: The mean sensory scores of different milks and plant-based milk alternative blends V_o- Cow's milk, VFM-Finger millet milk.VCM-Coconut milk; FiCo1- 60% finger millet milk extract, 40% coconut milk extract; FiCo2- 70% finger millet milk extract, 30% coconut milk extract; FiCo3- 80% finger millet milk extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	Fico1	FiCo2	FiCo3	p-value
Colour	8.1±0.2	8.1±0.1	8.5±0.3	8.1±0.2	7.8± 0.05	7.9±0.1	<.001**
Aroma	7.9± 0.1	8.3±0.1	8.3±0.05	8.06±0.1	7.7±0.2	7.8±0.05	<.001**
Consistency	8.06±0.2	8.2±0.1	8.2±0.1	7.9±0.2	7.8±0.2	7.8±0.3	<.001**
Taste	8.03±0.2	8.2±0.2	8.4±0.05	8.3±0.2	7.9±0.3	7.9±0.4	<.001**
Mouthfeel	8.1±0.3	8.2±0.1	8.2±0.2	8.3±0.2	7.8±0.05	7.7±0.2	<.001**
Overall acceptability	8.0±0.4	8.2±0.05	8.3±0.1	8.2±0.2	7.8±0.2	7.8±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05) by ANOVA

Table 3: The mean scores of physicochemical parameters of different milk, and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk.VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract.

Parameters	V _o	VFM	VCM	FiCo3	p-value
Moisture %	88.6±0.7	81.8±0.05	78.3±0.5	81.3±0.06	<.001**
Ash %	0.7±0.1	1.4±0.3	1.5±0.1	1.9±0.03	<.001**
pH	6.69	6.48	6.56	5.59	0.42*
TSS	13.5±0.04	3.7±0.5	3.1±0.06	4.2±0.1	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),

Table 4: The mean macronutrient content of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Energy (kCal/100ml)	64.2±0.1	46.2±0.04	272.9±0.01	156.4±0.3	<.001**
CHO (g/100ml)	4.2±0.2	8.4±0.9	6.6±0.4	8.7±0.6	<.001**
Protein (g/100ml)	3.3±0.1	2.3±0.4	5.6±0.5	5.2±0.8	<.001**
Fat (g/100ml)	3.8±0.2	0.3±0.05	24.9±0.9	11.2±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),





Samiya Mohammedi *et al.*,

Table 5: The mean micronutrient Content of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Calcium	116±0.8	380±0.3	7±0.2	292.2±0.6	<.001**
Iron	0.05±0.06	4.6±0.9	0.024±0.05	3.81±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),

Table 6: The mean antioxidant activity of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Antioxidant activity (%)	25.1± 0.09	46.2± 0.5	44.4± 0.1	39.4±0.02	<.001**

Mean ± SD; n=3, ** significantly different (p<0.01), *significantly different (p<0.05),

Table 7: The microbial analysis of blended milk FiCo3

Storage Time	TPC (10 CFU ^{-mL})	Yeast and mold
Day 1	2 ×10 ⁶ ±0.09	ND
Day 5	33 ×10 ⁶ ±0.05	ND
Day 10	3 ×10 ⁶ ±0.1	ND

ND-Not detected, Mean ± SD; n=3

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





REVIEW ARTICLE

Review on Engineering Porous Biopolymeric Gels for Regenerative Medicine: Structural Design Strategies for Mechanical Stability and Biological Performance

Karanam Mithun¹, Pratiksha Akki^{2*}, M Mahesh Yadav³, AHM Vishwanatha Swamy⁴, Fatima Sanjeri Dasankoppa⁵, Kusum S Akki⁶, Shreya A Prabhu² and Kamaladevi T Kshatriya²

¹PG Student, Department of Pharmaceutics, KLE College of Pharmacy, Hubballi, A Constituent Unit of KLE Academy of Higher Education and Research, Belagavi, Karnataka, India

²Assistant Professor, Department of Pharmaceutics, KLE College of Pharmacy, Hubballi, A Constituent Unit of KLE Academy of Higher Education and Research, Belagavi, Karnataka, India

³Ph.D Research Scholar (Reg.No.: DO1223053), Department of Pharmaceutics, KLE College of Pharmacy, Hubballi, A Constituent Unit of KLE Academy of Higher Education and Research, Belagavi, Karnataka, India

⁴Principal and Professor, Department of Pharmacology, KLE College of Pharmacy, Hubballi, A Constituent Unit of KLE Academy of Higher Education and Research, Belagavi, Karnataka, India

⁵Professor and HOD, Department of Pharmaceutics, KLE College of Pharmacy, Hubballi, A Constituent Unit of KLE Academy of Higher Education and Research, Belagavi, Karnataka, India

⁶Professor, Department of Pharmacognosy, AGMR College of Pharmacy, Hubballi, (Affiliated to Rajiv Gandhi University of Health Sciences (RGUHS), Bengaluru, Karnataka, India

Received: 10 Mar 2026

Revised: 11 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Pratiksha Akki

Assistant Professor,

Department of Pharmaceutics,

KLE College of Pharmacy, Hubballi,

A Constituent Unit of KLE Academy of Higher Education and Research,

Belagavi, Karnataka, India

E.Mail: pratiksha.akki8@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Porous biopolymeric gels have emerged as sophisticated scaffold systems that incorporate hydration mimicking the extracellular matrix, interconnected porosity and adjustable mechanical properties for regenerative medicine. Their effectiveness is influenced by factors such as polymer composition, pore structure, crosslinking chemistry and fabrication methods, which together control cellular infiltration, nutrient transport, biodegradation and mechanotransduction. This review provides a systematic analysis of the classification of natural, synthetic and hybrid gels; essential design parameters; key crosslinking methods; and fabrication techniques including sol-gel processing, cryogelation, freeze-drying,



**Karanam Mithun et al.,**

interpenetrating polymer networks, injectable gelation and three-dimensional bioprinting. Sections focused on applications emphasize their usefulness in therapies related to skeletal, osteochondral, dermal, vascular, neural, cardiac and immunomodulation. Recent advancements indicate that the thoughtful engineering of network topology and physicochemical characteristics can resolve the longstanding trade-off between porosity and mechanical strength. Thus, porous biopolymeric gels serve as a strong and clinically applicable platform for the next generation of regenerative therapeutics.

Keywords: Porous biopolymeric gels, regenerative medicine, tissue engineering, crosslinking Strategies, scaffold fabrication, mechanical robustness, biomimetic scaffolds, controlled biodegradation

ABBREVIATIONS

ECM – Extracellular Matrix; PEG – Polyethylene Glycol; PVA – Polyvinyl Alcohol; IPN – Interpenetrating Polymer Network; 3D – Three-Dimensional; FAK – Focal Adhesion Kinase; MAPK – Mitogen-Activated Protein Kinase; YAP – Yes-Associated Protein; TAZ – Transcriptional Co-Activator with PDZ-Binding Motif; DNA – Deoxyribonucleic Acid; RNA – Ribonucleic Acid; AI – Artificial Intelligence; CAD – Computer-Aided Design; MMP – Matrix Metalloproteinase; VEGF – Vascular Endothelial Growth Factor; BMP – Bone Morphogenetic Protein; M1 – Classically Activated Macrophage Phenotype; M2 – Alternatively Activated Macrophage Phenotype; pH – Potential of Hydrogen; UV – Ultraviolet; CaP – Calcium Phosphate; SEM – Scanning Electron Microscopy.

INTRODUCTION

Background and evolution of porous biopolymeric gels

Porous biopolymeric gels have advanced from simple water-saturated polymer networks to highly sophisticated biomaterials that can replicate essential structural and functional aspects of the extracellular matrix [1,2]. Initially, hydrogel systems were primarily recognized for their high hydration and cytocompatibility; however, their dense architecture and limited mechanical properties restricted tissue integration [3]. Subsequent innovations in cryogelation, freeze-drying and sol-gel processing enabled the formation of interconnected pore networks that support cell infiltration, vascularization and effective mass transport [4,5]. Parallel advancements in polymer chemistry introduced controllable crosslinking strategies, allowing for precise regulation of stiffness, degradation and viscoelastic behavior [6]. The integration of natural and synthetic polymers has further enhanced design flexibility by combining biological recognition with structural reproducibility. Consequently, porous biopolymeric gels now serve as a versatile scaffold platform capable of addressing the specific mechanical and biological requirements of both soft and load-bearing tissues in regenerative medicine [2,3].

Importance in regenerative medicine

Porous biopolymeric gels play a crucial role in regenerative medicine as they mimic the physicochemical and biomechanical properties of the natural extracellular matrix [1,3]. Their interconnected macroporous structure promotes cell adhesion, migration, proliferation and lineage-specific differentiation, while also allowing for the convective and diffusive transport of oxygen, nutrients, cytokines and metabolic waste [2,5]. The ability to tune viscoelasticity, degradation rates and bioactive surface chemistry enables precise control over mechanotransduction and cell-matrix signaling [3,6]. Additionally, these scaffolds can concentrate growth factors and therapeutic agents, creating instructive microenvironments that enhance angiogenesis, immunomodulation and tissue remodeling [2,7]. As a result, porous biopolymeric gels act as biomimetic matrices for the functional regeneration of complex tissues that are both structurally and physiologically intricate [1,3].



**Karanam Mithun et al.,****Challenges in balancing porosity and mechanical strength**

The main design challenge in porous biopolymeric gels lies in the inverse relationship between porosity and mechanical integrity [1,3]. While increasing pore volume and interconnectivity promotes cellular infiltration, vascularization and mass transport, it simultaneously decreases the effective load-bearing area and diminishes compressive modulus, tensile strength and fracture resistance [1,5]. On the other hand, a higher crosslink density enhances stiffness and dimensional stability but limits pore accessibility and matrix permeability [3,6]. Therefore, achieving both macroporosity and structural robustness necessitates hierarchical architectures, optimized network topology and energy-dissipating polymer configurations that separate biological functionality from mechanical performance [1,7].

Scope and objectives of the review

This review provides a critical assessment of the choices of materials, pore engineering, crosslinking approaches and the methodologies used in the fabrication of porous biopolymeric gels. Its goal is to establish design principles that merge mechanical durability, controlled biodegradation and biological performance for regenerative scaffolds applicable in a range of tissue engineering scenarios.

Classification of Biopolymeric Gels**Natural polymer-based gels**

Natural polymer-based gels are synthesized from biomacromolecules such as collagen, gelatin, alginate, chitosan, hyaluronic acid, fibrin and cellulose derivatives [1,3]. Their primary advantage is their inherent bioactivity, which includes cell-adhesive motifs, enzymatic degradability and a structural likeness to native extracellular matrix components [1,4]. These materials enable integrin-mediated adhesion, cytoskeletal organization and lineage-specific differentiation in physiologically relevant environments [14,5]. However, their networks often display a low elastic modulus, rapid hydrolytic or enzymatic degradation and variability between batches due to biological sourcing. The mechanical performance is often improved through covalent crosslinking, polymer blending, or the creation of interpenetrating networks, while still maintaining their favorable cytocompatibility and tissue-integrative features [2,6].

Synthetic polymer-based gels

Synthetic polymer-based gels are made from materials like polyethylene glycol, polyvinyl alcohol, polyacrylamide and copolymers derived from polycaprolactone [3]. These systems provide precise control over factors such as molecular weight, crosslink density, network topology and degradation kinetics, allowing for reproducible adjustments of elastic modulus, swelling ratio and mesh size [4,5]. Their chemical consistency reduces batch variability and supports scalable production [2,3]. However, they typically do not possess intrinsic cell-recognition domains, necessitating biofunctionalization with adhesive peptides, polysaccharides, or protein derivatives to promote cellular attachment and signaling. Synthetic gels are especially important when consistent mechanical performance, long-term structural stability and tightly controlled physicochemical properties are critical for the design of regenerative scaffolds [2,7].

Hybrid and composite gel systems

Hybrid and composite gel systems combine natural and synthetic polymers to synergistically merge bioactivity with mechanical reliability [1]. The natural components offer cell-interactive motifs and enzymatically degradable domains, while the synthetic parts provide structural consistency and adjustable viscoelastic properties [2,4]. In composite designs, secondary phases such as ceramics, bioactive glass, or fibrous reinforcements enhance stiffness, fracture resistance and dimensional stability [5,7]. These multiphase networks facilitate independent modulation of degradation behavior, swelling and biomechanical performance [6,8]. By decoupling biological functionality from structural reinforcement, hybrid and composite gels present a versatile platform for creating scaffolds that closely replicate the biochemical and mechanical heterogeneity of native tissues [2,8].



**Karanam Mithun et al.,****Structural categories: hydrogels, cryogels and aerogels**

Hydrogels are networks of polymers that absorb water, noted for their high hydration, nanoscale mesh structures and viscoelasticity akin to that of biological tissues. Their soft and permeable matrices enable the diffusion-driven transport of nutrients and signaling molecules, rendering them suitable for cell encapsulation and soft tissue regeneration. Nevertheless, conventional hydrogels frequently exhibit limited pore interconnectivity and only modest mechanical strength [3,5]. Cryogels are produced by crosslinking in partially frozen conditions, where solvent crystals function as porogens. Upon thawing, they result in highly interconnected macroporous networks with pore sizes typically ranging from tens to hundreds of micrometers. Their sponge-like architecture facilitates rapid fluid perfusion, efficient cellular infiltration and outstanding elastic recovery after compression, making them particularly effective for load-bearing and injectable applications [7,8]. Aerogels are created by removing solvent from wet gels while preserving the three-dimensional network [9,10]. They are known for their ultralow density, extremely high porosity and large specific surface area. These characteristics provide exceptional absorptive capacity and diffusion properties, although their mechanical brittleness may require secondary reinforcement. Collectively, these structural categories present distinct combinations of porosity, stiffness and transport behavior tailored to various regenerative requirements [10,11].

Injectable and in situ forming gels

Injectable and in situ forming gels are delivered as precursor solutions or shear-thinning formulations that gel directly at the defect site [1,3]. The formation of the network is initiated by thermal transitions, ionic interactions, enzymatic reactions, pH changes, or photoactivation [2,5]. This method allows for minimally invasive delivery, uniform cell encapsulation and accurate adaptation to irregular anatomical shapes [3,6]. It is essential to carefully balance gelation kinetics to maintain injectability while avoiding premature leakage [4,5]. These systems are extensively used for localized drug delivery, soft tissue enhancement and regenerative therapies, where conforming architecture, controlled degradation and minimized surgical trauma are vital for therapeutic success [6,7]. Table 1 shows Comparison between different types of biopolymeric gels

Critical Design Parameters

The functional performance of porous biopolymeric gels is governed by a tightly interconnected set of structural, physicochemical and biomechanical parameters. Factors such as pore topology, network mechanics, swelling thermodynamics, degradation kinetics, interfacial bioactivity and mass transport collectively influence cell fate and tissue integration. Thus, effective scaffold engineering requires the simultaneous optimization of these variables to achieve reliable and tissue-specific regenerative results.

Pore architecture and interconnectivity

Pore architecture is essential in regulating the spatial organization of cells and the transport of solutes within the scaffold. Key descriptors include the distribution of pore sizes, tortuosity, connectivity density and anisotropy [2,4]. Macropores promote cellular infiltration and neovascularization, while micropores increase the surface area available for protein adsorption and matrix anchorage [3,5]. High interconnectivity reduces diffusion dead zones and creates continuous pathways for the exchange of oxygen and nutrients [4,6]. Hierarchical architectures that integrate multiple pore scales more accurately replicate the heterogeneity of the native extracellular matrix and enhance biomechanical load transfer [5,7]. However, excessive porosity can lead to a decrease in strut thickness and an increase in stress concentration, making the network prone to mechanical collapse [2,8]. Therefore, pore topology must be designed to maximize biological accessibility while maintaining structural integrity and compressive stability under physiological loading conditions [3,7].



**Karanam Mithun et al.,****Mechanical strength and viscoelastic properties**

The mechanical performance of a scaffold is crucial for its capacity to endure both static and cyclic physiological loads without experiencing plastic deformation or structural failure. Important parameters include elastic modulus, compressive strength, tensile toughness, fracture energy and fatigue resistance [2,4]. Biopolymeric gels demonstrate viscoelastic properties, which are defined by time-dependent stress relaxation, creep compliance and hysteretic energy dissipation due to reversible molecular rearrangements [3,5]. These characteristics influence mechanotransduction by modulating cytoskeletal prestress, focal adhesion maturation and nuclear deformation [5,6]. Matching tissue-specific modulus is vital to avoid stress shielding and to guide lineage commitment through cues provided by matrix stiffness [6,7]. Traditional highly hydrated networks typically show limited toughness due to a low polymer volume fraction and weak intermolecular interactions [3,8]. Mechanical reinforcement can be achieved by increasing crosslink density, utilizing double-network architectures, incorporating sacrificial bonds and employing interpenetrating polymer configurations that dissipate energy through reversible bond rupture [8,9]. The best designs integrate high resilience, quick elastic recovery and resistance to cyclic degradation while ensuring interconnected porosity and biological permissiveness [2,9].

Swelling and water retention behaviour

The swelling behaviour is influenced by the thermodynamic balance between the affinity of the polymer for the solvent and the elastic retractive forces within the crosslinked network. The uptake of water determines the mesh size, diffusivity, osmotic pressure and compliance akin to that of tissue [4]. Sufficient hydration is vital for maintaining a pericellular microenvironment that supports protein mobility, ion transport and biomolecular signalling [3,5]. When swelling is excessive, it can cause pore walls to expand, decrease effective crosslink density and undermine dimensional stability and mechanical stiffness [4,6]. Conversely, inadequate swelling can limit permeability and disrupt metabolite exchange [3,5]. Water retention is affected by the hydrophilicity of the polymer, ionic charge density, crystallinity and the heterogeneity of the network [2]. Furthermore, polyelectrolyte gels also show Donnan swelling due to an imbalance of counterions [7,8]. Thus, it is essential to control equilibrium swelling to maintain scaffold geometry, regulate release kinetics and uphold structural integrity throughout the processes of implantation and tissue remodeling [1,5].

Biodegradation and scaffold longevity

Biodegradation refers to the duration of the scaffold's existence and its ability to offer mechanical support during the process of tissue regeneration. The degradation occurs through mechanisms such as hydrolytic cleavage, enzymatic catalysis, oxidative scission, or the dissociation of reversible crosslinks [2,5]. The kinetics are influenced by factors including polymer chemistry, crystallinity, crosslink density and local biochemical conditions [4,6]. Ideally, the loss of mass and reduction in modulus should coincide with the deposition of the extracellular matrix and the maturation of host tissue [1,7]. If degradation occurs too early, it can result in structural failure, while excessive persistence may hinder remodeling and trigger chronic foreign body reactions [5,8]. The byproducts of degradation must be non-cytotoxic, non-immunogenic and easily metabolized or excreted [4,8]. Thoughtful management of scaffold longevity guarantees a coordinated transfer of load from the biomaterial to the regenerating tissue [1,7].

Surface characteristics and cell–material interactions

The scaffold interface plays a crucial role in regulating the initial adsorption of serum proteins, which subsequently determines cellular responses downstream. Elements such as surface chemistry, charge density, wettability and nanoscale roughness significantly influence integrin engagement, focal adhesion assembly and the activation of signaling pathways including FAK, MAPK and YAP/TAZ [4,6]. While natural polymers often contain intrinsic ligands for receptor-mediated adhesion, synthetic matrices typically require biofunctionalization with peptides or motifs from the extracellular matrix [7,8]. Surfaces that are moderately hydrophilic tend to favor selective protein adsorption and decrease nonspecific denaturation [9,10]. Surface-bound morphogens and matrix-bound cytokines can provide localized instructive cues that steer osteogenic, chondrogenic, angiogenic, or neurogenic differentiation



**Karanam Mithun et al.,**

[11,12]. Thus, interfacial engineering is vital for controlling cytocompatibility, immunomodulation and the regeneration of tissue specific to its type [8,13].

Nutrient transport and oxygen diffusion

The mass transport within porous gels is controlled by diffusion, convection and partitioning through the hydrated polymer network. Effective transport is dependent on factors such as pore connectivity, tortuosity, permeability and equilibrium water content [2,4]. Oxygen diffusion is especially critical since hypoxic gradients can develop rapidly in thick cellular constructs [5,6]. Interconnected macropores help to decrease transport resistance and ensure a uniform distribution of glucose, amino acids, growth factors and dissolved gases, while also facilitating the removal of metabolic waste [7,8]. Inadequate transport can lead to nutrient depletion, acidosis and the formation of necrotic cores [5,9]. Consequently, scaffold architecture must be designed to minimize diffusional limitations and sustain cellular homeostasis throughout the regenerating tissue volume [4,10].

Integrated optimization of scaffold properties

The design variables that influence porous biopolymeric gels are significantly interrelated and cannot be optimized separately. Increasing the crosslink density typically improves modulus and reduces creep, but it also decreases mesh size, equilibrium swelling and enzymatic accessibility [4,6]. Enhancing porosity facilitates cellular infiltration and mass transport, yet it diminishes the effective load-bearing area and fracture resistance [7,9]. Surface functionalization encourages receptor-mediated adhesion but may change hydrophilicity and degradation behavior [10,11]. Similarly, accelerated biodegradation promotes matrix remodeling but can weaken mechanical support before adequate neo tissue deposition takes place [12,13]. Consequently, effective scaffold engineering depends on a systems-level design approach that harmonizes thermodynamic, kinetic and biomechanical constraints [14,15]. Hierarchical pore structures, gradient crosslinking and multiphase polymer networks allow for independent adjustment of transport, stiffness and degradation [16,17]. Quantitative metrics such as storage modulus, permeability and degradation half-life offer objective benchmarks for optimization [6,18]. Computational modeling, design-of-experiments techniques and multivariate analysis further minimize empirical trial-and-error [15,19]. By integrating parameter control, porous biopolymeric gels can be customized to replicate the structural, mechanical and biological intricacies of native tissues while ensuring strong translational potential [14,20]. In summary, these design parameters establish the structure-property-function relationship of porous biopolymeric gels [3,20]. Their coordinated optimization is crucial for developing biomimetic scaffolds with predictable mechanics, biological responsiveness and long-term regenerative effectiveness [15,18].

Crosslinking Strategies

Crosslinking determines the molecular configuration of biopolymeric gels by creating junctions that influence network density, pore stability, viscoelasticity and degradation kinetics. The mechanism chosen influences scaffold mechanics, injectability and cytocompatibility, thus significantly affecting regenerative performance and clinical application. **Figure 1** shows schematic illustration of major crosslinking strategies used in porous biopolymeric gels and their relative effects on mechanical strength, degradation behavior, injectability and cytocompatibility.

Covalent crosslinking approaches

Covalent crosslinking creates permanent chemical bonds between reactive functional groups like amines, carboxyls, thiols and hydroxyls. This approach results in mechanically strong networks that exhibit high dimensional stability and extended resistance to hydrolytic breakdown [4,5]. The properties of the network are influenced by the functionality of the crosslinker and the stoichiometric ratio [3,6]. While covalent structures offer enhanced modulus and structural durability, an excessive density of crosslinks can hinder pore accessibility and increase brittleness, making it essential to optimize carefully to maintain both mechanical integrity and biological compatibility [7,8].



**Karanam Mithun et al.,****Physical network formation mechanisms**

Physical gelation occurs due to non-covalent interactions such as ionic coordination, hydrogen bonding, hydrophobic association, crystallite formation and supramolecular host-guest recognition. These reversible interactions facilitate gel formation in mild aqueous environments without the need for reactive crosslinking agents [2,4]. Networks that are physically assembled demonstrate shear-thinning, self-healing and stress-relaxation properties, which are beneficial for injectable applications [5,6]. Nonetheless, their junctions are thermodynamically unstable and can dissociate when there are changes in ionic strength, temperature, or pH [1,4]. The mechanical stability can be improved by increasing polymer entanglement or by adding secondary reinforcing domains [5,9].

Enzymemediated gelation

Enzyme-mediated gelation utilizes biocatalysts to form covalent bonds at physiological temperature and pH. This method provides outstanding cytocompatibility and accurate kinetic control while steering clear of harsh reagents [2,4]. The rate of gelation and the density of the network can be adjusted by varying enzyme concentration and substrate availability [3,5]. Since polymerization occurs in aqueous environments, this technique is especially appropriate for cell encapsulation, minimally invasive delivery and the creation of bioresponsive scaffolds [4,6].

Light-triggered crosslinking methods

Light-activated crosslinking depends on photoactivatable functional groups that undergo polymerization when exposed to ultraviolet or visible light. This method provides spatiotemporal control over gelation, facilitating on-demand adjustments of crosslink density, stiffness gradients and microscale patterning [2,4]. Factors such as exposure parameters, photo initiator concentration and oxygen levels affect the efficiency of the reaction and the resulting network structure [3,5]. Systems utilizing visible light are becoming more favored as they minimize phototoxicity and enhance compatibility with living cells, growth factors and delicate biomolecules integrated into the scaffold [6,7].

Dual-network and hybrid crosslinking systems:

Dual-network and hybrid systems incorporate two or more orthogonal crosslinking mechanisms to address the shortcomings of single-mode gelation. Generally, one network offers rigidity and load-bearing capabilities, while a second reversible network dissipates mechanical energy through the rupture and reformation of sacrificial bonds [4,5]. This synergistic design significantly enhances fracture toughness, fatigue resistance and elastic recovery [4,6]. Hybrid systems can integrate covalent, physical, enzymatic and photochemical interactions to independently manage injectability, porosity, degradation and stiffness [3,8]. Such multiscale designs are especially effective in mechanically demanding tissues where both resilience and biological adaptability are essential [6,9].

Influence of crosslinking on mechanical and biological performance

Crosslinking density has a direct effect on mesh size, equilibrium swelling, elastic modulus and degradation rate. An increase in network connectivity usually results in greater stiffness and dimensional stability, but it can also limit cellular infiltration and nutrient transport [2,4]. The chemistry involved in crosslinking further influences protein adsorption, immune recognition and cell-mediated remodeling [6,8]. Thus, it is important to select a crosslinking strategy that balances mechanical strength with permeability, biodegradability and cytocompatibility [9]. Crosslinking serves as the molecular basis for porous biopolymeric gels, combining structural stability with biological functionality [9,10]. The strategic selection and combination of crosslinking mechanisms provide precise control over network architecture, allowing scaffolds to achieve tissue-specific mechanical properties, regulated degradation and regenerative responsiveness, which are essential for effective clinical translation [10,11].

Fabrication Techniques

The fabrication process governs pore morphology, network topology and mechanical anisotropy, thus influencing the structural and biological performance of porous biopolymeric gels in regenerative applications, **Table 2** shows Comparative assessment of fabrication techniques for porous biopolymeric gels



**Karanam Mithun et al.,****Solgel processing**

Sol-gel processing refers to the transformation of polymeric or hybrid precursors from a colloidal sol into a percolated three-dimensional network via hydrolysis, condensation, or crosslinking reactions. This technique allows for molecular-level control over composition, crosslink density and nano structural uniformity [2,4]. Factors such as precursor concentration, solvent polarity, pH, ionic strength and aging time influence gelation kinetics and pore development [3,5]. The subsequent drying process maintains the interconnected network, resulting in highly porous structures with a large specific surface area and adjustable mechanical properties [1,6]. Sol-gel processing is especially beneficial for creating aerogel-like matrices and hybrid systems that require a uniform architecture, controlled porosity and precise adjustments in degradation and mechanical performance [6,7].

Cryogelation

Cryogelation takes place under subzero temperatures, where the partial crystallization of the solvent leads to phase separation and the concentration of polymers within unfrozen microdomains [8,10]. Crosslinking happens around these ice templates and upon thawing, a highly interconnected macroporous network is formed [8,11]. The size of the pores and the thickness of the walls are influenced by the freezing temperature, cooling rate, polymer concentration and gelation kinetics [9,12]. Cryogels are characterized by low flow resistance, quick swelling and remarkable elastic recovery due to their sponge-like structure [10,11]. Their capacity to endure reversible compression without losing structural integrity makes them especially ideal for injectable scaffolds and applications that require load-bearing [11,13]. Cryogelation is extensively utilized when high permeability, mechanical strength and effective cell infiltration are necessary [8,13].

Freezedrying and porogenbased techniques

Freeze-drying creates porous scaffolds by first freezing a hydrogel precursor and then removing the solvent via sublimation under reduced pressure [14,16]. Ice crystals act as sacrificial templates that determine the morphology of the pores [14,17]. Quick freezing results in smaller, more uniform pores, while slower cooling leads to larger and more anisotropic structures [15,17]. Porogen-based techniques utilize removable particulate templates like salts, sugars, or gas-generating agents to form controlled voids [16,18]. Both methods achieve high porosity and interconnected pathways, but they may compromise mechanical strength due to thin pore walls and structural variability [17,19]. Crosslinking after fabrication is frequently used to enhance dimensional stability and resistance to deformation when subjected to physiological loads [18,19].

Interpenetrating polymer network fabrication

Interpenetrating polymer networks are created by either sequentially or simultaneously constructing two distinct yet physically intertwined networks. This design redistributes stress across various phases and improves fracture energy, toughness and fatigue resistance [2,4]. The ability to independently control each network allows for the concurrent adjustment of stiffness, swelling and degradation, rendering IPN fabrication particularly effective for mechanically challenging regenerative scaffolds [3,6].

Injectable and in situ gelation approaches

Injectable systems are provided as low-viscosity precursors that gel within the defect site when exposed to thermal, ionic, enzymatic, or photochemical stimuli. This approach allows for minimally invasive delivery and precise fitting to irregular shapes. Effective formulations necessitate optimized rheological properties, quick gelation and sufficient mechanical stability after implantation [9,11].

Three-dimensional bioprinting and emerging technologies

Three-dimensional bioprinting utilizes a layer-by-layer approach to deposit cell-laden bioinks, forming scaffolds with specific geometries, pore orientations and compositional gradients. The fidelity of the print is influenced by factors such as shear-thinning behavior, yield stress and the kinetics of post-print crosslinking [13,15]. This innovative technology provides spatial control over mechanical heterogeneity and localized biofunctionalization, which aids in the recreation of intricate tissue architectures [14,16]. Newly developed techniques, such as digital light processing,



**Karanam Mithun et al.,**

microfluidic templating and electrohydrodynamic printing, enhance resolution and structural precision [17,19]. The combination of computer-aided design and computational modeling facilitates predictive optimization of scaffold architecture, allowing for the creation of patient-specific constructs with precisely controlled biomechanical and biological properties [21,22].

Biomedical Applications

The integration of porous biopolymeric gels has enabled the design of application-specific scaffolds that incorporate tissue-matched mechanics, hierarchical porosity and localized bioactivity, which collectively support functional regeneration in a wide array of structurally and physiologically diverse tissues.

Skeletal tissue reconstruction:

Porous gels created for skeletal repair must ensure the presence of osteoconductive microenvironments, exhibit high compressive resilience and possess interconnected macroporosity to facilitate vascular invasion and the deposition of a mineralized matrix. Composite cryogels that are reinforced with calcium phosphate phases are particularly effective as they blend load-bearing capacity with controlled biodegradation [4,6].

Dermal repair and chronic wound management

Cutaneous regeneration requires scaffolds that can sustain a hydrated microenvironment, absorb exudate and shield against microbial contamination, all while facilitating fibroblast infiltration and re-epithelialization. Porous biopolymeric gels made from gelatin, alginate and chitosan demonstrate advantageous oxygen permeability, haemostatic properties and degradation that responds to matrix metalloproteinases. Their high-water content helps prevent desiccation and the interconnected porosity speeds up the formation of granulation tissue and neovascularization. Mechanical compliance reduces shear-induced trauma at the wound interface [3,8].

Guided angiogenesis and microvascular regeneration

The formation of vascularized tissue relies on scaffolds that possess high permeability, interconnected pore channels and the ability to signal pro-angiogenic activity. Porous gels facilitate endothelial sprouting, the creation of lumens and the anastomosis of host vessels by allowing for oxygen transport and matrix remodeling [6].

Localized therapeutic delivery platforms

Porous biopolymeric gels serve as depot systems for proteins, peptides, nucleic acids and small-molecule therapeutics. The release of drugs is influenced by factors such as mesh size, degradation kinetics and interactions between the polymer and the drug, allowing for sustained and localized delivery. Their hydrated structure protects sensitive biomolecules and reduces systemic exposure [23].

Post-surgical tissue reconstruction

After the resection of a tumor or following trauma, biomaterials are needed to fill irregular cavities, prevent the creation of dead space and support quick tissue integration. Porous gels conform to complex anatomical structures and provide temporary structural support while offering haemostatic, antimicrobial, or regenerative cues. Their interconnected pore networks facilitate the infiltration of fibroblasts, endothelial cells and progenitor populations, which speeds up functional restoration and reduces scar formation [24].

Soft tissue augmentation and defect filling

The process of soft tissue restoration requires materials that possess a low elastic modulus, high fidelity in shape retention and a gradual biodegradation capability. Porous gels serve to distribute mechanical loads uniformly and enable the infiltration of host cells, facilitating a progressive replacement by natural adipose or connective tissue. Injectable formulations are particularly useful for contour adjustments and volumetric reconstruction [25].



**Karanam Mithun et al.,****Immunomodulatory and anti-inflammatory applications:**

In addition to providing structural support, porous gels have the ability to modulate both innate and adaptive immune responses by regulating cytokine presentation, macrophage polarization and leukocyte infiltration. Matrix stiffness, degradation products and surface chemistry work together to affect the shift from pro-inflammatory M1 to regenerative M2 phenotypes. This capacity for immunoregulation helps to diminish chronic inflammation and encourages constructive remodeling [26].

Comparative assessment of fabrication methods

Each fabrication technique has its own set of advantages tailored to specific applications. Sol-gel processing enables nanoscale compositional control and extremely high porosity, although it may require longer processing times [2]. Cryogelation results in mechanically durable macroporous scaffolds with excellent permeability. Freeze-drying and porogen leaching are simple to operate and highly versatile, but they often lead to mechanical fragility. The fabrication of interpenetrating polymer networks provides outstanding toughness and fatigue resistance [7,8]. Injectable gelation allows for minimally invasive delivery, while three-dimensional bioprinting facilitates precise spatial patterning and customization for individual patients. The choice of method should be guided by the desired pore architecture, mechanical requirements, degradation profile and translational feasibility [12,14]. The fabrication strategy ultimately dictates the architecture and performance of the scaffold, translating molecular designs into constructs that are clinically relevant, with optimized porosity, mechanical strength and biological functionality.

Future Perspectives

The next generation of porous biopolymeric gels will be defined by the integration of adaptive material chemistry, computational design and precision manufacturing. Future scaffold systems are expected to incorporate dynamic covalent bonds, supramolecular interactions and enzyme-cleavable motifs that enable spatiotemporally regulated remodeling in response to local biochemical and mechanical cues. Such adaptive networks will permit on-demand modulation of stiffness, permeability and degradation, thereby more closely recapitulating the evolving extracellular matrix during tissue repair [4,6]. The use of artificial intelligence in materials discovery and multiphysics modeling will enhance the optimization of polymer composition, pore topology and crosslinking density by forecasting structure–property–function relationships prior to experimental fabrication [7]. Integrating these technologies with three-dimensional bioprinting and patient-specific imaging data will enable the creation of customized scaffolds designed to meet defect geometry, tissue biomechanics and individual regenerative needs [9]. A key area of emphasis is the advancement of immuno-instructive matrices that are capable of steering macrophage polarization, controlling fibrotic responses and facilitating constructive remodeling. Simultaneously, multifunctional gels that merge therapeutic delivery, biosensing and real-time monitoring could revolutionize scaffolds from mere passive substrates to dynamic therapeutic platforms [12]. Despite significant advancements, translation is still limited by factors such as sterilization compatibility, batch reproducibility, long-term *in vivo* safety and regulatory complexities. Consequently, standardized characterization metrics and strong manufacturing protocols will be crucial. The ongoing integration of polymer science, bioengineering and translational medicine is anticipated to produce clinically applicable porous biopolymeric gels with unmatched precision and therapeutic effectiveness [13,14].

CONCLUSION

Porous biopolymeric gels are adaptable biomaterials that integrate hydration resembling the extracellular matrix, interconnected porosity and adjustable mechanical properties within a single scaffold platform. Their functionality is shaped by polymer composition, pore architecture, crosslinking chemistry and fabrication strategies, which together regulate cellular infiltration, nutrient transport, vascularization and tissue-specific mechanotransduction. Natural polymers offer intrinsic bioactivity, synthetic polymers ensure reproducibility and hybrid systems help mitigate the trade-off between porosity and mechanical strength. Applications include bone and cartilage repair, wound healing, angiogenesis and therapeutic delivery. Continued progress in predictive design and scalable manufacturing is expected to speed up their clinical application as next-generation regenerative scaffolds.



Karanam Mithun *et al.*,

ACKNOWLEDGMENT

The authors gratefully acknowledge KLE College of Pharmacy, Hubballi, for providing academic infrastructure, research support and an intellectually stimulating environment for this review.

REFERENCES

1. Ilić-Stojanović S, Nikolić L, Cakić S. A review of patents and innovative biopolymer-based hydrogels. *Gels* 2023;9:556.DOI: 10.3390/gels9070556
2. Nikolova MP, Chavali MS. Recent advances in biomaterials for 3D scaffolds: A review. *Bioact Mater* 2019;4:271-92.DOI: 10.1016/j.bioactmat.2019.10.005
3. Carriero VC, Causa F, Netti PA. Cryogel scaffolds for tissue-engineering: Advances and challenges for effective bone and cartilage regeneration. *Gels* 2023;9:979. DOI: 10.3390/gels9120979
4. Omidian H, Rocca JG, Park K. Cryogels: Advancing biomaterials for transformative biomedical applications. *Biomater Sci* 2023;11:5565-92.DOI: 10.3390/pharmaceutics15071836
5. Karamikamkar S, Balakrishnan P, Hedayati M, et al. Aerogel-based biomaterials for biomedical applications. *Adv Sci (Weinh)* 2023;10:2204681.DOI: 10.1002/advs.202204681
6. Le Fer G, Chiono V, Vozzi G, et al. Photopolymerized porous hydrogels. *Biomacromolecules* 2021;22:1282-95.DOI: 10.1021/acs.biomac.0c01671
7. Place ES, Evans ND, Stevens MM. Complexity in biomaterials for tissue engineering. *Nat Mater* 2009;8:457-70. DOI: 10.1038/nmat2441
8. Chimene D, Lennox KK, Kaunas RR, Gaharwar AK. Advanced bioinks for 3D printing: A materials science perspective. *Ann Biomed Eng* 2016;44:2090-102.DOI: 10.1007/s10439-016-1638-y
9. Karamikamkar S, Balakrishnan P, Hedayati M, et al. Aerogel-based biomaterials for biomedical applications. *Adv Sci (Weinh)* 2023;10:2204681.DOI: 10.1002/advs.202204681
10. Maleki H, Durães L, Portugal A. An overview on silica aerogels synthesis and different mechanical reinforcing strategies. *J Non Cryst Solids* 2014;385:55-74.DOI: 10.1016/j.jnoncrystsol.2013.10.017
11. Stergar J, Maver U. Review of aerogel-based materials in biomedical applications. *J Sol Gel Sci Technol* 2016;77:738-52.DOI: 10.1007/s10971-016-3968-5
12. Lee K, Silva EA, Mooney DJ. Growth factor delivery-based tissue engineering: General approaches and a review of recent developments. *J R Soc Interface* 2011;8:153-70.DOI: 10.1098/rsif.2010.0223
13. Anderson JM, Rodriguez A, Chang DT. Foreign body reaction to biomaterials. *Semin Immunol* 2008;20:86-100.DOI: 10.1016/j.smim.2007.11.004
14. Place ES, George JH, Williams CK, Stevens MM. Synthetic polymer scaffolds for tissue engineering. *Chem Soc Rev* 2009;38:1139-51.
15. Gaharwar AK, Singh I, Khademhosseini A. Engineered biomaterials for in situ tissue regeneration. *Nat Rev Mater* 2020;5:686-705.DOI: 10.1038/s41578-020-0209-x
16. Levingstone TJ, Matsiko A, Dickson GR, O'Brien FJ, Gleeson JP. A biomimetic multi-layered collagen-based scaffold for osteochondral repair. *Acta Biomater* 2014;10:1996-2004.DOI: 10.1016/j.actbio.2014.01.012
17. Chimene D, Lennox KK, Kaunas RR, Gaharwar AK. Advanced bioinks for 3D printing: A materials science perspective. *Ann Biomed Eng* 2016;44:2090-102.DOI: 10.1007/s10439-016-1638-y
18. Burdick JA, Prestwich GD. Hyaluronic acid hydrogels for biomedical applications. *Adv Mater* 2011;23:H41-H56.DOI: 10.1002/adma.201003963
19. Zhao F, Ma T. Perfusion bioreactor system for human mesenchymal stem cell tissue engineering: Dynamic cell seeding and construct development. *BiotechnolBioeng* 2005;91:482-93.DOI: 10.1002/bit.20532
20. Moroni L, Burdick JA, Highley C, Lee SJ, Morimoto Y, Takeuchi S, et al. Biofabrication strategies for 3D *in vitro* models and regenerative medicine. *Nat Rev Mater* 2018;3:21-37.DOI: 10.1038/s41578-018-0006-y



Karanam Mithun *et al.*,

21. Mota C, Camarero-Espinosa S, Baker MB, Wieringa P, Moroni L. Bioprinting: From tissue and organ development to *in vitro* models. Chem Rev 2020;120:10547-607.DOI: 10.1021/acs.chemrev.9b00789
22. Skylar-Scott MA, Uzel SGM, Nam LL, Ahrens JH, Truby RL, Damaraju S, et al. Biomanufacturing of organ-specific tissues with high cellular density and embedded vascular channels. Sci Adv 2019;5:eaaw2459.DOI: 10.1126/sciadv.aaw2459
23. Li J, Mooney DJ. Designing hydrogels for controlled drug delivery. Nat Rev Mater 2016;1:16071.DOI: 10.1038/natrevmats.2016.71
24. Gaharwar AK, Singh I, Khademhosseini A. Engineered biomaterials for in situ tissue regeneration. Nat Rev Mater 2020;5:686-705.DOI: 10.1038/s41578-020-0209-x
25. Chhaya MP, Melchels FPW, Holzapfel BM, Baldwin JG, Huttmacher DW. Sustained regeneration of high-volume adipose tissue for breast reconstruction using computer aided design and biomanufacturing. Biomaterials 2015;52:551-60.DOI: 10.1016/j.biomaterials.2015.02.055
26. Sadtler K, Singh A, Wolf MT, Wang X, Pardoll DM, Elisseeff JH. Design, clinical translation and immunological response of biomaterials in regenerative medicine. Nat Rev Mater 2016;1:16040.DOI: 10.1038/natrevmats.2016.40

Table 1. Comparison of natural, synthetic and hybrid polymer systems used in porous biopolymeric gels, highlighting representative polymers, key advantages, major limitations and typical regenerative medicine applications

Category	Representative Polymers	Key Advantages	Major Limitations	Typical Applications
Natural [1,14]	Collagen, Gelatin, Alginate, Chitosan	Intrinsic bioactivity	Limited mechanical strength	Wound healing, cartilage
Synthetic [2,4]	PEG, PVA, Polyacrylamide	Reproducible properties	Poor cell adhesion	Drug delivery, load-bearing
Hybrid [5,7]	Gelatin-PEG, Collagen-PVA	Balanced bioactivity and mechanics	More complex fabrication	Multifunctional scaffolds

Table 2. Comparative assessment of fabrication techniques for porous biopolymeric gels, summarizing pore architecture, mechanical performance, injectability and principal advantages of each processing method

Technique	Typical Pore Structure	Mechanical Performance	Injectability	Key Advantages
Sol-Gel Processing [2,7]	Nano-mesoporous	Moderate	No	High surface area
Cryogelation [8,11]	Interconnected macroporous	High elasticity	Yes	Excellent permeability
Freeze-Drying [14,17]	Sponge-like macroporous	Moderate	No	Simple and versatile
IPN Fabrication [3,6]	Controlled hierarchical	Very high	Very high	Superior toughness
In Situ Gelation [9,11]	Variable	Moderate	Yes	Minimally invasive
3D Bioprinting [17,19]	Precisely defined	Tunable	Yes	Patient-specific design





Karanam Mithun et al.,

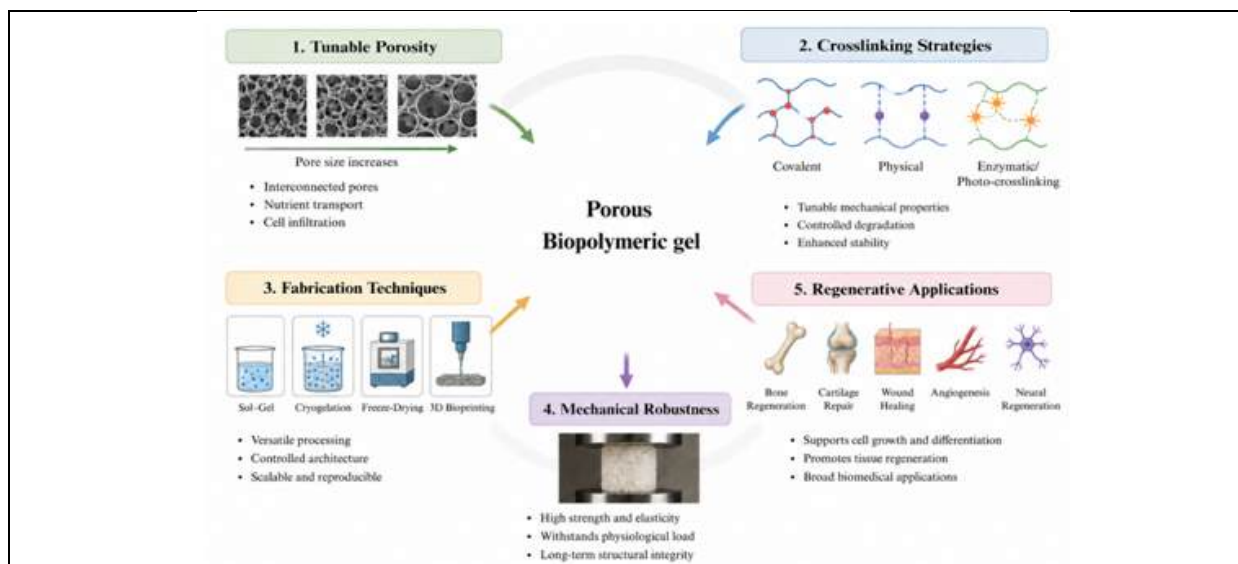


Figure 1. Graphical Abstract

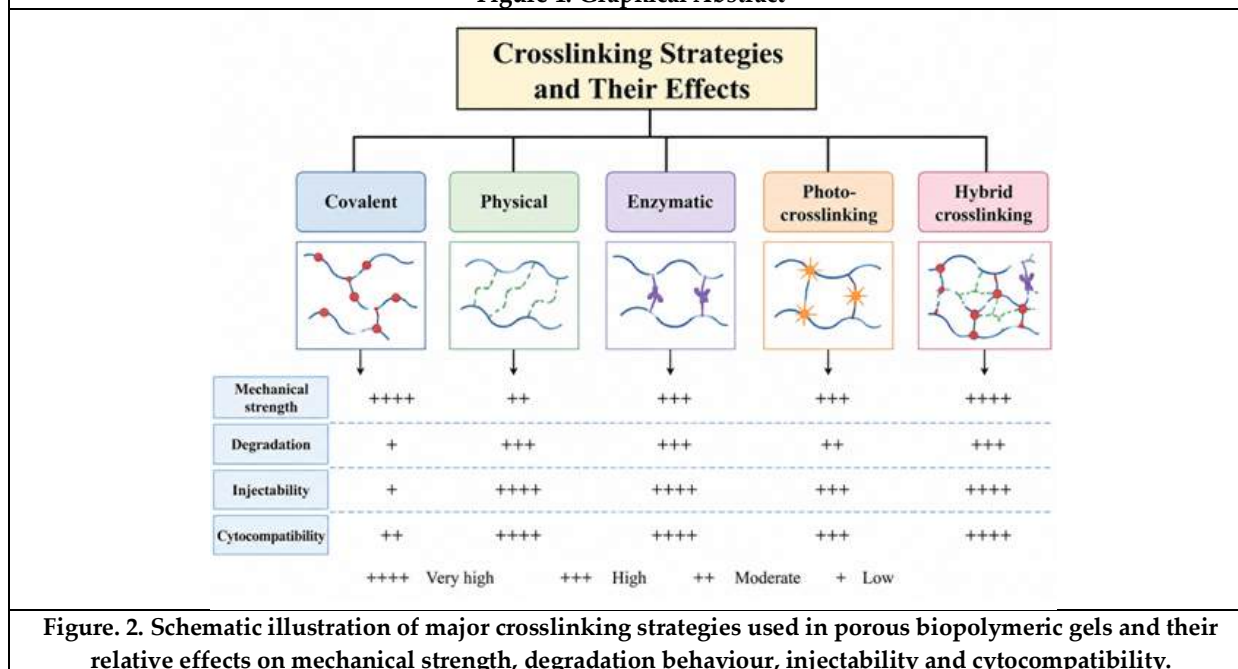


Figure 2. Schematic illustration of major crosslinking strategies used in porous biopolymeric gels and their relative effects on mechanical strength, degradation behaviour, injectability and cytocompatibility.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

The Bengal Florican (*Houbaropsis bengalensis*) : Its Conservation and Habitat Crisis in Southeast Asian Countries

Krishna Ghosh^{1*} and Atreyee Saha²

¹Assistant Professor, Department of Law, Brainware University, Barasat, Kolkata, India

²Student, Department of Law, Brainware University, Barasat, Kolkata, India

Received: 18 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Krishna Ghosh

Assistant Professor,

Department of Law,

Brainware University,

Barasat, Kolkata, India

E.Mail: krishnag232@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The Bengal Florican is one of the world's rarest grassland birds and is now facing a severe risk of extinction across India, Nepal, and Cambodia. The article examines the present conservation status of the species, the reasons behind its rapid population decline, and the measures required for its survival. The study shows that fewer than one thousand Bengal Floricans remain globally, with populations becoming increasingly fragmented and isolated. Nepal has experienced drastic declines, including local extinction in several protected areas, while Cambodia is witnessing rapid habitat destruction due to large-scale irrigated rice cultivation and infrastructure projects. India still retains some stable populations, especially in protected areas such as Manas National Park, where scientific grassland management has produced encouraging conservation outcomes. The article identifies habitat loss and habitat mismanagement as the principal threats to the species. Conversion of natural grasslands into agricultural land, invasion of harmful weeds, uncontrolled burning practices, tourism pressure, grazing, pesticide exposure, and collisions with power lines have collectively reduced breeding success and survival rates. The study further explains the ecological requirements of the Bengal Florican, particularly its dependence on a balanced mosaic of short and tall grasslands for feeding, nesting, shelter, and courtship displays. The paper also evaluates several conservation strategies, including controlled grassland management, community participation, nest protection schemes, environmental education, satellite tracking, and cross-border cooperation among South Asian countries. Although captive breeding is discussed as a possible last-resort strategy, the article emphasises that habitat restoration and community-led conservation remain the most effective long-term solutions. The study concludes that the Bengal Florican is not only an endangered bird but also an important indicator of the health of fragile floodplain grassland ecosystems.



**Krishna Ghosh and Atreyee Saha**

Its disappearance would signal the wider ecological collapse of these habitats and the loss of many associated species.

Keywords: Bengal Florican, Grassland Conservation, Habitat Loss, Endangered Species, Community-Based Conservation, Floodplain Ecosystem

INTRODUCTION

A Global Perspective on a Critically Endangered Bustard

Global Conservation Status and National Legal Protections

The Bengal Florican is a rare bird that is currently in grave danger. It is listed as Critically Endangered, meaning its population is very small and dropping. Today, there are only about 250 to 999 of these birds left across the Indian subcontinent and Southeast Asia. To protect the species from being traded, international laws like CITES place it under strict protection in Appendix I (Poudyal et al., 2008). The bird is also fiercely guarded at the national level. In Nepal, it is one of just nine birds given a special "Protected" status for urgent care. In India, severe penalties exist for harming the bird or its grassland home (Thakur et al., 2024). These laws guide conservation efforts, like Nepal's 2024–2033 action plan, to save the bird from vanishing forever.

Global Taxonomy and Population Fragility

The Bengal Florican is actually divided into two distinct groups based on location. The first group, *H. b. bengalensis*, lives in scattered grasslands in northern India and southern Nepal (Thakur et al., 2024). The second group, *H. b. blandini*, survives mostly in the flooded grasslands of Cambodia, as populations in Vietnam are already gone (Gray et al., 2009). The total numbers remain incredibly low (Poudyal et al., 2008). Roughly 350 to 400 stay in India, fewer than 100 in Nepal, and about 200 in Cambodia. They live in small, isolated pockets separated by human activity (Mahood et al., 2019). In Southeast Asia, survival is even harder because birds leave safe breeding areas for unprotected fields during the year, facing dangers from hunters and farming.

The Overarching Crisis: Habitat Modification and Loss

The biggest crisis facing the Bengal Florican is the rapid destruction of its natural home (Pokharel, 2025). This bird desperately needs open grasslands to survive (Thakur et al., 2024). In Southeast Asia, people are turning grassy areas into dry-season rice fields. In Cambodia, dams and reservoirs caused 28 percent of the bird's habitat to vanish in just 27 months (Packman et al., 2014). In India and Nepal, the problem is slightly different. Open grass is slowly growing into bushes and trees, ruining the clear ground the male birds need (Poudyal et al., 2008; Thakur et al., 2024). Additionally, dangerous foreign weeds are pushing out native plants. Even inside protected nature parks, people mistakenly burn or cut grass at the wrong times, which destroys nests. Human activities like gathering wood and tourism add more stress (Inskipp et al., 2024). Ultimately, the Bengal Florican is an important warning sign. If this bird disappears, it tells us that the floodplains are failing and other wildlife will follow (Pokharel, 2025).

Regional Status and Population Trends

Nepal: A Precipitous Decline Toward Extirpation

In Nepal, the Bengal Florican is Critically Endangered, with fewer than 100 birds left scattered across disconnected protected areas (Inskipp et al., 2024). The population is dropping fast across its national parks. In Shuklaphanta National Park, numbers crashed by 93% between 1982 and early 2024, dropping from 15 birds to just 1, though a wider search later found 5 (Inskipp et al., 2024). Chitwan National Park saw a 75% drop since 1982; despite a brief increase in 2012, no birds were found in the 2024–2025 survey, showing local extinction (Pokharel, 2025). Koshi Tappu Wildlife Reserve holds Nepal's largest remaining group, but numbers still fell 55% from 47 birds in 2012 to 21



**Krishna Ghosh and Atreyee Saha**

in 2022 (Baral et al., 2013), with 32 counted over a larger area in 2024 (Inskipp et al., 2024). Sadly, the bird is completely gone from Bardia National Park. While there were 9 birds in 1982 and just 1 in 2007 (Poudyal et al., 2008), no birds have been confirmed there since 2010 despite multiple surveys (Inskipp et al., 2024).

India: Success Stories Amidst General Decline

In India, there is still hope for the Bengal Florican, with about 350 to 400 birds surviving in the floodplains and grasslands (Collar et al., 2017; Thakur et al., 2024). Through careful conservation, some areas are seeing success. Manas National Park is a great example of population growth. By burning old grass in February before nesting season, fresh shoots grow back perfectly for the birds. This effort helped numbers rise to 50 territorial males and 17 females by 2021 (Brahma et al., 2009), with 20 males living safely at the community-managed Kokilabari Agriculture Farm (Thakur et al., 2024). D'Ering Wildlife Sanctuary is also a top priority. It is uniquely managed for the bird rather than large grazing animals like rhinos (Mahood et al., 2019). This special focus maintains the perfect mix of short and tall grass needed for the floricans and other important grassland birds (Rahmani et al., 2016b; Mahood et al., 2019).

Cambodia: Industrial-Scale Habitat Loss

The situation in Cambodia is very critical for the Indochinese bird, which is already extinct in Vietnam and southern Cambodia (Collar et al., 2017). Today, these birds only survive in one single area: the seasonally flooded grasslands around Tonle Sap in central Cambodia (Gray et al., 2009). Unfortunately, this important habitat is being destroyed at an industrial scale. The land is shrinking so quickly that experts warn this unique group of birds could completely disappear within the next ten years if the rapid destruction continues (Packman et al., 2014).

Statistical Trends: The Precipitous Decline of Displaying Males

Comprehensive counts made between 2005 and 2012 show how hard the fall has been in Cambodia. In 2012, the number of displaying males was down by 44–64% from what had been recorded in 2005–2007. Where there were once 416 displaying males in 2005, only 216 were counted in 2012 (Packman et al., 2014; Gray et al., 2009). The drop did not stop there. By 2018, the whole population was thought to be about 138 birds, a steady loss of more than ten percent each year (Mahood et al., 2019). The figures are plain, and they tell of a bird slipping away year by year.

The Primary Driver: Industrial-Scale Irrigated Rice Cultivation

The bird faces many pressures, but one stands above the rest. Its biggest threat is the loss of open grasslands because of farming, dams, and human activities (Pokharel, 2025). In Cambodia, many grasslands were changed into rice fields, causing major habitat loss (Packman et al., 2014). In India and Nepal, bushes, trees, and harmful weeds are damaging its habitat (Thakur et al., 2024). Wrong grass cutting and burning also destroy nests (Inskipp et al., 2024). The bird is protected by strict laws, but its future is still at risk.

Ecological Requirements and Breeding Biology**Alluvial Grassland Specialisation**

The Bengal Florican strictly needs lowland river grasslands to survive, or it cannot live at all (Gray et al., 2009). It prefers open areas filled with Siru grass, formally known as *Imperata cylindrica* (Pokharel, 2025). When this specific grass is cut or burned, it grows back short at about ten to fifty centimeters, creating the perfect open space for the birds to find food and for the males to display to the females (Thakur et al., 2024). However, short grass is not enough on its own; the birds also need a mix of tall grass over a meter high to provide shade from the hot sun and safe cover for their nests (Pokharel, 2025). When these important grasslands are ploughed for farming or become overgrown with bushes, the bird population drops quickly and sharply (BirdLife International, 2024).

The "Sward Mosaic" Requirement

The Bengal Florican requires a "sward mosaic," which means a perfect mix of short and tall grasses living right next to each other across the plains. Short grasses are essential for the birds to feed on insects and for the males to perform



**Krishna Ghosh and Atreyee Saha**

their jumping dances to attract mates. Because the grass is kept short, the black and white males can easily be seen from a distance. Meanwhile, the tall, strong grasses are used by the birds to hide from dangerous predators and the hot midday sun. Females heavily rely on this thick, tall cover to hide their eggs safely on the ground. If land managers cut all the grass to the same height or let wild trees take over, this vital living pattern breaks down.

Breeding Dynamics: The Exploded Lek System

These birds have a unique mating style called an "exploded lek system," where each male claims his own wide, open space roughly a kilometer away from any other males. During the breeding season from mid-March to June, males perform jumping dances up to three meters in the air. While jumping, they puff out their black chests, flash their white wings, and make loud booming and clapping sounds that travel far. The brown females stay quietly hidden in the tall grass most of the time, only briefly coming out to the short grass to watch a male. The males fiercely protect their chosen dancing spots, aggressively fighting off any rivals that come near.

Dietary and Foraging Habits

The Bengal Florican eats both plants and animals, mainly searching for food in the short grass areas during the cool mornings and late afternoons. Its daily diet includes fresh plant shoots, flowers, and many insects like grasshoppers and beetles. During the hottest parts of the day, the bird stops eating and slips deep into the tall grass to rest in the shade. How humans manage the land directly affects their food supply. Burning the grass too late in the year kills off the important insects that the adults and chicks need to eat. However, early burning before the breeding season helps fresh plants grow and keeps the ground perfectly open for feeding.

Critical Threats to Survival**Habitat Conversion and Management Issues**

The Bengal Florican's survival is in extreme danger because its grassy homes are being turned into farms or poorly managed. In Cambodia, building dams to support large dry-season rice farms destroyed a massive amount of grassland very quickly (Packman et al., 2014; Gray et al., 2009). In India and Nepal, farming near places like Chitwan National Park and the Kokilabari Agriculture Farm damages native plants and breaks up the wide areas the birds need to live (Pokharel, 2025; Thakur et al., 2024). Even without farming, open grasslands in places like Bardia National Park are naturally growing into thick bushes and trees, which ruins the clear, open views male birds need to attract mates (Thakur et al., 2024; Poudyal et al., 2008). Harmful foreign weeds are also taking over, crowding out the native plants the birds rely on for food and shelter in areas like Manas National Park (Inskipp et al., 2024; Thakur et al., 2024). Finally, when park managers burn the grass too late in the dry season (March to May), the fires kill nesting birds and chicks; to keep them safe, all burning must be finished before mid-February (Inskipp et al., 2024).

Human Disturbance and Infrastructure

These shy birds are severely stressed by human activities and machines, especially during their breeding season (Inskipp et al., 2024; Pokharel, 2025). Growing tourism in Nepal's Chitwan and Bardia National Parks has brought noisy jeep roads and walking trails straight through their habitats. When locals enter the parks to collect wood or let their cattle graze in places like the Koshi Tappu Wildlife Reserve during the breeding months, the birds are scared away and their nests fail (Inskipp et al., 2024; Pokharel, 2025). Furthermore, deadly power lines are a major threat. When the birds fly up to thirty kilometers outside of protected zones to find food in farmlands, they often crash into these hard-to-see wires and die (Inskipp et al., 2024; Mahood et al., 2019; Pokharel, 2025). This is a severe problem in Cambodia's Stoung-Chikreang Bengal Florican Conservation Area (Mahood et al., 2021). To save the florican, roads must be moved away from their homes and power lines must be made safe (Inskipp et al., 2024).

Biological and Chemical Risks

The Bengal Florican faces natural predators and harmful chemicals. Because they lay their eggs on the ground, their nests are easily eaten by growing numbers of jackals and mongooses in parks like Bardia and Koshi Tappu (Inskipp



**Krishna Ghosh and Atreyee Saha**

et al., 2024; Poudyal et al., 2008). In Cambodia, pet and stray village dogs are a leading cause of death, easily hunting the birds and destroying nests (Mahood et al., 2021). Crows and other birds also steal eggs from above, especially if late fires burn away hiding spots or humans scare the parents off the nest (Inskipp et al., 2024; Thakur et al., 2024). Additionally, when the birds leave safe areas to feed in farmlands, like India's Kokilabari Agriculture Farm, they are exposed to dangerous farming chemicals (Inskipp et al., 2024; Mahood et al., 2019; Thakur et al., 2024). These pesticides can poison the birds directly or kill off the grasshoppers and beetles they eat, leaving the adults weak and the chicks starving (Inskipp et al., 2024).

Conservation Strategies and Recommendations**Optimised Habitat Management**

To protect the Bengal Florican, grasslands must be managed carefully by cutting and burning grass before the breeding season begins (Inskipp et al., 2024; Mahood et al., 2019; Thakur et al., 2024). In drier areas, this work should be finished by mid-February, while places with taller grass can wait until late February. Burning later, from March to May, destroys nests, kills eggs, and scares away males (Inskipp et al., 2024). It is also highly important to maintain a mix of tall and short grass, leaving some tall patches over a meter high so female birds can hide and safely build nests on the ground (DNPWC, 2024; Inskipp et al., 2024; Thakur et al., 2024). When grass is burned, the leftover ash should stay to nourish the soil and help fresh green shoots grow. Finally, the land must be closely watched to stop dangerous weeds like *Mikania micrantha* and *Parthenium hysterophorus* from taking over the clear ground (Inskipp et al., 2024).

Community-Based Initiatives

Because these birds often move into village fields after breeding, conservation must involve local lands (Jha et al., 2018). Under Promoting Multi-Year Crops for Habitat Stability, farmers near the borders of parks in Nepal and India are encouraged to plant crops that last for several years, such as sugarcane, lemongrass, and mentha (Thakur et al., 2024; Jha et al., 2018). These crops do not require constant ploughing, which reduces machine use and gives the birds a steady, safe place to hide and feed (Inskipp et al., 2024). Additionally, through Incentive-Led Nest Protection Schemes in Cambodia, villagers receive money for finding and protecting nests instead of harming them (Gray et al., 2009; Pokharel, 2025). Using funds from bird-watching tours, locals get one payment for reporting a nest and a bigger reward if the eggs hatch safely. This simple trade stops hunting and prevents nests from being crushed by cattle or tractors, encouraging the community to actively protect the birds (Pal et al., 2024).

Education and Stakeholder Engagement

The Bengal Florican cannot endure on grassland work alone. It must also live in the minds of people. Because most students did not know the Bengal Florican existed or was in danger, conservationists started teaching locals to build deep awareness and care for the bird (Pokharel, 2025).

School-Based Initiatives: Clubs and Creative Arts

Programs in eleven schools created Bengal Florican Clubs. Through fun activities like drawing contests, quizzes, and face painting, more than eighty percent of students successfully learned to recognise the bird and its needs (Pal et al., 2024; Pokharel, 2025).

Community Engagement through Storytelling

Education also moved into the villages. Simple community dramas were performed at local homestays to show the bird's struggles with fires and farming, successfully bringing hundreds of farmers and fishers together to discuss solutions (Pokharel, 2025; Pal et al., 2024).

Educational Materials and Emotional Connection

**Krishna Ghosh and Atreyee Saha**

To create a lasting emotional bond, children's books, bookmarks, and posters were handed out to locals and guides. Keeping the bird's image visible helps ensure it is remembered and protected by the community (Inskipp et al., 2024; Pal et al., 2024). In such ways, the bird becomes more than a name. It becomes something known. And what is known stands a better chance of being kept.

Ex-Situ Conservation (Captive Breeding)

Captive breeding is considered a risky and expensive last resort to save the Bengal Florican. The goal is to build a safe, captive population that can eventually be returned to the wild (Mahood et al., 2021). However, raising birds in enclosures can artificially change their behavior, physical shape, and genetics over time.

Cambodia: Initiation of Egg Harvesting

Because the Cambodian birds are disappearing so fast, a special program began at the Angkor Centre for Conservation of Biodiversity. Since capturing adult birds is too dangerous, the team focused on collecting eggs instead (Mahood et al., 2021). In 2019, they gathered nine eggs from the wild; five hatched, but two chicks died for unknown reasons (Mahood et al., 2021). Experts warn it could take twenty to thirty years to raise enough birds to release, and by then, their natural grassland homes might be completely gone.

Nepal: Feasibility Evaluation

In Nepal, conservationists are being very cautious. The Bengal Florican Conservation Action Plan for Nepal 2024–2033 recommends closely watching the results of Cambodia's program before trying it themselves (Inskipp et al., 2024; DNPWC, 2024). Experts worry that actively searching for nests to collect eggs will scare and harm the highly sensitive wild birds. For now, Nepal is choosing to focus its efforts on protecting the natural grasslands so the birds can survive in the wild without fences.

Transboundary Research and Monitoring

The survival of the Bengal Florican depends on teamwork between different countries because these birds often fly between safe parks, busy farms, and even across national borders. To protect them properly, countries must work as one and share the important information they learn (Inskipp et al., 2024; Mahood et al., 2019).

The Need for Satellite Tracking and Migration Mapping

For a large part of the year, these birds live outside of their safe breeding zones, so experts need to know exactly where they travel to keep them from being lost (Jha et al., 2018; Mahood et al., 2019). Satellite tracking in Nepal and India shows that after nesting, the birds fly up to thirty kilometers into open village farmlands and even cross the border from Nepal into India (Inskipp et al., 2024; Pokharel, 2025). In Southeast Asia, more tracking work is needed to map how Cambodian birds move into dry forests (Gray et al., 2009; Packman et al., 2014). Mapping these travel paths is extremely important because it helps conservationists find hidden hazards, like deadly low power lines and farming fields heavily sprayed with pesticides, before more birds are harmed.

Species Working Groups and Sharing Best Practices

Instead of keeping knowledge scattered, countries like Nepal, India, and Cambodia need to create dedicated working groups to share their best conservation ideas and track their success. By sharing what works well, they can use successful fire management techniques from India's Manas National Park to help Shuklaphanta and Chitwan National Parks in Nepal, or use farming lessons from one part of Cambodia to save birds in another (Mahood et al., 2019; Thakur et al., 2024). Joining efforts like this saves valuable time and money from being wasted on repeating the same mistakes, ensuring that funds are spent effectively across the bird's entire natural home.

Conclusion: The Indicator of Ecosystem Health

The Bengal Florican is more than a rare bird. It is a sign. Where it stands and displays, the lowland alluvial grassland still holds together. Where it vanishes, the land is already failing. Its presence tells of balance. Its absence tells of loss.





Krishna Ghosh and Atreyee Saha

The forces that drive it down do not stop with one species. They move through the floodplains and They share the floodplains with other species —the Pygmy Hog, the Hispid Hare, the Hog Deer. All depend on the same grass, the same open ground. When that ground is broken, they fall in turn. To steady the future, action must be plain and swift. National Conservation Action Plans, such as Nepal's 2024–2033 strategy, set a course built on habitat restoration and work led by communities. In Southeast Asia, the grasslands must be guarded by stronger law. Bengal Florican Conservation Areas must stand firm under government decree, and the spread of irrigated rice must be checked. Both subspecies—*H. b. bengalensis* in South Asia and *H. b. blandini* in Cambodia—hang in the balance. Their survival calls for work across borders. Countries must share what they know. Satellite tracking must mark the corridors the birds follow. Fire must be managed with care. Farming must bend where it can to spare the grass. If this is not done, the silence that follows the florican's last display will mean more than the loss of a single bustard. It will mark the wider collapse of the fragile grasslands it has long stood to represent.

REFERENCES

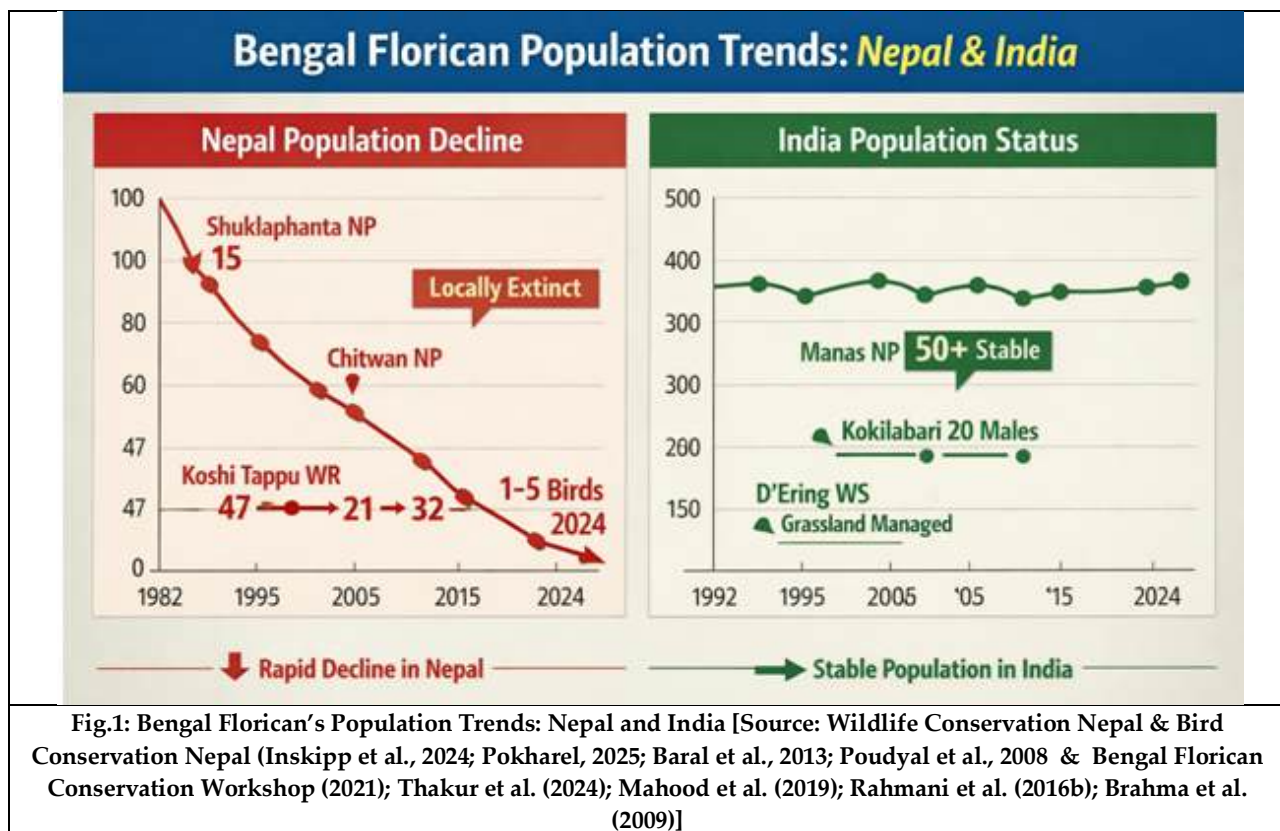
1. Mahood, S. P., Jha, R. R., Rahmani, A. R., Thakuri, J. J., Chamnan, H., Bhargava, R., ... & Garnett, S. T. (2019). A systematic expert-based assessment of progress and priorities for conservation of the Bengal Florican *Houbaropsis bengalensis*. *Conservation Science and Practice*, 1(12), e121.
2. Inskipp C, Collar NJ. The Bengal florican: its conservation in Nepal. *Oryx*. 1984;18(1):30-35. doi:10.1017/S0030605300018561
3. PACKMAN CE, SHOWLER DA, COLLAR NJ, et al. Rapid decline of the largest remaining population of Bengal Florican *Houbaropsis bengalensis* and recommendations for its conservation. *Bird Conservation International*. 2014;24(4):429-437. doi:10.1017/S0959270913000567
4. GRAY TNE, COLLAR NJ, DAVIDSON PJA, et al. Distribution, status and conservation of the Bengal Florican *Houbaropsis bengalensis* in Cambodia. *Bird Conservation International*. 2009;19(1):1-14. doi:10.1017/S095927090800765X
5. Thakur, M., Kalita, J., Brahma, N., Rajbongshi, K., Bhattacharyya, K., Sarmah, A. C., ... & Lahkar, B. P. (2024). Current conservation status of Bengal Florican *Houbaropsis bengalensis* in Manas National Park, Assam, India. *Journal of Threatened Taxa*, 16(7), 25507-25515.
6. Inskipp, C., Poudyal, L. P., Chaudhary, D. B., Shahi, R., & Baral, H. S. (2024). Overview of status and conservation of Bengal florican *Houbaropsis bengalensis* in Nepal. *Nepalese Journal of Zoology*, 8(2), 30–39. <https://doi.org/10.3126/njz.v8i2.74929>
7. Pal A, Regmi T, Shakya S, Sah G. Conserving the Bengal florican in Nepal: a collaborative education and awareness campaign. *Oryx*. 2024;58(6):695-696. doi:10.1017/S0030605324001157
8. Poudyal, L. P., Singh, P. B., & Maharjan, S. (2008). The decline of Bengal Florican *Houbaropsis bengalensis* in Nepal. *Danphe*, 17(1), 4-6.
9. Poudyal, L. P., Singh, P. B., & Maharjan, S. U. J. A. N. (2008). Bengal Florican *Houbaropsis bengalensis* in Nepal: an update. *Birding Asia*, 10, 43-47.
10. National Parks and Wildlife Conservation Act 2029 (1973)[Nepal]
11. Wildlife Protection Act, 1972
12. Convention on International Trade in Endangered Species of Wild Fauna and Flora. <https://cites.org/eng/disc/text.php>
13. San, S., Thi, S., Eang, S., Son, V., & Chhin, S. (2022). The Effectiveness of Bengal florican (*Houbaropsis bengalensis*) Conservation in Cambodia. *Insight: Cambodia Journal of Basic and Applied Research*, 4(2), 16-37.
14. Chowdhary, C. L., Chaudhary, G., & Majhi, N. L. (2025). Restoring the critically endangered Bengal Florican (*Houbaropsis bengalensis*) population in Koshi Tappu wildlife reserve and buffer Zone. *Sustainability and Biodiversity Conservation*, 4(2), 89-95.
15. Packman, C. (2012). *Seasonal landscape use and conservation of a critically endangered bustard: Bengal florican in Cambodia* (Doctoral dissertation, University of East Anglia).





Krishna Ghosh and Atreyee Saha

16. Mahood, S. P. (2019). *Conservation of a Very Rare Species in a Rapidly Changing Context: Cambodia's Bengal Florican* (Doctoral dissertation, Charles Darwin University (Australia)).
17. Prasai, R., Kafley, H., Upadhaya, S., Thapa, S., Shrestha, P., Dudley, A., & Timilsina, Y. P. (2021). Population status and distribution of the critically endangered Bengal florican *Houbaropsis bengalensis* in the grassland of Koshi Tappu Wildlife Reserve, Nepal. *Journal of Threatened Taxa*, 13(9), 19293-19301.
18. Baral, H. S., Ram, A. K., Chaudhary, B., Basnet, S., Chaudhary, H., Giri, T. R., & Chaudhary, D. (2012). Conservation status of Bengal Florican *Houbaropsis bengalensis* (Gmelin, 1789)(Gruiformes: Otidae) in Koshi Tappu Wildlife Reserve and adjoining areas, eastern Nepal. *Journal of Threatened Taxa*, 4(3), 2464-2469.
19. Baral, N. A. B. I. N., Timilsina, N. I. L. E. S. H., & Tamang, B. I. J. A. Y. (2003). Status of Bengal florican *Houbaropsis bengalensis* in Nepal. *Forktail*, 51-56.
20. Chakdar, B., Jathar, G. A., & Das, J. P. (2002). Bengal Florican, *Houbaropsis bengalensis*.
21. Pokharel, A. (2025). Wings of hope: Population monitoring and conservation of critically endangered Bengal Florican in Chitwan National Park, Nepal. Humanitarian and Biodiversity Conservation Society.





Krishna Ghosh and Atreyee Saha

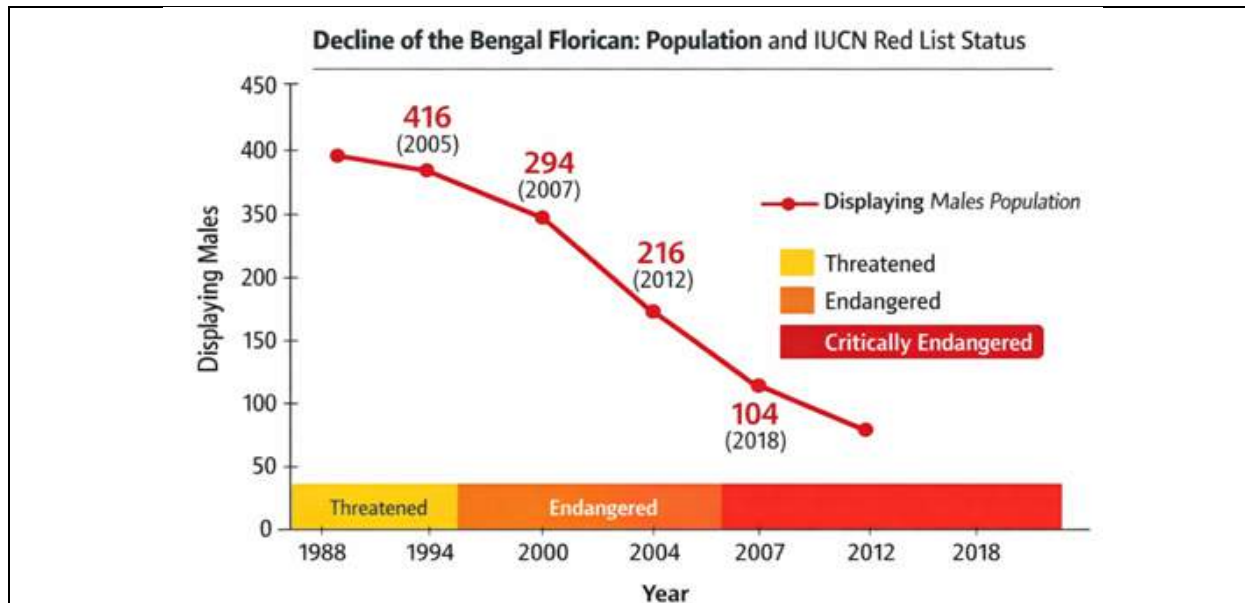


Fig.2: Bengal Florican's population counts with the IUCN Red List status changes across 1988–2018. (Data from Gray et al. (2009), Packman et al. (2014), Mahood et al. (2019)).

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Formulation and Evaluation of Antimicrobial Herbal Soap Containing *Chlorophytum Borivilianum* (Safed Musli) Extract

Hitesh A. Patil^{1*}, Om C. Patil¹, Rupesh R. Chaure¹, Kishor S. Rath², Vaishali D. Shewale³

¹Research Student, N.T.V.S Institute of Pharmacy, Nandurbar, Maharashtra, India

²Professor, Department of Pharmaceutics, N.T.V.S Institute of Pharmacy, Nandurbar, Maharashtra, India

³Principal, Department of Pharmacognosy, N.T.V.S Institute of Pharmacy, Nandurbar, Maharashtra, India

Received: 21 Mar 2026

Revised: 19 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

Hitesh A. Patil

Research Student,

N.T.V.S Institute of Pharmacy,

Nandurbar, Maharashtra, India

E.Mail: hiteshpatil2064@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

With increasing awareness about the harmful effects of chemical-based soaps, there is a growing demand for natural and skin-friendly alternatives. This study focuses on the formulation and evaluation of a herbal soap using *Chlorophytum borivilianum* (Safed Musli), A well-known medicinal plant in Ayurveda recognized for its rejuvenating and therapeutic properties. The Safed Musli extract was prepared using the Soxhlet extraction method and subjected to phytochemical screening, which confirmed the presence of important bioactive compounds such as saponins, alkaloids, flavonoids, and steroids. These compounds are known for their antimicrobial, antioxidant, and moisturizing effects. The antimicrobial activity of the extract was tested against common skin pathogens like *Escherichia coli* and *Staphylococcus aureus*, showing effective inhibition. The herbal soap was formulated using a stearic acid-based soap matrix along with natural ingredients such as coconut oil, glycerin, and propylene glycol. The prepared soap was evaluated for various parameters including pH, foam stability, Total Fatty Matter (TFM), moisture content, and skin irritation. The results showed that the soap had a near skin-friendly pH, good foaming ability, high TFM (indicating good quality), and no signs of irritation on the skin. Additionally, antimicrobial testing using the thumb impression method confirmed a significant reduction in microbial load after use. Stability studies also indicated that the formulation remained stable over time. In conclusion, the Safed Musli herbal soap proved to be a safe, effective, and natural alternative to synthetic soaps, offering both cleansing and antimicrobial benefits.

Keywords: saponins, alkaloids, flavonoids, and steroids, antimicrobial benefits, natural ingredients,





Hitesh A. Patil et al.,

INTRODUCTION

In the evolving landscape of natural healthcare, phytomedicine has remained a cornerstone of therapeutic interventions for centuries. While many botanical species are recognized for their systemic benefits, *Chlorophytum borivillianum*, popularly known as Safed Musli, stands out as a high-value medicinal herb native to the tropical wet forests of India. Historically revered in Ayurvedic literature as a "Rasayana" or rejuvenator, this perennial herb is rich in bioactive constituents, primarily steroidal saponins, polysaccharides, alkaloids, and proteins. Recent pharmacological investigations have highlighted its diverse profile, ranging from immunomodulatory and antioxidant activities to potential applications in managing skin-related oxidative stress and cellular regeneration [1].

Morphology

Safed musli is a tiny annual herb that grows well in tropical and sub-tropical climates with altitudes upto 1500m. It grows to a maximum height of 1.5 ft. Tubers can grow upto a depth of 10 inches.

Root

Roots pale brown to white colour with characteristic odour and are tasteless in nature. Root tubers are fleshy, fascicled and directly originate from the stem disc devoid of any fibrous structure and distinguished it from other species of *Chlorophytum* genus. The shape of tubers were cylindrical, the thickness being on the average 0.9 cm and the length 8cm. The number of tubers varies from plant to plant and on an average 5-30 tubers/ plant are observed and slightly tapering towards lower side look like pestle.

Leaf

It has 6 -13 radical leaves spirally imbricate at the base, sessile in nature, lanceolate and linear or ovate with acute apex and slightly narrowed at the base and less than 30cm long. The leaves spread horizontally, with smooth surfaces, wavy margins and parallel venation.

Flowers and fruit:

Flowers of *C. borivillianum* (Figure No.1) are small, white, bracteate, pedicillate, zygomorphic usually arranged in alternate clusters, each cluster comprising of 3 flowers. The flower clusters are dense on the upper part of the scape; bracts are linear, papery and purplish, 1.0 - 10.5cms long; pedicel whitish and 6 -10 mm long. It bears green to yellow coloured fruit which is almost equal in length and breadth. The seed is very small, black and enclosed in the holes.

The integrity of the skin barrier is frequently compromised by environmental stressors, leading to infections, inflammatory rashes, and chronic irritation. In this context, herbal soaps formulated with bioactive plant extracts offer a synergistic approach to skin health, providing antimicrobial protection alongside deep nourishment. Unlike conventional synthetic cleansers, herbal formulations leverage the natural mucilage and saponin content of plants like *C. borivillianum* to soothe sensitive and dry skin types. However, the commercial market is often saturated with soaps that utilize harsh surfactants and maintain high alkalinity, which disrupts the skin's natural acid mantle, leading to xerosis, pruritus, and contact dermatitis [2]. This study aims to bridge the gap between traditional ethnobotany and modern dermo-cosmetics by evaluating the comparative efficacy of available commercial soaps against a specialized Safed Musli-based herbal formulation. A primary focus of this research is the development of a soap with a neutral pH, ensuring that the cleansing process does not strip the skin of essential lipids. By optimizing pH neutralization and harnessing the moisturizing properties of *Chlorophytum borivillianum*, this formulation intends to provide a therapeutic alternative that promotes long-term dermatological health and prevents common integumentary diseases [3, 4].



Hitesh A. Patil *et al.*,

Objective of Work

- **Extraction of Bioactive Compounds:** To perform extraction of *Chlorophytum borivilianum* using the Soxhlet method in order to obtain a concentrated extract rich in saponins and other active constituents
- **Formulation Development:** To develop a potent, nutrient-rich herbal soap by integrating the bioactive saponins of Safed Musli with essential oils, ensuring an eco-friendly formulation that provides both effective cleansing and skin-nourishing benefits.
- **Antimicrobial Assessment:** To evaluate the efficacy of the formulated soap against common skin pathogens (bacteria and fungi) present in the environment, ensuring its potency in preventing infectious diseases and maintaining skin barrier integrity.
- **Physicochemical Evaluation:** To standardize the formulation by assessing parameters such as pH neutrality, foaming height, moisture content.
- **Ensure Safety and Skin Compatibility of the Formulation:** To assess the formulated herbal soap for skin irritation and ensure that it is safe for regular use without causing any harmful effects.
- **To study the stability of the formulated herbal soap:** To evaluate the stability of the soap under different storage conditions to ensure its quality, effectiveness, and shelf-life over time.
- **To compare herbal soap with conventional soaps:** To analyze and highlight the advantages of the Safed Musli herbal soap over synthetic soaps in terms of safety, effectiveness, and skin-friendliness.

MATERIALS AND METHODS

Plan of Work

- **Collection and Authentication**
 - Procurement of high-quality roots (tubers) of *Chlorophytum borivilianum*.
 - Authentication of the plant material by a certified botanist or recognized herbarium.
- **Extraction and Phytochemical Screening**
 - **Processing:** Cleaning, drying, and grinding of the tubers to obtain a fine crude drug powder.
 - **Extraction:** Cold maceration or **Soxhlet extraction** using solvents of varying polarity (e.g., Ethanol, Methanol, and Aqueous) to ensure maximum recovery of saponins.
 - **Phytochemical Testing:** Qualitative screening of the extracts for alkaloids, glycosides, flavonoids, and specifically **saponins (Foam test)**.
 - **Antimicrobial Evaluation:** Determining the **Zone of Inhibition (ZOI)** against common skin pathogens like *Staphylococcus aureus* (Bacteria) and *Candida albicans* (Fungi).
- **Formulation and Development**
 - Selection of an optimized soap base (Stearic acid-based) and natural emollients.
 - Incorporation of *Chlorophytum borivilianum* extract into the formulation at varying concentrations.
 - Addition of essential oils for aroma and synergistic antimicrobial effects.
 - Finalizing the cold-process or melt-and-pour methodology to ensure heat-sensitive bioactives remain intact.
- **Evaluation Parameters of Formulated Herbal Soap**

To ensure the safety and efficacy of the Safed Musli soap, the following parameters will be evaluated:

 - **Physical Parameters:** Organoleptic properties (color, odor, clarity) and texture.
 - **Chemical Analysis:**
 - Determination of pH (aiming for skin-neutrality).
 - Total Fatty Matter (TFM) determination.



Hitesh A. Patil *et al.*,

- Percentage of Free Alkali and Alcohol insoluble matter.
- Saponification Value and Moisture content.
- **Performance Tests:**
 - Foam formation and Foam retention time.
 - Dirt dispersion and cleansing efficiency.
- **Biological & Safety Tests:**
 - Skin Irritation Test (Patch test on volunteers or animal models as per ethics).
 - Thumb Impression Method (to check for microbial load reduction).
- **Stability Studies:** Accelerated stability studies as per ICH guidelines (monitoring changes in pH and physical state at varying temperatures).

Extraction and Extract Tests

- **Extraction Of *Chlorophytum borivilianum*:**

The tubers of *Chlorophytum borivilianum* were sourced from an authenticated supplier, washed, shade-dried, and pulverized into a coarse powder. The extraction was carried out using the **Soxhlet** extraction method. The crude drug powder was packed into a thimble and extracted using Ethanol as the solvent in a ratio of 1:10 [drug (g) : solvent (ml)]. The process was continued for 10-12 cycles to ensure complete recovery of bioactive saponins. The resulting extract was filtered and concentrated using a rotary evaporator [5].

- **Phytochemical Testing**

Phytochemical screening of the *Chlorophytum borivilianum* extract was performed using different solvents (Water, Ethanol, and n-hexane) to identify the following bioactive constituents [5, 6]:

➤ **Test for Saponins (Foam Test):** 0.5 mL of the extract was shaken vigorously with 2 mL of distilled water. Formation of a stable, honeycomb-like froth persistent for 15 minutes confirmed the presence of saponins.

➤ **Test for Carbohydrates (Molisch's Test):**

0.5 mL of crude extract was mixed with 2 mL of Molisch's reagent. 2 mL of concentrated H_2SO_4 was added carefully along the side of the test tube. A violet ring at the junction indicates carbohydrates.

➤ **Test for Flavonoids (NH_3 Test):** 2 mL of extract was mixed with 5 mL of dilute ammonia solution, followed by 1 mL of concentrated H_2SO_4 . A yellow coloration was observed.

➤ **Test for Tannins:**

2 mL of diluted extract was mixed with 3-4 drops of 10% FeCl_3 solution. A brownish-green precipitate was noted.

➤ **Test for Glycosides (Keller-Kilani Test):**

0.5 mL of extract, 2 mL of glacial acetic acid with 2-3 drops of 2% FeCl_3 , and 2 mL of concentrated H_2SO_4 were added. A brown ring at the interface indicates glycosides.

➤ **Test for Alkaloids (Mayer's Test):**

2 mL extract was mixed with 1 mL of Mayer's reagent. Formation of a cream-colored precipitate indicates alkaloids.

➤ **Test for Phenols:**

1 mL of crude extract was mixed with 2 mL of alcohol and 2-3 drops of ferric chloride solution.

➤ **Test for Terpenoids:**

2 mL of extract was added to 2 mL chloroform and evaporated to dryness; 2 mL of concentrated H_2SO_4 was added and heated for 2 minutes.

➤ **Test for Steroids:**

2 mL of chloroform and 2 mL of extract were mixed with 2 mL of concentrated H_2SO_4 and acetic acid. A color change indicates the presence of steroidal saponins.

➤ **Test for Proteins (Ninhydrin Test):**

2 mL of crude extract was mixed with 2 mL of 0.2% solution of Ninhydrin. A violet/purple color confirms proteins.



Hitesh A. Patil *et al.*,

Antimicrobial Test (Zone of Inhibition)

The antimicrobial study of the ethanolic extract of *Chlorophytum borivillianum* was performed using the Agar Well Diffusion technique. Mueller-Hinton Agar (for bacteria) and Sabouraud Dextrose Agar (for fungi) were used for plate preparation. The plates were inoculated and incubated for 24 hours at 37°C. The results showed significant antimicrobial potency due to the presence of steroidal saponins. The Zone of Inhibition (ZOI) against *Staphylococcus aureus* and *Escherichia coli* was found to be 8 mm and 7 mm respectively [7, 8].

Herbal Soap Formulation

The formulation of herbal soap involves the saponification of triglycerides with a strong alkali, resulting in the formation of carboxylate salts (soap) and glycerol. In this study, *Chlorophytum borivillianum* extract was integrated into a transparent soap base to leverage its saponin-rich profile for skin nourishment and antimicrobial protection. The batch size for the formulation was standardized to approximately 130 g [8, 9].

Formulation Procedure

- **Preparation of Solution A (Alkali Phase):** 9 g of Sodium Hydroxide (NaOH) was dissolved in 40 mL of distilled water. The exothermic reaction was allowed to stabilize, and the solution was left undisturbed for 30 minutes to reach room temperature.
- **Preparation of Solution B (Oil Phase):** 98 mL of Coconut oil and 30 g of Stearic acid were heated in a water bath until a homogenous molten mixture was formed. Stearic acid was utilized specifically to ensure the structural hardness of the final bar.
- **Saponification:** Solution A was added to Solution B gradually with continuous stirring. The mixture was cooked for 10 minutes at a controlled temperature to initiate the saponification reaction.
- **Clarification and Humectants:** 59.5 mL of Glycerin (humectant) and 74 mL of Ethanol (solubilizer for transparency) were added. The vessel was covered for 5 minutes to prevent solvent evaporation. Subsequently, 28.8 mL of Propylene glycol was added to enhance the skin-conditioning properties.
- **Incorporation of Active Ingredient:** Once the soap base preparation was complete and the temperature slightly reduced, 2 mL of *Chlorophytum borivillianum* ethanolic extract was added. This was followed by the addition of 1 mL of Apple cinnamon perfume for fragrance.
- **Molding:** The final liquid mixture was homogenized using an electric blender and poured into suitable molds to solidify [10].

Evaluation Parameters of Formulated Herbal Soap

Organoleptic Properties

The formulated Safed Musli herbal soap was evaluated for its sensory characteristics. The soap exhibited a creamy off-white to pale-yellowish hue (characteristic of the root extract) with a smooth texture. The dimensions were standardized as: Length (8 cm), Breadth (6 cm), and Thickness (5 cm) [3].

pH Determination

The pH of the formulated soap was measured to ensure skin compatibility. 10 g of the soap was dissolved in 100 mL of distilled water, and the pH was recorded using a digital pH meter. The formulation aimed for a near-neutral pH (range 7.0–8.5) to prevent disruption of the skin's acid mantle [3, 8]. [Figno.8]

Foam Formation and Foam Retention

To examine the surfactant activity, 1 g of soap was dissolved in 50 mL of distilled water in a measuring cylinder and shaken vigorously for 2 minutes. The high saponin content of *Chlorophytum borivillianum* contributed to a stable and dense lather. The foam height was recorded at intervals of 0, 5, 10, and 15 minutes to assess retention stability [3].



**Skin Irritation Test (Patch Test)**

The safety of the Safed Musli soap was assessed on 3 to 4 healthy human volunteers. The soap was applied to a small area of the skin to observe any redness, edema, or irritation. No adverse reactions were reported, indicating the formulation is dermatologically safe [3].

Thumb Impression Method (Antimicrobial Assay)

To evaluate the in-vivo antimicrobial efficacy, the thumb impression method was used.

- A thumb impression of an unwashed hand (exposed to the environment) was taken on sterile Nutrient Agar/Sabouraud Dextrose Agar.
- The same hand was then washed with the formulated Safed Musli herbal soap for 30 seconds and dried.
- A second thumb impression was placed on the same agar plate.

After incubation for 24 hours at 37°C, a significant reduction in microbial colony forming units (CFU) was observed in the washed thumbprint compared to the unwashed one, validating the antimicrobial potential of Safed Musli [9].

Determination Of Percentage Free Alkali

Free alkali can cause skin dryness. 5 g of soap was dissolved in neutralized alcohol and refluxed for 30 minutes. After cooling, 1 mL of phenolphthalein was added and titrated against 0.1M HCl.

Formula: % Free Alkali = $(V \times N \times 4) / W$, Where, V = volume of standard HCL in mL, N = Normality of standard HCL, W = Weight of soap sample in grams, 4 = Equivalent weight factor for NaOH.

Alcohol Insoluble Matter

5 g of soap was dissolved in warm ethanol and filtered through a tared filter paper. The paper was dried at 105°C. The absence of significant residue indicates high purity and proper saponification [6].

Formula: Alcohol Insoluble Matter (%) = $(W_2 - W_1) / W \times 100$

Where,

W_1 = Initial weight of filter paper (g)

W_2 = Final weight of filter paper + residue (g)

W = Weight of soap sample (g)

Determination Of Total Fatty Matter (Tfm)

TFM is a crucial indicator of soap quality. 10 g of soap was dissolved in hot water and reacted with 15% Sulfuric Acid. Bee wax (7 g) was added to solidify the fatty acids.

Formula: % TFM = $((A - X) \times 100) / W$

Where,

A = wt. of wax cake,

X = wt. of beeswax,

W = wt. of soap.

High TFM (Grade 1) ensures better moisturizing effects [11].

Dirt Dispersion Test

A 1% soap solution was treated with two drops of ink. After shaking, the distribution of ink was observed. Minimal ink in the foam portion and maximum dispersion in the water section indicates superior cleansing quality [3].

“The dirt dispersion test indicates the ability of soap to prevent redeposition of dirt. Maximum dispersion of ink in water and minimal presence in foam confirms superior cleansing performance.”

Saponification Value

2 g of the sample was refluxed with 0.5M KOH. Titration was performed with 0.5M HCl using phenolphthalein.



**Hitesh A. Patil et al.,**

Formula: Saponification Value = (Mass of KOH / Mass of soap) × 1000 [13, 12].

Moisture Content

5 g of soap was heated at 105°C in a hot air oven for 2 hours.

Formula: % Moisture Content = (W₁ - W₂) × 100 / W₁

Where,

W₁ = Initial weight of sample (before drying)

W₂ = Final weight of sample (after drying) [12].

Accelerated Stability Studies

Following ICH guidelines, the soap was stored at 30°C (ambient) and 4±2°C (refrigerated) for one month. The formulation remained stable with no significant changes in physical appearance, pH, or cleaning efficacy [3,11].

RESULTS AND DISCUSSIONS

A rejuvenating herbal soap was formulated using a transparent soap base containing sodium hydroxide, coconut oil, stearic acid, glycerin, ethanol, and propylene glycol, enriched with an optimized concentration of *Chlorophytum borivilianum* extract.

Phytochemical and Antimicrobial Screening

The pre-formulation study of the ethanolic root extract of Safed Musli showed highly positive results for Saponins, Steroids, and Alkaloids, which are the primary bioactive compounds responsible for its medicinal value. Unlike grass extracts, Safed Musli showed strong positive results for Steroids (Saponins are steroidal glycosides). These constituents are essential for the soap's emollient and antimicrobial properties [3]. The antimicrobial assay revealed a promising Zone of Inhibition (ZOI) of 8 mm for *E. coli* and 7 mm for *S. aureus*. The higher ZOI compared to conventional herbs is attributed to the membrane-disrupting properties of steroidal saponins present in the roots [3, 5].

Physicochemical Evaluation

The formulated soap exhibited a pH of 8.95, which is slightly lower (better) than conventional soaps, aligning well with skin safety standards. The foam formation was instantaneous, and the foam height of 4.8 cm remained stable for over 15 minutes due to the natural foaming nature of Safed Musli saponins [11]. Skin irritation tests on volunteers confirmed zero signs of erythema or irritation, validating the "Rasayana" (rejuvenating) nature of the drug [10]. The Thumb Impression Method showed a drastic reduction in microbial colonies after washing, proving the soap's efficacy as a daily-use antiseptic cleanser [8]. The Total Fatty Matter (TFM) was found to be 76.15%, classifying it as a Grade-1 soap, which provides superior moisturizing effects. The moisture content (3.12%) and free alkali (0.05%) were within the permissible limits of BIS standards [6, 11]. Stability studies confirmed that the formulation remains physically and chemically intact under accelerated conditions [3].

CONCLUSION

The present study successfully formulated and evaluated a therapeutic herbal soap integrated with *Chlorophytum borivilianum* (Safed Musli) root extract. The phytochemical screening of the extract confirmed a high concentration of steroidal saponins, alkaloids, and flavonoids, which are pivotal for its potent antimicrobial and skin-rejuvenating properties. The extract demonstrated superior antibacterial efficacy with inhibition zones of 8 mm against *E. coli* and 7 mm against *S. aureus*, significantly outperforming many common herbal alternatives. The physicochemical evaluation of the formulated soap revealed a pH of 8.95, ensuring it is mild and skin-friendly. The natural surfactant properties of Safed Musli saponins resulted in excellent foam stability (lasting over 15 minutes) and a rich lather.

115703



**Hitesh A. Patil et al.,**

With a Total Fatty Matter (TFM) of 76.15%, the formulation meets the criteria for Grade-1 toilet soap, offering enhanced moisturizing benefits. The safety profile was validated through volunteer skin irritation tests and the thumb impression method, which showed zero adverse reactions and effective microbial reduction. In conclusion, the *C. borivillianum* herbal soap stands as a promising, safe, and effective natural alternative to synthetic antimicrobial soaps.

Future Scope

The successful development of this formulation opens several avenues for future research and commercial application:

- **Advanced Clinical Trials:** Future studies can focus on long-term dermatological effects and its efficacy against specific skin conditions like eczema or fungal infections.
- **Synergistic Formulations:** Exploring the combination of Safed Musli with other high-value herbs (e.g., Ashwagandha or Aloe Vera) to create a multi-functional "Rasayana" skincare range.
- **Product Diversification:** The antimicrobial and emollient properties of *C. borivillianum* can be utilized to develop a complete skincare line, including liquid body washes, medicated shampoos, and moisturizing lotions.
- **Nanotechnology Integration:** Future research could involve the use of nano-emulsions of Safed Musli extract to enhance the penetration of bioactive saponins into deeper skin layers for better therapeutic outcomes.
- **Personalized Skincare:** Developing customized soap variants where the concentration of Safed Musli extract is adjusted based on individual skin types (oily, dry, or sensitive) or specific antimicrobial requirements.

REFERENCES

1. Thakur, M., & Dixit, V. K. (2008). *Chlorophytum borivillianum*: A Review of its Ethnobotany, Phytochemistry and Pharmacological Importance. *Indian Journal of Pharmaceutical Sciences*, 70(4), 440–448.
2. Goyal, M., & Sharma, S. K. (2015). Traditional and Medicinal Uses of *Chlorophytum borivillianum*: A Review. *International Journal of Pharmaceutical Sciences and Research*, 6(3), 971-981.
3. Tarun, J., et al. (2014). Evaluation of pH of Bathing Soaps and Cleansers for Use in Psoriasis as well as Normal Skin. *Indian Journal of Dermatology*, 59(5), 442–444.
4. Saha, S., et al. (2018). Formulation and Evaluation of Herbal Soap using Plant Extracts for Antifungal and Antibacterial Activity. *Journal of Pharmacognosy and Phytochemistry*, 7(3), 1144-1147.
5. Thakur, M., & Dixit, V. K. (2008). *Chlorophytum borivillianum*: A review of its ethnomedicinal, phytochemical and pharmacological profile. *Natural Product Radiance*, 7(4), 362-373.
6. Kothari, S. K. (2004). Safed Musli (*Chlorophytum borivillianum*): A white gold. *Journal of Medicinal and Aromatic Plant Sciences*, 26, 349-355.
7. Harborne, J. B. (1998). *Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis*. 3rd Edition, Chapman & Hall, London.
8. Kokate, C. K., Purohit, A. P., & Gokhale, S. B. (2010). *Pharmacognosy*. 45th Edition, Nirali Prakashan, Pune.
9. Panda, S. K., et al. (2016). Antibacterial and Antifungal Activities of *Chlorophytum borivillianum* Root Extracts. *Frontiers in Microbiology*, 7, 1-12.
10. Valgas, C., et al. (2007). Screening methods to determine antibacterial activity of natural products. *Brazilian Journal of Microbiology*, 38, 369-380.
11. Sharma, P., & Rawat, S. (2017). Critical review on herbal soaps: Formulation and evaluation parameters. *International Journal of Pharmaceutical Sciences and Research*, 8(2), 435-442.
12. Mandal, S. S., et al. (2013). Formulation and evaluation of a herbal soap containing *Chlorophytum borivillianum*. *Journal of Pharmacognosy and Phytochemistry*.
13. Kuntal, D., et al. (2015). Preparation and evaluation of medicated soap containing *Chlorophytum borivillianum*. *Global Journal of Pharmacy & Pharmaceutical Science*.
14. BIS (Bureau of Indian Standards). IS 2888: Toilet Soap - Specification.
15. ICH Guidelines (2003). Q1A(R2) Stability Testing of New Drug Substances and Products.





Hitesh A. Patil et al.,

16. Giri, T. K., et al. (2021). Natural surfactants and their role in pH-balanced herbal cleansing formulations. *Journal of Phytomedicine and Therapeutics*.
17. Kuntal, D. (2015). Evaluation of specialty herbal soaps. *Journal of Pharmacognosy*, 4(2), 112-118.
18. Khare, C. P. (2007). *Indian Medicinal Plants: An Illustrated Dictionary*. Springer Science & Business Media, New York.
19. Trease, G. E., & Evans, W. C. (2009). *Trease and Evans Pharmacognosy*. 16th Edition, Saunders Elsevier, London.
20. Evans, W. C. (2002). *Pharmacognosy*. 15th Edition, W.B. Saunders Company Ltd., London.
21. Chaturvedi, M., & Sharma, P. K. (2012). Evaluation of herbal formulations and their antimicrobial activity. *International Journal of Pharmaceutical and Biological Archives*, 3(5), 1056-1060.
22. Kapoor, V. P. (2005). Herbal cosmetics for skin and hair care. *Natural Product Radiance*, 4(4), 306-314.
23. Ali, M., & Ansari, S. H. (1997). Hair care and herbal drugs. *Indian Journal of Natural Products*, 13(1), 3-5.
24. Mukherjee, P. K. (2002). *Quality Control of Herbal Drugs: An Approach to Evaluation of Botanicals*. Business Horizons Pharmaceutical Publishers, New Delhi.
25. Cowan, M. M. (1999). Plant products as antimicrobial agents. *Clinical Microbiology Reviews*, 12(4), 564–582.
26. Barel, A. O., Paye, M., & Maibach, H. I. (2009). *Handbook of Cosmetic Science and Technology*. 3rd Edition, Informa Healthcare, New York.
27. Kapoor, L. D. (2001). *Handbook of Ayurvedic Medicinal Plants*. CRC Press, Boca Raton.
28. Nadkarni, K. M. (2009). *Indian Materia Medica*. Popular Prakashan Pvt. Ltd., Mumbai.
29. Khandelwal, K. R. (2008). *Practical Pharmacognosy: Techniques and Experiments*. 19th Edition, Nirali Prakashan, Pune.
30. Gaud, R. S., & Gupta, G. D. (2008). *Practical Physical Pharmacy*. CBS Publishers & Distributors, New Delhi.

Table 1: Antimicrobial Test (Zone Of Inhibition)

Ingredients	Quantity	Category
Sodium Hydroxide	9 g	Saponifying Agent
Coconut oil	98 mL	Lathering Agent
Stearic acid	30 g	Hardening Agent
Glycerin	59.5 mL	Humectant / Emollient
Ethanol (95%)	74 mL	Clarifying Agent (Transparency)
Propylene glycol	28.8 mL	Humectant / Solvent
Distilled water	40 mL	Vehicle
Apple cinnamon perfume	1 mL	Fragrance
Safed Musli Extract	2 mL	Active Ingredient (Antimicrobial)

Table 2: Results of Phytochemical Testing (*C. borivilianum*)

Tests	Water	Ethanol	n-Hexane
Saponins (Foam Test)	++	++	--
Steroids	++	++	+
Carbohydrates	--	++	++
Flavonoids	++	++	+
Alkaloids	--	++	--
Proteins	++	++	--
Tannins/Phenols	--	++	--





Hitesh A. Patil et al.,

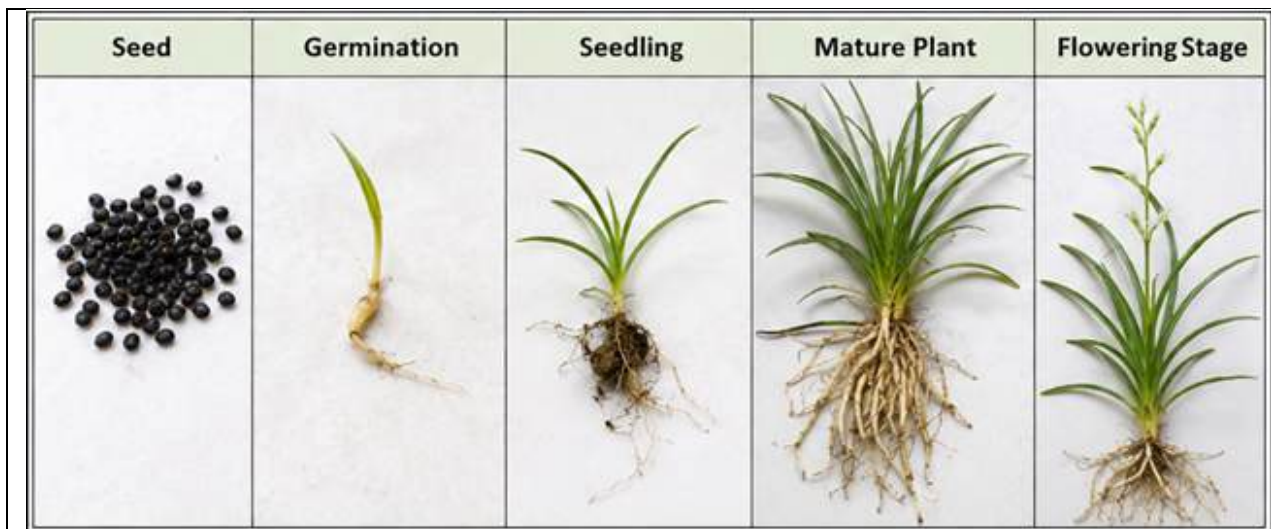
Table 3: Antimicrobial Activity (Zone of Inhibition)

Microorganism	Zone of Inhibition (mm)
<i>Escherichia coli</i>	8 mm
<i>Staphylococcus aureus</i>	7 mm

Table 4 Result of Stability And Stability Studies

Parameter	Initial Reading	After 1 Month
Colour /Odour	Pale Creamy / Aromatic	No Change
PH	8.95	8.92
Foam Height(0 min)	4.8 cm	4.6 cm
TFM (%)	76.15%	76.10%
Skin Irritation	None	None

**Fig no.1: Plant Of Chlorophytum Borivilianum (Safed Musli)****Figure No.2: Whole Plant of Safed Musli****Figure No.3: Crude Drug****Figure No.4: Roots Of Safe Musli**



FigureNo.5: Different stages of safed musli plant.

FigureNo.6: Soxhlet Extraction Of *C. Borivilianum*Figure No. 7 Prepared *Chlorophytum Borivilianum* (SafedMusli) Herbal Soap.

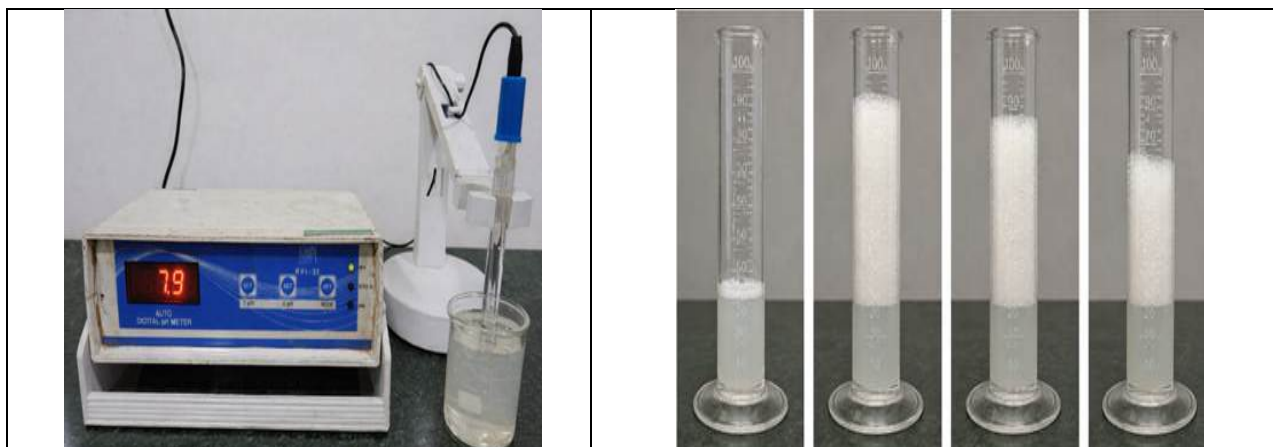
Hitesh A. Patil *et al.*,

Figure no. 8: Result of PH Determination Test.

Figure No. 9 Result Of Foam Formation And Foam Retention



Before

Washing

After WashWash

Figure No.10 Result of Skin Irritation Test



Figure No.11 Result of Thumb Impression Method (Antimicrobial Assay)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Antimicrobial, Antioxidant and Anti-Inflammatory Activities of the Siddha Polyherbal Formulation Megarajanga Kirutham

S.P Kopperundevi^{1*}, S.Santhanakittu² and M.N Parandhaman¹

¹Associate Professor, Department of Aruvai Thol Maruthuvam, JSA Medical College for Siddha and Research Centre, Ulundurpet, Kallaluruchi, (Affiliated to The Tamil Nadu Dr. MGR Medical University, Chennai), Tamil Nadu, India

²Lecturer, Department of Noinaadal, Sudha Saseendran Siddha Medical College and Research Centre, Kaliakkavilai, Kanniyakumari, (Affiliated to The Tamil Nadu Dr. MGR Medical University, Chennai), Tamil Nadu, India.

Received: 12 Mar 2026

Revised: 10 Apr 2026

Accepted: 21 May 2026

*Address for Correspondence

S.P Kopperundevi

Associate Professor,

Department of Aruvai Thol Maruthuvam,

JSA Medical College for Siddha and Research Centre,

Ulundurpet, Kallaluruchi,

(Affiliated to The Tamil Nadu Dr. MGR Medical University, Chennai),

Tamil Nadu, India

E.Mail: dr.kopperundevipitchai@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Infectious diseases continue to be a leading cause of illness and death worldwide. Antimicrobials are used to manage them. However, microbial resistance to these medicines is becoming more prevalent. Disease conditions are also accompanied by inflammation and oxidative stress. In order to combat oxidative stress, inflammation and microorganisms, newer drugs are required. Therefore, biomaterials like herbal medicines with strong antibacterial, anti inflammatory and antioxidant properties can take the place of current antibiotic medications. Megarajanga Kirutham (MRK) is frequently used by Siddha physicians as a traditional cure for a variety of ailments, including inflammation, infections, and improving overall health. It was prepared using the method outlined in the classical Siddha treatise "Sigicha rathna deepam". Hence, the purpose of this study was to investigate the anti microbial, anti-inflammatory and antioxidant properties of Megarajanga kirutham. The disc diffusion method, albumin denaturation assay and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, nitric oxide radical scavenging assay and 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) assay were used to evaluate the antimicrobial, anti-inflammatory, and antioxidant properties. All of the bacteria showed different levels of sensitivity to the various extracts. MRK showed effective anti microbial activity against *Trichomonas Vaginalis*, *Staphylococcus aureus*, *E-Coli*, *Candida albicans* and not active against *Aspergillus niger* It had a



**Kopperundevi et al.,**

significant scavenging impact on hydroxyl and DPPH radicals as well as a robust reduction potential. The anti-inflammatory and antioxidant properties exhibited substantial efficacy at higher doses and were dose-dependent.

Keywords: Megarajanga Kirutham, anti microbial, anti inflammatory, anti oxidant, invitro, Siddha.

INTRODUCTION

Infectious diseases, particularly bacterial, are a major cause of death worldwide, with developing nations experiencing the highest mortality rates. Approximately 13.7 million people died from diseases in 2019 alone, with bacteria being responsible for 7.7 million of these deaths [1]. Antibiotics have been widely used to treat bacterial infections and increase the average survival rate of those who have been affected [2]. Antibiotics also significantly lower the rates of illness and mortality, especially in underdeveloped nations with limited or nonexistent medical services [3]. But repeated, careless use and misuse of antibiotics has led to a rise in microbial agent resistance [4]. Nowadays, one of the most important issues at the moment is antibiotic resistance, which is a natural phenomenon that involves adaptive mechanisms [5]. The lack of good alternative treatment options to treating infections caused by multidrug-resistant organisms is hugely tasking endeavor [6]. Globally, antibiotic resistance has emerged as a serious threat to human population health, which has led to a strong search for substitute sources of antimicrobial drugs [7]. Antimicrobial agents also have a number of negative effects especially raising the body's reactive oxygen species (ROS). ROS contribute to the development of cancer and are extremely harmful to human health and well being [8,9]. Oxidative stress is the primary cause for the pathogenesis of a variety of diseases, including cancer, diabetes mellitus, cardiovascular, neurodegenerative, and inflammatory disorders [10, 11]. Oxidative damage can cause cytokine release and the start of enzymes like lipoxygenases from cellular effectors, which can lead to cellular infiltration and the propagation of inflammation [12].

Inflammation is an active defensive response to counter mechanical injuries, burns, infections, or other toxic stressors. It is meant to be beneficial, but it could also be harmful, especially over time [13]. Chronic conditions such as cardiovascular, neurological, or inflammatory bowel disorders may arise from ongoing inflammatory reactions [14]. Oxidative stress may be reduced with synthetic phenolic antioxidants including butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), or propyl gallate (PG) might have harmful hepatotoxic and carcinogenic consequences [15]. So it is a need of the hour to find safer, more accessible, and more effective substitutes, like traditional herbal medicine. It is thought that medicinal plants represent a safer, more accessible, and less expensive alternative treatment for microbial infections and/or the treatment of oxidative stress-related illnesses, such as inflammatory processes [16]. Megarajanga Kirutham (MRK) is the Siddha polyherbal formulation frequently used as a traditional cure for a variety of ailments, including inflammation, infections, and improving overall health. It was prepared using the method outlined in the classical Siddha treatise "Sigicha rathna deepam". It has the specific indication for menorrhagia, dysuria, leucorrhoea, anemia and emaciation [17]. Hence, the purpose of this study was to investigate the anti microbial, anti-inflammatory and antioxidant properties of Megarajanga kirutham.

MATERIALS AND METHODS

Collection of raw materials

All of the raw drugs needed to prepare the test drug were bought from a reputable raw drug seller, Tambaram and the Medicinal botanist in National Institute of Siddha, Chennai, provided their authentication. After appropriate purification, the trial medication was manufactured in the Gunapadam Lab, National Institute of Siddha, Chennai.

Purification of raw drugs

All the herbal drugs are purified as per the classical Siddha text *Gunapadam Mooligai Vaguppu* ^[18].



**Kopperundevi et al.,****Method of preparation**

The ingredients of Megarajanga Kirutham were mentioned in the Table 1. The drug was prepared as per the Siddha classical text "Sigicha rathna deepam". 350grams of aththi pattai (*Ficus racemosa*), Naaval pattai (*Syzygium cumini*), othiyampattai (*Lannea coromandelica*) were crushed and to prepare the kudineer (decoction) 8 liters of water was added and reduced to 1 liter. Then juices of karumbu juice (*Saccharum officinarum*), nellikai juice (*Embllica officinalis*), lemon juice (*Citrus limon*), gingelly oil (*Sesamum indicum*) and cow's ghee were added into the decoction and boiled well. Each 26.25 grams powder of thalisapathiri (*Abies spectabilis*), elam (*Elettaria cardamomum*), kirambu (*Syzygium aromaticum*), jadhikkai (*Myristica fragrans*), chitrarathai (*Alpinia officinarum*), athimathuram (*Glycyrrhiza glabra*) and nilappanai kizhangu (*Curculigo orchioides*) were ground with the milk of three coconuts (*Cocos nucifera*). This kalkam was added to the decoction mixture and boiled until the ghee consistency.

Antimicrobial activity

The antimicrobial activities of the samples were appraised by disc diffusion method[19]. Antibacterial test was carried out on five species such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* and *Aspergillus niger*. The disc diffusion method was used to test the sample MRK's antimicrobial properties. The test chemicals were employed at doses of 500, 1000, and 2000 µg. Mueller-Hinton broth (MHB) was used to cultivate the target microorganisms. The suspensions were brought to standard subculture dilution after a 24-hour period. A diluted bacterial strain was cultivated in Petri dishes that contained Muller Hinton Agar (MHA) medium. *Trichomonas vaginalis* is incubated in Diamond's medium. A 6 mm diameter Whatman No. 1 disc was kept in an aseptic chamber after being pre-sterilized. The sterile disc papers were injected with each concentration. The discs that had been produced were then put on the culture medium. As a positive reference standard, the standard medications fluconazole (25µg), metronidazole (5µg) for *Trichomonas vaginalis*, and ciprofloxacin (5µg) to determine the sensitivity of each microbial species tested. After that, the inoculation plates were incubated for 24 hours (for bacteria) or 72 hours (for fungi) at 37°C. The anti-microbial property of the disc was determined by measuring and expressing the diameter of the clear zone surrounding it in millimeters.

DPPH (2, 2-Diphenyl 1-2 picrylhydrazyl) Assay for antioxidant activity

A free radical scavenging assay called 2,2-diphenyl 1-2 picrylhydrazyl (DPPH) was used to measure the antioxidant activity of test drug MRK[20]. The stock solution was prepared by mixing sample MRK with 95% methanol at the desired concentration (10 mg/100 ml or 100µg/ml). Five test tubes containing 1 ml, 2 ml, 4 ml, 6 ml, 8 ml, and 10 ml of the stock solution were used. The final volume of each test tube was increased to 10 ml by serial dilution with the same solvent, resulting in concentrations of 10µg/ml, 20µg/ml, 40µg/ml, 60µg/ml, 80µg/ml, and 100µg/ml, respectively. As a standard, ascorbic acid was made with methanol as a solvent at the same concentration as the sample extract. 2.5 ml of sample solution of varying concentrations was mixed with 1 ml of 0.3mM DPPH methanol solution to create the final reaction mixture, which was then left to react at room temperature. After 15 minutes of incubation at 37°C, absorbance was measured in the presence of test sample MRK at various concentrations (10µg, 20µg, 40µg, 60µg, 80µg, and 100µg/ml). Absorbance was read out at 517 nm utilizing double-beam U.V Spectrophotometer by using methanol as blank.

% scavenging = [Absorbance of control - Absorbance of test sample/Absorbance of control] X 100

Nitric Oxide Radical Scavenging Assay for antioxidant activity

The concentrations of test sample MRK are made into serial dilution from 10–100 µg/mL and the standard gallic acid. Griess reagent was prepared by mixing equal amounts of 1% sulphanilamide in 2.5% phosphoric acid and 0.1% naphthyl ethylene diamine dihydrochloride in 2.5% phosphoric acid immediately before use. A volume of 0.5 mL of 10 mM sodium nitroprusside in phosphate buffered saline was mixed with 1 mL of the different concentrations of the test drug (10–100 µg/mL) and incubated at 25°C for 180 mins. The test drug MRK was mixed with an equal volume of freshly prepared Griess reagent. Control samples without the test drug but with an equal volume of buffer were prepared in a similar manner as was done for the test samples. The absorbance was measured at 546 nm using a Spectra Max Plus UV-Vis microplate reader (Molecular Devices, GA, USA). Gallic acid was used as the positive





Kopperundevi et al.,

control. The percentage inhibition of the test drug MRK and standard was calculated and recorded. The percentage nitrite radical scavenging activity of the test drug MRK and gallic acid were calculated using the following formula [21]:

percentage nitrite radical scavenging activity:

$$\text{nitric oxide scavenged (\%)} = \frac{A_{\text{control}} - A_{\text{test}}}{A_{\text{control}}} \times 100,$$

where A_{control} = absorbance of control sample and A_{test} = absorbance in the presence of the samples extracts or standards.

ABTS Assay for anti oxidant activity

This assay carried out for the purpose of evaluating the anti-oxidant potential of test drug MRK against 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) or ABTS radicals^[22]. The ABTS radical cation method was modified to evaluate the free radical-scavenging effect of one hundred pure chemical compounds. The ABTS reagent was prepared by mixing 5mL of 7mM ABTS with 88μL of 140mM potassium persulfate. The mixture was then kept in the dark at room temperature for 16 h to allow free radical generation and was then diluted with water (1 : 44, v/v). To determine the scavenging activity, 100μL ABTS reagent was mixed with 100μL of test sample (10-100μg/ml) and was incubated at room temperature for 6 min. After incubation, the absorbance was measured 734 nm. 100% methanol was used as a control. Gallic acid with same concentrations of test drug MRK was measured following the same procedures described above and was used as positive controls. The antioxidant activity of the test sample MRK was calculated using the following equation: The ABTS scavenging effect was measured using the following formula:

Radical scavenging (%)

$$= \left[\frac{(A)_{\text{control}} - (A)_{\text{sample}}}{(A)_{\text{control}}} \right] \times 100.$$

Albumin denaturation assay for anti inflammatory activity

In-vitro anti-inflammatory activity of Megarajanga kritham (MRK) was investigated utilizing the albumin denaturation method^[23, 24]. The reaction mixture included standard diclofenac sodium at a concentration of 100 mcg/ml of final volume, test sample MRK at different concentrations ranging from 100 to 500 mcg/ml, and bovine serum albumin (5% aqueous solution). Using a tiny quantity of 1N hydrochloric acid, the pH was changed. The samples were heated for three minutes at 57°C after being incubated for twenty minutes at 37°C. 2.5 ml of phosphate buffer solution was added to each test tube once the material had cooled. Spectrophotometric measurements of the generated turbidity were made at 660 nm. Distilled water was utilized as a control sample, and bovine serum albumin was absent from product control tests. The experiment was carried out in triplicate.

The Percentage protection from denaturation is calculated by using the formulae

$$\left[\frac{(A)_{\text{control}} - (A)_{\text{sample}}}{(A)_{\text{control}}} \right] \times 100.$$

Statistical analysis:

Results are expressed as Mean ± SD. The difference between experimental groups was compared by One-Way Analysis Of Variance (ANOVA) followed by Dunnet Multiple comparison test.



Kopperundevi *et al.*,

RESULTS

Megarajanga Kirutham is the polyherbal formulation comprises 16 herbal compounds. Bioactive compounds present in the herbs are responsible for the pharmacological and therapeutic action of the formulation [25]. The investigation of antimicrobial activity of Siddha poly herbal extracts against human pathogens such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* and *Aspergillus niger* done by disc diffusion method which was shown in Figures 1-5 and Table 1. The antimicrobial activity of Siddha polyherbal formulation MRK possess strong antimicrobial activity against human pathogens such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* while low activity against *Aspergillus niger*. The antimicrobial activity of MRK's main ingredient *ficus racemosa* also revealed the significant bactericidal activity against *E.coli*, *S. aureus*, *S. typhi*, *K. pnem* at concentration and low activity against the *A. niger*[26]. Many of the herbals present in the MRK also possess the antimicrobial activity [27-31]. The inhibition zone is maximum in larger area in all the organisms except *Aspergillus niger*. The antimicrobial activity of liquorice revealed against *Staphylococcus aureus*, *Mycobacterium tuberculosis* and *Pseudomonas aeruginosa*[32,33]. *Syzygium aromaticum* extract was the most active against multi drug resistant and gram negative uropathogens[34].

Anti inflammatory activity

The result obtained from the present clearly indicates that the test drug MRK was effective in inhibiting heat induced albumin denaturation. Protein denaturation is a complex process that involves changes to hydrophobic, disulfide, and electrostatic hydrogen bonds [35]. Protein denaturation results in the generation of autoantigens in inflammatory diseases such diabetes, cancer, and rheumatic arthritis. Hence, inflammatory activity can be reduced by blocking protein denaturation[36]. Diclofenac, Non steroidal anti inflammatory drug is used as the reference drug in this study. Maximum percentage inhibition of about 69.54 % was observed at 500 µg/ml when compare to that of the Diclofenac sodium, a standard anti-inflammatory agent with the maximum inhibition 89.22 % at the concentration of 100 µg/ml. The anti inflammatory activity of MRK mentioned in the Table 2 and 3. In this study, MRK produced a dose-dependent anti-inflammatory activity which may be the first description in this particular species. The higher the concentration, the greater the inhibitory effect of the extracts and fractions on the serum albumin. Several studies had reported on anti-inflammatory effect of ingredient of this formulation. According to phytochemical research, *Ficus racemosa* contains biologically active components such as flavonoids, tannins, phenolic compounds, and phytosterols. It is hypothesized that one or more of these constituents, or their combination, is what produces the analgesic and anti-inflammatory effects [37]. The glabridin in liquorice exhibits the great anti inflammatory activity [38]. The petroleum ether extract of nutmeg showed activities similar to non-steroidal anti-inflammatory drugs [39]. The anti inflammatory and analgesic activity of cardamom demonstrated by using the carrageenan-induced rat paw edema and p-benzoquinone induced writhing method. Studies reveal that antispasmodic action of cardamom is produced through muscarinic receptor blockage [40].

Anti oxidant activity

The study formulation MRK was tested for its radical scavenging capacity against DPPH and ABTS, and the results were compared to those of ascorbic and gallic acid. The inhibition percentage against the corresponding radical was represented at the same dose (10-100µg/ml). In Table 4, The MRK formulation showed significant quenching of the DPPH radical, with inhibition percentages ranging from 7.778 ± 2.222% to 41.85 ± 3.395% when compared to the standard ascorbic acid, which had inhibition percentages ranging from 38.15 ± 3.395% to 88.15 ± 0.6415%. The IC₅₀ values for the MRK and standard ascorbic acid were determined to be 121 ± 12.15µg/ml and 23.55 ± 10.9µg/ml, respectively shown in Table 5. The formulation MRK demonstrates a noteworthy scavenging ability against the ABTS radical, reaching a maximum value of 55.86 ± 3.772%. This value is lower than the 88.45 ± 1.24% exhibited by the standard gallic acid (Table 6). In Table 7, the IC₅₀ values for the MRK and standard gallic acid were determined to be 42.48 ± 1.45µg/ml and 89.18 ± 2.81µg/ml respectively. The MRK formulation exhibited notable suppression of the NO radical, with inhibition percentages ranging from 6.069 ± 2.168% to 55.03 ± 7.536% in comparison to the standard ascorbic acid, which had inhibition percentages



**Kopperundeve et al.,**

ranging from $31.07 \pm 2.621\%$ to $82.81 \pm 0.6014\%$ (Table 8). The IC₅₀ values for the MRK and standard ascorbic acid were measured to be $93.74 \pm 16.24\mu\text{g/ml}$ and $40.41 \pm 2.46\mu\text{g/ml}$ respectively, as shown in Table 9. The methanolic extract of nutmeg seed showed good antioxidant activity by methods of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) due to high content of tannins, flavonoids, and terpenoids^[41]. Cardamom oil has potent antioxidant activity through increase the levels of glutathione^[42]. Clove is having a potential antioxidant property tested by using 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid), oxygen radical absorbance capacity, ferric-reducing antioxidant power, xanthine oxidase, and 2-deoxyguanosine^[43].

CONCLUSION

MRK is the Siddha polyherbal formulation which is widely used for reproductive diseases. The pharmacological activity of each ingredient of the MRK is responsible for the therapeutic effect of the formulation.. The pharmacological activities of MRK were analyzed, and the results showed promising antibacterial, antioxidant, and anti-inflammatory properties that were dose dependent. This formulation had strong antibacterial activity but weak antifungal efficacy. Further, clinical studies should be conducted on this popular and potent formulation to validate its antioxidant, anti-inflammatory and anti-microbial activity. Thus, there is a scope for further research on its properties and mode of action.

Conflict of Interest:

The authors declare that there are no conflicts of interest.

REFERENCES

1. Gray A, Sharara F (2022) Global and regional sepsis and infectious syndrome mortality in 2019: a systematic analysis. *Lancet* 10:S2.
2. Aslam B, Wang W, Arshad MI, Khurshid M, Muzammil S, Rasool MH et al (2018) Antibiotic resistance: a rundown of a global crisis. *Infect Drug Resist* 11:1645–1658
3. Rossolini GM, Arena F, Pecile P, Pollini S (2014) Update on the antibiotic resistance crisis. *Curr Opin Pharmacol* 18:56–60
4. Aslam B, Wang W, Arshad MI, Khurshid M, Muzammil S, Rasool MH et al (2018) Antibiotic resistance: a rundown of a global crisis. *Infect Drug Resist* 11:1645–1658.
5. Popa SL, Pop C, Dita MO, Brata VD, Bolchis R, Czako Z et al (2022) Deep learning and antibiotic resistance. *Antibiotics* 11:1674.
6. Tietgen M, Sedlaczek L, Higgins PG, Kaspar H, Ewers C, Göttig S (2022) Colistin resistance mechanisms in human and veterinary *Klebsiella pneumoniae* isolates. *Antibiotics* 11:1672.
7. Anand U, Jacobo-Herrera N, Altemimi A, Lakhssassi NA (2019) Comprehensive review on medicinal plants as antimicrobial therapeutics: potential avenues of biocompatible drug discovery. *Metabolites* 9:258
8. Raut P.K., Kim S.H., Choi D.Y., Jeong G.S., Park P.H. Growth of breast cancer cells by leptin is mediated via activation of the inflammation: Critical roles of estrogen receptor signaling and reactive oxygen species production. *Biochem. Pharmacol.* 2019;161:73–88.
9. Nakamura Y., Arakawa H. Discovery of MIEAP-regulated mitochondrial quality control as a new function of tumor suppressor p53. *Cancer Sci.* 2017;108:809–817.
10. Pham TNT, Nguyen TT, Nguyen TL, Tran AMN, Nguyen TN, Tong DT et al (2022) Antioxidant and anti-inflammatory activities of phytochemicals from *Ruellia tuberosa*. *J Chem* 2022:4644641.
11. Arika W, Kibiti CM, Ngugi NJM, MP, (2019) In vitro antioxidant properties of dichloromethanolic leaf extract of *Gnidia glauca* (Fresen) as a promising antiobesity drug. *J Evid-Based Integr Med* 24:2019





Kopperundevi et al.,

12. Zhang X-R, Kaunda JS, Zhu H-T, Wang D, Yang C-R, Zhang Y-J (2019) The genus *Terminalia* (Combretaceae): an ethnopharmacological, phytochemical and pharmacological review. *Nat Prod Bioprospect* 9:357–392.
13. Deng W, Du H, Liu D, Ma Z (2022) Editorial: The role of natural products in chronic inflammation. *Front Pharmacol* 13:901538.
14. Hussain T, Murtaza G, Yang H, Kalhor MS, Kalhor DH (2020) Exploiting anti-inflammation effects of flavonoids in chronic inflammatory diseases. *Curr Pharm Des* 26:2610–2619.
15. Yimta F, Simplic MR, François N, Singer NGS, Jean De Dieu T, Roger JK (2014) Antibacterial activity of methanol extracts from *Kalanchoe crenata*. *Terminalia Avicennioides* and *Sarcocephalus Latifolius* *Pharmacologia* 5(6):199–204
16. Goyal MR, Suleria HAR (eds) (2019) Human health benefits of plant bioactive compounds: potentials and prospects. CRC Press, Florida.
17. Kannusami pillai C. Chikitsa ratna deepam Irandam Baagamaagiya Vaithiya Chinthami. 1st edition. Chennai; B. Rathina Nayagar and Sons; 1927. 195p.
18. Murugesu Mudaliar KS, Gunapadam Mooligai Vaguppu, Fourth edition, Publisher; Tamilnadu Siddha Medical Council, Chennai, 1988
19. Bauer AW, Kirby WMM, Sherris JC, Turck M. Antibiotic susceptibility testing by a standardized single disk method. *Am J Clin Pathol.* 1966;45(4_ts):493–496.
20. Badami, Omprakash, DongrSH, Suresh B. *In-vitro* Antioxidant property of *Solanum Pseudocapsicum* leaf extract. *Indian J Pharmacol.* 2005; 37:251–252.
21. B. N. Panda, A. B. Raj, N. R. Shrivastava, and A. R. Prathani, "The evaluation of nitric oxide scavenging activity of *Acalypha indica* Linn Root," *Asian Journal Research Chemistry*, vol. 2, no. 2, pp. 148–150, 2009.
22. N. Pellegrini, M. Ying, and C. Rice-Evans, "Screening of dietary carotenoids and carotenoid-rich fruits extract for antioxidant activities applying 2,2'-azobis (3-ethylbenzothione-6-sulfonic acid) radical cation decolorization assay," *Methods in Enzymology*, vol. 299, pp. 384–389, 1999.
23. G. Leelaprakash, S. Mohan Dass. *In-vitro* anti-inflammatory activity of methanol extract of *enicostemma axillare*. *Int. J. Drug Dev. & Res.*, 2011, 3 (3): 189–196.
24. M. V. Anoop, A. R. Bindu. *In-vitro* Anti-inflammatory Activity Studies on *Syzygium zeylanicum* (L.) DC Leaves. *International Journal of Pharma Research & Review*, August 2015; 4(8):18–27.
25. Shrinet K, Singh RK, Chaurasia AK, Tripathi A, Kumar A. Bioactive compounds and their future therapeutic applications. *In Natural bioactive compounds 2021 Jan 1* (pp. 337–362).
26. Pingale T, Duse P, Ogale S. Antibacterial and Antifungal Approaches of *Ficus racemosa*. *Pharmacog J.* 2019;11(2):355–7
27. Jatinder Pal Singh, Amritpal Kaur, Narpinder Singh, Lovedeep Nim, Khetan Shevkani, Harpreet Kaur, Daljit Singh Arora, *In vitro* antioxidant and antimicrobial properties of jambolan (*Syzygium cumini*) fruit polyphenols, *LWT*, 65, (2016) 1025–1030.
28. Ferdous RN, Nebir SS, Das PK, Prova AH, Moniruzzaman M, Khan MS, Rokeya B, Asna SM. Antimicrobial activity of *Lannea coromandelica* bark extracts against methicillin-resistant *Staphylococcus aureus*. *BIRDEM Medical Journal.* 2022 Sep 11;12(3):201–6.
29. Rajalakshmi P, Vadivel V, Ravichandran N, Sudha V, Brindha P. Pharmacognostic evaluation of *Abies webbiana* leaf: a Siddha herbal ingredient. *Asian J Pharm Clin Res.* 2016 Jul 1;9(4):213–9.
30. Saeed M, Nadeem M, Khan MR, Shabbir MA, Shehzad A, Amir RM. Antimicrobial activity of *Syzygium aromaticum* extracts against food spoilage bacteria. *Afr. J. Microbiol. Res.* 2013;7(41):4848–56.
31. Rao K, Ch B, Narasu LM, Giri A. Antibacterial activity of *Alpinia galanga* (L) Willd crude extracts. *Applied biochemistry and biotechnology.* 2010 Oct;162:871–84.
32. Oyama, K., Kawada-Matsuo, M., Oogai, Y., Hayashi, T., Nakamura, N., & Komatsuzawa, H. (2016). Antibacterial Effects of Glycyrrhetic Acid and Its Derivatives on *Staphylococcus aureus*. *PLoS One*, 11(11), e0165831.
33. Gupta, V. K., Fatima, A., Faridi, U., Negi, A. S., Shanker, K., Kumar, J. K., Khanuja, S. P. S. (2008). Antimicrobial potential of *Glycyrrhiza glabra* roots. *Journal of Ethnopharmacology*, 116(2), 377–380.





Kopperunde et al.,

34. Faujdar, Sameer S.¹; Bisht, Dakshina¹; Sharma, Amisha². Antibacterial activity of *Syzygium aromaticum* (clove) against uropathogens producing ESBL, MBL, and AmpC beta-lactamase: Are we close to getting a new antibacterial agent?. *Journal of Family Medicine and Primary Care* 9(1):p 180-186, January 2020.
35. Sen S, Chakraborty R, Maramsa N, Basak M, Deka S, et al *In vitro* anti inflammatory activity of *Amaranthus caudatus* L leaves Indian J Nat Prod Resour. 2015;6:326–9.
36. Sangeetha G, Vidhya R. *In vitro* anti-inflammatory activity of different parts of *Pedaliu murex* (L.) Int J Herb Med. 2016; 4:31–6.
37. Dharmadeva, Sharmila; Galgamuwa, Lahiru Sandaruwan¹; Prasadine, C.²; Kumarasinghe, Nishantha³. In vitro anti-inflammatory activity of *Ficus racemosa* L.bark using albumin denaturation method. *AYU (An international quarterly journal of research in Ayurveda)* 39(4):p 239-242, Oct–Dec 2018.
38. Xiao, Y, Xu, J., Mao, C., Jin, M., Wu, Q. , Zou, J. Zhang, Y. (2010). 18β-Glycyrrhetic acid ameliorates acute *Propionibacterium acnes*-induced liver injury through inhibition of macrophage inflammatory protein-1α. *The Journal of Biological Chemistry*, 285(2), 1128–1137.
39. Olajide OA, Makinde JM, Awe SO. Evaluation of the pharmacological properties of nutmeg oil in rats and mice. *Pharmaceut Biol* 2000;38:385- 90.
40. Al-Zuhair H, el-Sayeh B, Ameen HA, al-Shoora H. Pharmacological studies of cardamom oil in animals. *Pharmacol Res* 1996;34:79-82
41. Assa JR, Widjanarko SB, Kusnadi J, Berhimpon S. Antioxidant potential of flesh seed and mace of nutmeg (*Myristica fragrans* Houtt). *Int J ChemTech Res* 2014;6:2460-8.
42. Singh, V. Pal, A., & Darokar, M. P. (2015). A polyphenolic flavonoid glabridin: Oxidative stress response in multidrug-resistant *Staphylococcus aureus* . *Free Radical Biology and Medicine*, 87, 48–57.
43. Badei AZM, Morsi HHH, El-Akel ATM. Chemical composition and antioxidant properties of cardamom essential oil. *Bull Faculty Agric Univ Cairo* 1991;42:199-215.

Table 1: Zone of Inhibition data of Anti-Microbial activity

Sample Code	<i>E-Coli</i>			<i>Staphylococcus aureus</i>			<i>Trichomonas vaginalis</i>			<i>Candida albicans</i>			<i>Aspergillus niger</i>		
Concentration	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg
MRK	-	2	4	-	4	8	-	3	6	-	-	3	-	-	-
Ciprofloxacin (10µg)	24			19			NA			NA			NA		
Metronidazole (5µg)	NA			NA			22			NA			NA		
Fluconazole (25µg)	NA			NA			NA			20			17		

- = Not active

NA = Not Applicable



Kopperundevi *et al.*,**Table 2: Anti inflammatory activity of MRK**

Concentration in $\mu\text{g/ml}$	Absorbance
Control	0.917 ± 0.020
MRK 100	0.61 ± 0.098
MRK 200	0.503 ± 0.076
MRK 300	0.406 ± 0.040
MRK 400	0.296 ± 0.080
MRK 500	0.203 ± 0.045
Diclofenac sodium (100 μg)	0.023 ± 0.011

Each value represents the mean $\pm$ SD. N=3**Table 3: Anti inflammatory activity of MRK**

Concentration in $\mu\text{g/ml}$	Percentage Inhibition of Protein Denaturation
MRK 100	25.18 ± 13.2
MRK 200	36.89 ± 8.97
MRK 300	47.46 ± 4.49
MRK 400	59.34 ± 10.9
MRK 500	69.54 ± 7.22
Diclofenac sodium (100 μg)	89.22 ± 2.83

Each value represents the mean $\pm$ SD. N=3**Table 4: Percentage inhibition of test drug MRK on DPPH radical scavenging assay**

Concentration ($\mu\text{g/ml}$)	% Inhibition of Ascorbic Acid	% Inhibition of MRK
10 $\mu\text{g/ml}$	38.15 ± 3.395	7.778 ± 2.222
20 $\mu\text{g/ml}$	50.37 ± 7.398	16.67 ± 1.925
40 $\mu\text{g/ml}$	61.11 ± 6.186	23.7 ± 1.697
60 $\mu\text{g/ml}$	70.74 ± 9.45	29.63 ± 3.395
80 $\mu\text{g/ml}$	80.37 ± 2.313	35.56 ± 1.925
100 $\mu\text{g/ml}$	88.15 ± 0.6415	41.85 ± 3.395

Data are given as Mean $\pm$ SD (n=3)**Table5: IC50 Values for DPPH radical scavenging Assay by MRK and standard.**

Test Drug / Standard	IC50 Value DPPH Assay $\pm$ SD ($\mu\text{g/ml}$)
ASCORBIC ACID	23.55 ± 10.9
MRK	121 ± 12.15

Data are given as Mean $\pm$ SD (n=3)**Table 6: Percentage inhibition of test drug MRK on Nitric Oxide radical scavenging assay**

Concentration ($\mu\text{g/ml}$)	% Inhibition of MRK	% Inhibition of Gallic Acid
10 $\mu\text{g/ml}$	13.97 ± 3.772	22.57 ± 3.772
20 $\mu\text{g/ml}$	20.78 ± 3.281	37.6 ± 4.341
40 $\mu\text{g/ml}$	27.58 ± 3.873	46.56 ± 5.298
60 $\mu\text{g/ml}$	36.89 ± 1.24	66.96 ± 2.236





Kopperundevi et al.,

80 µg/ml	44.76 ± 1.86	77.35 ± 3.281
100 µg/ml	55.86 ± 3.772	88.45 ± 1.24

Data are given as Mean ± SD (n=3)

Table 7: IC50 Values for Nitric Oxide radical scavenging assay by MRK and standard

Test Drug / Standard	IC50 Value ABTS Assay ± SD (µg /ml)
MRK	42.48 ± 1.45
GALLIC ACID	89.18 ± 2.81

Data are given as Mean ± SD (n=3)

Table 8: Percentage inhibition of test drug MRK on ABTS radical scavenging assay

Concentration (µg/ml)	% Inhibition of MRK	% Inhibition of Gallic Acid
10 µg/ml	6.069 ± 2.168	31.07 ± 2.621
20 µg/ml	19.61 ± 3.658	41.14 ± 0.6014
40 µg/ml	26.9 ± 4.21	52.94 ± 1.203
60 µg/ml	32.46 ± 6.831	60.58 ± 1.804
80 µg/ml	43.22 ± 9.679	67.18 ± 7.678
100 µg/ml	55.03 ± 7.536	82.81 ± 0.6014

Data are given as Mean ± SD (n=3)

Table 9: IC50 Values for ABTS radical scavenging assay by MRK and standard

Test Drug / Standard	IC50 Value NO Assay ± SD (µg /ml)
MRK	40.41 ± 2.46
GALLIC ACID	93.74 ± 16.24

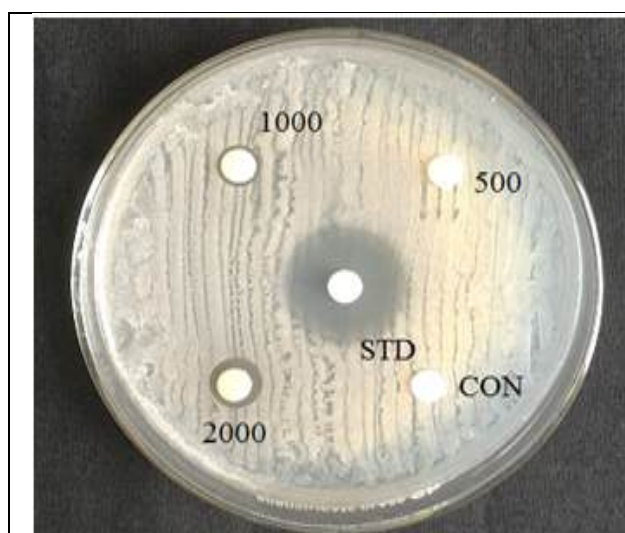


Figure 1: Anti- Microbial Effect of MRK against *Staphylococcus aureus*

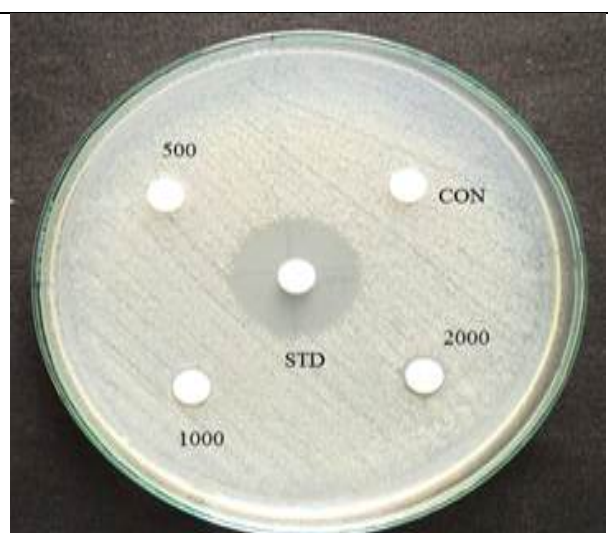


Figure 2: Anti- Microbial Effect of MRK against *E-Coli*





Kopperundevi et al.,

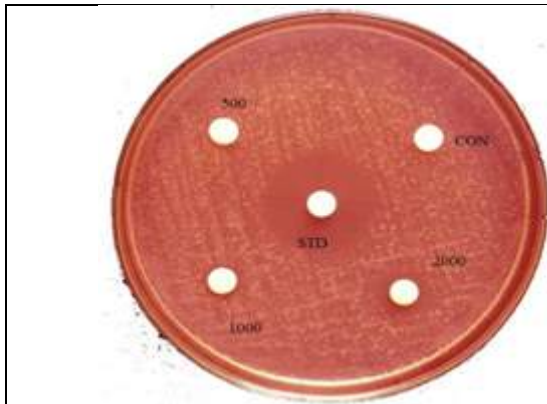


Figure 3: Anti- Microbial Effect of MRK against *Trichomonas Vaginalis*



Figure 4: Anti- Microbial Effect of MRK against *Candida albicans*



Figure 5: Anti- Microbial Effect of MRK against *Aspergillus niger*

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

The Use of Digital Marketing Strategies Impact on Consumer Purchase Intent and Brand Loyalty

A. Balamurugan^{1*}, Ramya Thiagarajan² and Anupa Mistry³

¹Professor, Department of Management Studies, School of Commerce and Management, Bharath Institute of Higher Education and Research (Deemed to be University), Chennai, Tamil Nadu, India

²Associate Professor, Department of Business Administration, School of Commerce and Management, Bharath Institute of Higher Education and Research (Deemed to be University), Chennai, Tamil Nadu, India

³Assistant Professor, Department of Business Administration, School of Commerce and Management, Bharath Institute of Higher Education and Research (Deemed to be University), Chennai, Tamil Nadu, India

Received: 13 Mar 2026

Revised: 10 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

A. Balamurugan

Professor,

Department of Management Studies,

School of Commerce and Management,

Bharath Institute of Higher Education and Research (Deemed to be University),

Chennai, Tamil Nadu, India

E.Mail: , balamurugan.mba@bharathuniv.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The influence of digital marketing tactics on customer purchase intent and brand loyalty is the focus of this study. Marketing has completely changed in the digital era, moving from conventional tactics to innovative digital ideas. This study investigates how customer purchase intent and long-term brand loyalty are affected by digital marketing tactics such as influencer relationships, email campaigns, content marketing, SEO, and social media marketing. In order to comprehend the factors influencing online customer behavior, this thesis employs a mixed-method approach, combining quantitative data from consumer surveys with qualitative interviews with marketing experts. For the quantitative survey, 300 respondents in total were chosen. This figure is enough to carry out reliable statistical analysis, such as regression and correlation, with sufficient power to find important connections between digital marketing tactics and customer purchase intent and brand loyalty. According to the results, digital marketing strategies that are tailored, interesting, and value-driven have a big impact on customers' initial intent to buy as well as their continued loyalty. The report offers useful suggestions for marketers to create successful digital strategies that promote stronger customer bonds and brand loyalty. Thus, the effect of digital marketing tactics on customer purchase intent and brand loyalty is determined. Understanding how internet marketing tools affect customer behavior and long-term brand connections is crucial for businesses due to the marketplace's fast digital transition.

Keywords: Digital Marketing, Consumer, Purchase Intent, Brand Loyalty.



Balamurugan *et al.*,

INTRODUCTION

The way companies engage with customers has changed as a result of the digital revolution. Digital marketing tactics that make use of the internet, mobile devices, social media platforms, search engines, and other digital channels have greatly eclipsed traditional marketing approaches, even if they are still relevant. These platforms enable marketers to more efficiently measure customer interaction, tailor content, and reach a wider audience. Customers are continuously exposed to targeted advertisements, influencer content, email campaigns, and tailored product suggestions in today's fiercely competitive and information-rich world. These digital marketing tactics seek to promote long-term brand loyalty in addition to increasing purchase intent. Businesses must constantly modify their digital strategies to remain relevant and competitive as customer tastes change quickly. Even while digital marketing is becoming more and more important, research on how it really affects customer behavior specifically, buy intent and brand loyalty is still ongoing. For marketers looking to create more successful campaigns and sustain a solid brand-consumer relationship, it is essential to comprehend this relationship.

Digital Marketing

Digital marketing is the deliberate use of digital platforms and internet-based technology to sell goods, services, or brands to specific people. In order to engage clients, foster connections, and increase conversions, it entails utilizing channels including websites, social media, email, search engines, and mobile applications (Chaffey & Ellis-Chadwick, 2019). Due to the quick expansion of social media, mobile connection, and internet usage, digital marketing is becoming a crucial part of contemporary corporate plans. Digital marketing allows for two-way, interactive, and real-time customer involvement, in contrast to traditional marketing, which frequently entails one-way communication through print or broadcast media. In addition to increasing brand awareness, this enables highly customized and targeted messages. Pineiro-Otero and Martínez-Rolan (2016) assert that including a website component and using the internet as a platform for diverse strategic actions are two ways to implement effective and efficient digital marketing strategies. Digital public relations, internet-based advertising, improving search engine visibility (SEO), using search engine marketing (SEM) for promotion, using social media as a marketing tool (SMM), using email as a marketing channel, electronic newsletters, affiliate marketing, content-driven promotional strategies, and many other approaches are just a few examples of the diverse range of derivative activities that fall under this category (Kannan and Li, 2017; Rizvanovic et al., 2023).

A website is a network of linked webpages maintained on a server that allows people, organizations, or groups to share information. Websites are often hosted on web servers that are reachable via networks such local area networks or the internet, as indicated by Uniform Resource Locators (URLs) Berendt and Spiliopoulou (2000). Websites are an affordable marketing tool for businesses. The literature highlights how crucial it is to integrate a well-designed website into an organization's marketing initiatives, whether they include promoting goods or services. Consumers favor businesses with attractive websites (Gibson, 2018).

Digital Marketing Capabilities

According to Trainor et al. (2011), digital marketing capabilities include an organization's ability to use online and digital technology to create meaningful interactions with customers. According to Herhausen et al. (2020), businesses obtain important insights on their clientele through these exchanges, and customers may access corporate resources and information. Additionally, define digital marketing skills as the organization's ability to effectively plan and implement digital marketing campaigns.

There are seven criteria used to evaluate a digital marketing capacity, which are listed below:

- **Planning:** Developing a comprehensive plan to incorporate digital marketing across all organizational strategies.
- **Reach:** Enhancing awareness and attracting Increasing the number of website visitors through successful marketing communication
- **Action:** Engaging with customers on internet to generate leads and foster meaningful interactions.



**Balamurugan et al.,**

- **Conversion:** Enhancing the effectiveness of sales channels such as email, website, and targeting to successfully convert leads into purchases.
- **Engage:** Enhancing customer retention and encouraging repeat purchases by putting in place methods and procedures that foster consumer loyalty and support.
- **Brand:** Forming an emotional bond with clients by utilizing more frequent interaction and communication through internet channels that emphasize the company's distinctive value offer.
- **Governance:** Executing digital transformation strategies that smoothly incorporate digital media, technology, and data into the company. This requires the strategic alignment of appropriate staff, procedures, marketing tools, and data to efficiently conduct digital marketing initiatives.

Importance of Digital Marketing in Modern Business

Digital marketing has become a key component of contemporary corporate strategy in today's increasingly linked society. Consumer behavior has drastically changed from conventional to digital channels due to the quick growth of cellphones, social media, and internet access. Due to this change, companies of all sizes are now forced to use digital marketing techniques as an essential part of their marketing campaigns rather than just as a supplemental tool. Businesses may operate beyond geographic borders thanks to digital marketing. Digital platforms enable firms to instantaneously access worldwide consumers, in contrast to conventional techniques that are constrained by geography and distribution. Businesses may interact with customers all around the world through search engines, social media, email, and mobile applications, frequently at a cheaper cost than traditional advertising. Digital marketing is more cost-effective and scalable than traditional advertising (such as TV, print, and billboards). Businesses may precisely analyze return on investment (ROI), target certain demographics, and manage budgets using pay-per-click (PPC) advertising, social media advertisements, and content marketing initiatives. Businesses and customers may communicate in both directions thanks to digital marketing. Businesses may engage with consumers, get feedback, and develop connections using social media platforms, blogs, chatbots, and email marketing. In addition to raising consumer pleasure, this interaction fosters the development of devoted brand ambassadors. Before making a purchase, consumers now use a variety of channels and gadgets. An omnichannel presence is supported by digital marketing, which guarantees consumer satisfaction and brand coherence across websites, social media, mobile applications, and email. This holistic approach significantly influences consumer purchase decisions and fosters brand trust.

REVIEW OF LITERATURE

Shams Mukhtar (2023) According to a survey, digital media has forced companies to implement digital marketing techniques in order to improve brand perception, encourage customer interaction, and guarantee client loyalty. In order to provide empirical insights into the interactions between these dimensions, this study looks at how digital marketing methods affect brand image, customer engagement, purchase intention, and loyalty. The purpose of the study is to evaluate how digital marketing tactics affect customer engagement and brand perception, as well as how these factors subsequently affect purchase intention and loyalty. Through rigorous statistical analysis, specific hypotheses are tested to determine the strength and importance of these associations. 300 respondents were given a structured questionnaire as part of a quantitative approach. Descriptive statistics, reliability analysis (Cronbach's Alpha), Pearson's correlation, and multiple regression were used to assess the correlations between digital marketing tactics, customer engagement, brand perception, purchase intention, and loyalty. Social media usage trends and demographic factors were also taken into account. The findings show that digital marketing tactics greatly improve brand image and consumer engagement, which are important factors influencing purchase intention and loyalty. In order to improve good brand views, maintain long-term loyalty, and establish brand-consumer interactions, the study emphasizes how important it is for firms to use interactive and consumer-centric digital marketing strategies.



**Balamurugan et al.,**

The changing effects of new digital technology and ethical issues in digital marketing tactics should be investigated in future studies.

Kumar et al. (2024) the impact of company-generated social media content on consumer behavior. Marketing Journal. This study emphasized the importance of company-generated content on Twitter and Facebook. It came to the conclusion that, particularly when combined with user-generated material, this kind of content boosts consumer spending and fosters enduring loyalty. This study investigated the use of social media marketing (SMM) by luxury companies to affect consumer behavior and brand equity. It was discovered that brand preference and purchase intention are strongly influenced by social media content's interaction, entertainment value, and trendiness.

METHODOLOGY

The study employed a Descriptive Design methodology, gathering information from both Primary and Secondary sources. Primary Data was gathered through surveys and face-to-face interviews using a structured questionnaire for Providing predefined options for participants to select from. We gathered secondary information from various sources such as books, the internet, digital platforms, and social media websites. Random sampling was employed, with a sample size of 200 respondents. This study adopts a combining both quantitative and qualitative approaches to gain a comprehensive understanding of how digital marketing strategies influence consumer purchase intent and brand loyalty. The quantitative method provides measurable data on consumer behavior patterns, while the qualitative approach offers deeper insights into consumer attitudes and motivations.

Significance of the study

For marketers, companies, and digital strategists looking to improve the efficacy of their online efforts, this research offers insightful information. This research supports more focused and customer-focused marketing strategies by pinpointing the precise tactics that affect purchase intent and loyalty. It fills in the gaps in current research and makes recommendations for future lines of inquiry by offering a modern viewpoint on the theoretical frameworks that explain consumer reactions to digital interaction. The study is important because it closes the gap between consumer psychology and marketing strategy in the digital sphere, providing insightful information for a range of stakeholders engaged in developing and reacting to digital marketing strategies. By providing empirical insights into the efficacy of digital methods in influencing customer behavior, this study adds to the scholarly and professional conversation on digital marketing. The study will determine certain relationships between digital marketing initiatives and important consumer indicators including engagement, brand perception, purchase intention, and loyalty by thoroughly evaluating ideas. Additionally, the study offers prescriptive insights for businesses looking to maintain competitive advantage in the changing digital world, enhance their digital branding initiatives, and create consumer-centric marketing strategies. Future research on consumer behavior analytics, digital marketing trends, and the incorporation of developing technology into marketing strategies will also benefit from the findings of this study.

Objectives

The primary objectives of this study are:

- To examine the influence of various digital marketing strategies on consumer purchase intent.
- To assess the relationship between digital marketing engagement and brand loyalty.
- To identify the most effective digital marketing tactics in fostering consumer trust and long-term relationships.

Hypotheses

- There will be significant positive relationship between the use of digital marketing strategies and consumer purchase intent.
- There will be significant difference between increased consumer engagement with digital marketing content with higher levels of brand loyalty.





- There will be significant difference between Personalized and interactive digital marketing tactics consumer trust and contribute to long-term brand relationships.

Sampling size

The study's sample size was chosen to strike a compromise between practicality and representativeness. For the quantitative survey, 300 respondents in total were chosen. This figure is enough to carry out reliable statistical analysis, such regression and correlation, with sufficient power to find important connections between digital marketing tactics and customer purchase intent and brand loyalty. Fifteen people were specifically chosen from the survey respondents to take part in in-depth interviews for the qualitative portion. This smaller sample size preserves the richness of qualitative data while enabling in-depth investigation of specific customer experiences and perspectives. The sample size was selected in accordance with conventional marketing research guidelines, which state that 10–20 interviews are usually required for qualitative research to attain topic saturation and that respondents are deemed suitable for survey-based studies combining several variables.

Data collection

In order to provide thorough insights on how digital marketing techniques affect customer purchase intent and brand loyalty, this study used both primary and secondary data gathering approaches. Using Google Forms, a structured online survey was created and sent to the 300 respondents in the target sample. To make statistical analysis easier, the questionnaire included a 5-point Likert scale for attitudinal items, ranging from "Strongly Disagree" to "Strongly Agree." Fifteen respondents were chosen for follow-up interviews in order to supplement the survey results and get qualitative insights into their perspectives and experiences with digital marketing. The interviews lasted around 20 to 30 minutes apiece and were conducted over the phone or via video conferencing. In order to give theoretical underpinnings and help data interpretation, pertinent academic publications, books, and industry reports on digital marketing, consumer behavior, and brand loyalty were examined.

Statistical tools used

The statistical tools used for SPSS Software, version 25.0 was used to carry out analysis. The analysis techniques are:

- Descriptive Analysis (Tabulation, Percentage, Mean, etc.)
- Independent-samples t-test
- Chi-Square
- Pearson Correlation
- Multiple Regression

RESULT AND DISCUSSION

The sample population's demographics assist evaluate how representative the data is of the target market and offer context for the conclusions. There are 51.7% female respondents and 48.3% male respondents in the sample. The almost equal distribution indicates a gender representation that is balanced, guaranteeing that both male and female viewpoints are included in the conclusions derived from the data. Gender may affect how customers interact with digital marketing material and react to brand messaging, so striking this balance is crucial. With fewer participation in the older age categories, the bulk of respondents (40%) are between the ages of 18 and 24, followed by those between the ages of 25 and 34 (31.7%). Of the participants, 56.7% have undergraduate degrees, 30% have finished graduate school, and 13.3% have "other" educational backgrounds.

The strength and direction of the association between digital marketing tactics and two important consumer outcomes—purchase intent and brand loyalty—were investigated using the Pearson correlation analysis. Purchase intent and brand loyalty are strongly positively correlated ($r > 0.50$) with social media marketing, content marketing, and influencer marketing. These findings suggest that consumers are more likely to make a purchase and stick with a business when they engage with these digital marketing tactics. The strong link indicates that customers are very



**Balamurugan et al.,**

receptive to online tactics that are interesting, genuine, and content-driven. Following influencers may help consumers believe their product recommendations, which improves both initial purchasing decisions and long-term emotional ties to the companies they support.

Gender and brand loyalty are statistically significantly correlated, according to the Chi-square test ($\chi^2 = 6.214$, $p = 0.045$). Compared to male respondents, female respondents expressed greater levels of brand loyalty. This implies that when creating focused campaigns, digital marketing techniques may have a somewhat greater emotional or trust-building impact on female customers. The results of the above table indicate that the five digital marketing methods account for 58% of the variation in customer purchase intent. When it comes to influencing customer purchasing decisions, social media marketing has the most influence ($\beta = 0.31$). Influencer marketing and content also play a major role. Despite being less powerful predictors, email and SEO/SEM are statistically significant, indicating that they aid in decision-making, particularly during the conversion phase. The aforementioned data indicates that the average brand loyalty score of female respondents is considerably greater than that of male respondents. This suggests that female customers are a strategically significant category for loyalty-building campaigns because they may react more emotionally or regularly to digital marketing initiatives.

FINDINGS

The following important conclusions were drawn from the descriptive, correlation, regression, ANOVA, and cross-tabulation statistical analyses:

- According to the results, social media marketing was shown to be the best predictor of consumer purchase intent ($\beta = 0.31$, $p < 0.001$), followed by influencer and content marketing.
- Purchase intent was positively impacted by all five techniques (including email marketing and SEO/SEM) in a statistically significant way ($R^2 = 0.58$). Customers are more likely to make a purchase when they engage with businesses through interesting digital channels.
- Brand loyalty was most strongly impacted by content marketing ($\beta = 0.29$, $p < 0.001$), indicating that meaningful and pertinent material is essential to establishing enduring connections.
- Influencer marketing and social media also demonstrated significant results, highlighting their significance for continuous interaction. 55% of the variance in brand loyalty was explained by the regression model ($R^2 = 0.55$), suggesting a significant overall impact of digital marketing initiatives.

CONCLUSION

The purpose of this study was to look at how customer purchase intent and brand loyalty are affected by digital marketing tactics. Understanding how internet marketing tools affect customer behavior and long-term brand connections is crucial for businesses due to the marketplace's fast digital transition. The study discovered that digital marketing tactics, namely influencer relationships, social media marketing, content marketing, and customized email campaigns, had a statistically significant impact on customer purchase intent based on the data gathered and examined. These tactics successfully boost engagement, perceived value, and product awareness, which in turn motivates customers to make purchases. Additionally, the results corroborate the idea that brand loyalty is significantly shaped by digital marketing. Digital interactions that are value-driven, customized, and consistent have been demonstrated to increase consumer trust, brand attachment, and repeat purchase behavior. In particular, loyalty indicators like customer retention and brand advocacy were most strongly correlated with social media involvement and email customization. This study adds to the body of knowledge by demonstrating that digital marketing plays a crucial role in fostering enduring client connections and loyalty in addition to being a tool for attracting new clients. It emphasizes how important it is for companies to create their digital marketing campaigns using a data-driven and customer-centric approach.





REFERENCES

1. Noyola-Medina, A., Pinzon-Castro, S., & Maldonado-Guzman, G. (2018). Innovation and Digital Marketing Adoption in Mexican Small Business. *Journal of Management and Sustainability*, 8(2), 18.
2. Anand, N., Thomas, C., Jain, P. A., Bhat, A., Thomas, C., Prathyusha, P. V., Aiyappa, S., Bhat, S., Young, K., & Cherian, A. V. (2018). Internet Use Behaviors, Internet Addiction and Psychological Distress Among Medical College Students: A Multi Centre Study from South India. *Asian Journal of Psychiatry*, 37, 71-77.
3. Rong-An, S., Yu-Chen, C., & Shen, L. (2005, March). Extrinsic Versus Intrinsic Motivations for Consumers to Shop On-Line. *Information & Management*, 42(3), 401-413.
4. Richards, K. A., & Jones, E. (2008 April). Customer Relationship Management : Finding Value Drivers. *Industrial Marketing Management*, 37(2), 120-130
5. Chaffey, D., & Smith, P. R. (2022a, July 22). *Digital Marketing Excellence: Planning, Optimizing and Integrating Online Marketing*. Taylor & Francis, 676.
6. Royle, J., & Laing, A. (2014, April). The Digital Marketing Skills Gap : Developing a Digital Marketer Model for the Communication Industries. *International Journal of Information Management*, 34(2), 65-73.
7. Mimmo, S. S., Roy, A., & Billal, S. A. (2025). Integrating artificial intelligence across the fashion value chain: AI transforming design, production, and consumer experience. *Applied IT & Engineering*, 3(1), 1–10. <https://doi.org/10.25163/engineering.3110210>.
8. Nylén, D., & Holmström, J. (2015, January-February). Digital Innovation Strategy: A Framework for Diagnosing and Improving Digital Product and Service Innovation. *Business Horizons*, 58(1), 57-67.
9. Odoom, R., Odoom, P. T., Amu, P. Y., & Adams, M. (2025). Sustainable digital marketing practices and consumer brand engagement – a brand reputation mediation investigation. *Journal of Strategic Marketing*, 1–17. <https://doi.org/10.1080/0965254X.2025.2453690>.
10. Tasnim, K., Abdullah, M. S., Karim, M. Z., & Hasan, R. (2025). AI-driven innovation, privacy issues, and gaining consumer trust: The future of digital marketing. *Business & Social Sciences*, 3(1), 1–7. <https://doi.org/10.25163/business.3110212>.
11. Tochukwu Ignatius Ijomah, Courage Idemudia, Nsiong Louis Eyo-Udo, & Kikelomo Fadilat Anjorin. (2024). Innovative digital marketing strategies for SMEs: Driving competitive advantage and sustainable growth. *International Journal of Management & Entrepreneurship Research*, 6(7), 2173–2188. <https://doi.org/10.51594/ijmer.v6i7.1265>
12. Yasmin, A., Tasneem, S., & Fatema, K. (2015, April). Effectiveness of Digital Marketing in the Challenging Age: An Empirical Study. *The International Journal of Management Science and Business Administration*, 1(5), 69-80.
13. Ezzaouia, I., & Bulchand-Gidumal, J. (2020, April). Factors Influencing the Adoption of Information Technology in the Hotel Industry. An Analysis in a Developing Country. *Tourism Management Perspectives*, 34, 100675.

Table: 1 Demographic Profile of Respondents

Variable	Category	N	Percent
Gender	Male	145	48.3%
	Female	155	51.7%
Age	18–24	120	40.0%
	25–34	95	31.7%
	35–44	50	16.7%
	45 and above	35	11.6%
Education	Undergraduate	170	56.7%
	Postgraduate	90	30.0%
	Other	40	13.3%



Balamurugan *et al.*,**Table: 2 The relationship between digital marketing strategies and consumer behavior**

Variable	Purchase Intent	Brand Loyalty
Social Media Marketing	0.65**	0.62**
Influencer Marketing	0.58**	0.59**
Content Marketing	0.60**	0.63**
Email Marketing	0.42**	0.47**
SEO/SEM	0.50**	0.54**

Table: 3 Gender and Brand Loyalty Response

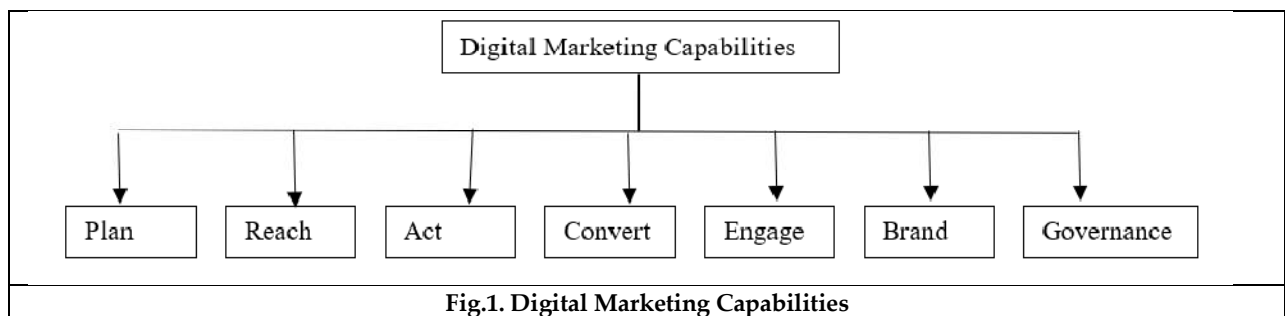
Brand Loyalty Level	Male (%)	Female (%)
High	58%	65%
Medium	32%	28%
Low	10%	7%
Chi-Square	6.214	p = 0.045

Table: 4 Multiple Regression for Predictors of Purchase Intent Regression Coefficients

Predictor	Unstandardized B	Standardized β	t	p-value
Social Media Marketing	0.415	0.31	6.25	0.000**
Influencer Marketing	0.362	0.25	4.80	0.000**
Content Marketing	0.288	0.21	4.01	0.000**
Email Marketing	0.142	0.10	1.98	0.049*
SEO/SEM	0.155	0.13	2.45	0.015*

Table: 5 Showing mean, S.D and t-value respondents level of Perceived Brand Loyalty based gender

Gender	Mean	Std. Deviation	t-value	p-value
Male	4.03	0.72	2.89	0.004**
Female	4.26	0.70		



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Influence of Ladder and SAQ Training on Selected Motor Fitness Parameters Among Basketball Players

D. Boopathi*

Assistant Professor, Department of Physical Education, National College, (Affiliated to Bharathidasan University), Tiruchirapalli, Tamil Nadu, India

Received: 15 Mar 2026

Revised: 17 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

D. Boopathi

Assistant Professor,

Department of Physical Education,

National College, (Affiliated to Bharathidasan University),

Tiruchirapalli, Tamil Nadu, India

E.Mail: boopathype@nct.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The study sought to investigate the influence of ladder and saq training on selected motor fitness parameters among basketball players. To achieve the purpose of the study (N=60) sixty men basketball players were selected from National college, Tiruchirapalli, Tamilnadu, India as subjects. The age of the subjects ranged from 19 to 25 years. The selected subjects were divided into three equal groups (N=20). Group I underwent ladder training. Group II underwent saq training. Group III acted as control group who did not undergo any specialized training program other than their daily routine. The motor fitness parameters such as speed, agility, leg explosive power. Were selected as dependent variables and they were assessed by 50m dash, 3x10 shuttle run, standing broad jump respectively. The subjects were concerned with their particular training for a period of six weeks, three days per week. The collected data from three groups prior to and immediately after the training programme on selected criterion variables were statistically analyzed with analysis of covariance (ANCOVA). The level of confidence was fixed at 0.05 for all the cases to test the hypothesis. The result of the study reveals that the ladder training and saq training groups achieved significant improvement on selected respiratory variables such as speed, agility, leg explosive power of college men basketball players.

Keywords: Ladder Training, Saq Training, Motor Fitness Parameters, Speed, Agility and Leg Explosive Power.





INTRODUCTION

Basketball

Basketball is one of the most popular sports in the world. Participations of all ages have discovered basketball to be fun, competitive, educational, and recreational and fitness oriented. Individual skills such as shooting, passing, dribbling and rebounding along with offensive and defensive teamwork are prerequisites for successful participation in the sport (TeWierike SC, de Jong MC, Tromp EJ, Vuijk PJ, Lemmink KA, Malina RM, Elferink-Gemser MT, Visscher C (2014). Although the traditional 5-on-5 game is probably the most popular basketball format over the year a wide assortment of fun basketball related games and competitions have evolved to help participants develop fundamental skills and knowledge. The type of game or competition played will depend on available equipment, player skill level and number of participants. Regardless of game or competition format, basketball participation can be enriching and provide lifelong enjoyment to participants who choose to “tie up the laces” and play the game (Diana Star Helmer& Tomas s Owens, 2000).

Ladder Training

Ladder training is the multi-directional training, because the elements of strength, power, balance, agility, co-ordination, proprioception, core and joint stability, foot speed, hand eye coordination, reaction time and mobility. Each component should be integrated in to daily training session. Ladder skills are fun and functional ways to teach movement skills. By training, the mind and body to understand a verity of foot combinations. There are four basic skills is used when training with ladder. Runs, skips, shuffles and jump/hops. Ladder drills are fun and functional ways to teach movement skills (Arul Deva Paul, P. &Dr. D Sakthignanavel (2017). Although linear and lateral movements are biomechanical simple, their combination can be complex and many times overwhelming for the athlete. Buy teaching the mind and body to understand a variety of foot combinations, the chance for confusion and subsequent error decreases. Ladder drills should be learned in a slow controlled environment. Introducing movement skills too rapidly can ingrain poor motor patterns that may be difficult to override. Skilled movement should be optimized before the drill is advanced. The training incorporates three different types of drills. The first types of drill are steady state drills. These drills focus on quickness endurance and utilize a constant rhythm throughout the ladder. The second types of drill are burst drills. These drills focus on the ability to turn on rapid burst of foot movement. The third types of drill are elastic response drills. These drills focus on improving the reactive speed components of the lower leg. Ladder drills are also called as speed ladder drills are very important for any sport where agility, leg explosive strength, aerobic capacity and speed are important. It will greatly improve the player's footwork which will improve player's quickness, agility and coordination after constantly performing different speed ladder training. Drills for agility ladder training should be done right after warming up so that the muscles are fresh and ready to give 100% under correct form (Brown & Ferrigno, 2014).

SAQ Training

The demand to promote athletic ability is continually increasing for this SAQ training becoming a popular way to train athlete. SAQ training has proven to enhance the abilities of participants in different sports. This training improves the skills which is helpful for every sport where movements of arm fast & leg is required. Therefore all athletes should integrate to SAQ training (BujjiBabu., & Jhonson. (2012). Earlier SAQ training was not practiced by athlete due to lack of education regarding specific benefits and how it should involve in a complete training program. These training acts are a bridge between the gap of traditional resistance training & functional specific movements. Benefits of SAQ training increase the ability to exert maximal force while high speed movements it also include increased muscular power in all multi planner movements, reaction time,, motor skills, brain signal efficiency. With the acquisition of greater balance & reaction time an athlete is able to maintain proper body position at the time of skill execution and also react more pro efficiently in changing playing environment Devaraju, D. (2014).



**Boopathi****Objectives**

This study was designed to investigate the influence of ladder and saq training on selected motor fitness parameters among basketball players.

METHODOLOGY

To achieve the purpose of the study (N=60) sixty men basketball players were selected from National college, Tiruchirapalli, Tamilnadu, India as subjects. The age of the subjects ranged from 19 to 25 years. The selected subjects were divided into three equal groups (N=20). Group I underwent ladder training. Group II underwent saq training. Group III acted as control group who did not undergo any specialized training program other than their daily routine. The motor fitness parameters such as speed, agility, leg explosive power. Were selected as dependent variables and they were assessed by 50m dash, 3x10 shuttle run, standing broad jump respectively. The subjects were concerned with their particular training for a period of six weeks, three days per week. The collected data from three groups prior to and immediately after the training programme on selected criterion variables were statistically analyzed with analysis of covariance (ANCOVA). The level of confidence was fixed at 0.05 for all the cases to test the hypothesis.

RESULTS

The pre, post-test and adjusted post-test mean values of Speed on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 7.36, 7.09, 7.05: 7.38, 7.14, 7.07 and 7.28, 7.39, 7.42 respectively. The pre, post-test and adjusted post-test mean values of Agility on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 13.68, 12.60, 12.48: 13.79, 12.74, 12.60 and 13.75, 13.00, 12.80 respectively. The pre, post-test and adjusted post-test mean values of Leg explosive power on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 2.32, 2.80, 2.80: 2.32, 2.53, 2.53 and 2.32, 2.53, 2.53 respectively. The obtained F values of adjusted post-test were greater than the table value of 3.16. Hence it was proved that there were significant improvements on speed, agility and leg explosive power of college basketball players.

DISCUSSION ON FINDINGS

The results of the study indicates that the experimental group namely as ladder training and saq training had significantly improved in the selected dependent variables speed, agility and leg explosive power improvement caused by ladder training and saq training. The results of the studies are in line with the studies of (Abbas, H. H. (2023).

CONCLUSION

The experimental groups namely as ladder training and saq training had achieved significant improvement on selected the motor fitness parameters such as speed, agility and leg explosive power when compared to control group. It was concluded that saq training shown better improvement when comparing to the ladder training groups on selected the motor fitness parameter. It was concluded that college level player should practice both ladder training and saq training for positive enhancement of playing.





Boopathi

REFERENCES

1. TeWierike SC, de Jong MC, Tromp EJ, Vuijk PJ, Lemmink KA, Malina RM, Elferink-Gemser MT, Visscher C (2014) "Development of repeated sprint ability in talented youth basketball players" *Journal of Strength and Conditioning Research*, Apr;28(4):928-34.
2. Diana Star Helmer, Tomas s Owens (2000) "The history of basketball", the Rosen Publishing Group, Inc, New York.
3. Arul Deva Paul, P. &Dr. D Sakthignanavel (2017). Circadian rhythm based 16 week ladder and circuit training programme for selected strength related variables on sports Homo sapiens. *International Journal of Yoga, Physiotherapy and Physical Education*, 2, 5,165-168.
4. Brown, L., &Ferrigno, V. (Eds.). (2014). *Training for Speed, Agility, and Quickness*, 3rd Edition. Human Kinetics.
5. BujjiBabu.,&Jhonson. (2012). Effect of Plyometric Training and Speed Agility and Quickness (Saq) Training on Speed and Agility of Male Handball Players. *Asian Journal of Physical Education and Computer Science in Sports*, 7(1), 26-30.
6. Devaraju, D. (2014). The purpose of the study was to examine the effect of S.A.Q training on vital capacity among Hockey players. *International Journal of Management*, 5(1), 102-105.
7. Abbas, H. H. (2023), The Effect of (Saq) Exercises On the Development of Some Physical and Motor Abilities and Basic Skills in Football Junior Category. *Sciences Journal of Physical Education*, 16(3). PP-702-722.

Table 1: Computation of Analysis of Covariance of Means of Ladder Training and Saq Trainingand Control GroupsSpeed, Agility, Leg Explosive Power.

Variable	Test Type	LTG Mean	STG Mean	CG Mean	Source	df	SS	MS	F-Ratio
Speed	Pre	7.36	7.38	7.28	Between	2	0.07	0.03	0.27
					Within	57	6.54	0.11	
	Post	7.09	7.14	7.39	Between	2	3.20	1.6	7.08*
					Within	57	12.90	0.226	
	Adjusted	7.05	7.07	7.42	Between	2	0.86	0.43	10.75*
					Within	56	2.07	0.04	
Agility	Pre	13.68	13.79	13.75	Between	2	0.28	0.14	0.43
					Within	57	18.78	0.32	
	Post	12.60	12.74	13.00	Between	2	1.28	0.64	4.26*
					Within	57	8.41	0.15	
	Adjusted	12.48	12.60	12.80	Between	2	5.38	2.69	15.82*
					Within	56	9.58	0.17	
Leg Explosive Power	Pre	2.32	2.32	2.32	Between	2	106.71	53.36	2.08
					Within	57	1085.87	19.05	
	Post	2.80	2.53	2.53	Between	2	196.84	98.42	3.91*
					Within	57	1433.47	25.14	
	Adjusted	2.80	2.53	2.53	Between	2	11.87	5.94	6.99*
					Within	56	47.37	0.85	

*Significantat 0.05level of confidence. (Table value required for significantat 0.05level of confidence were 3.16 respectively.





Boopathi

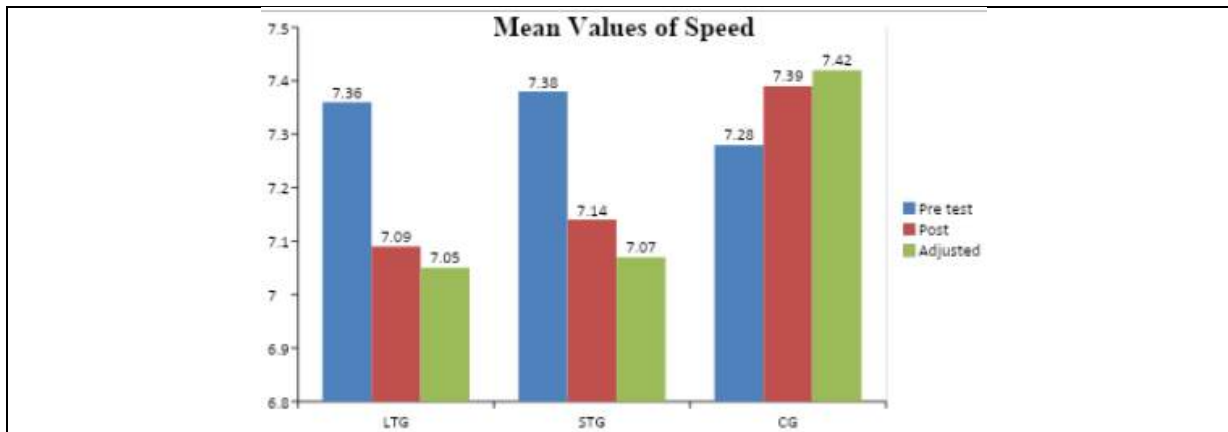


Figure-1: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Speed.

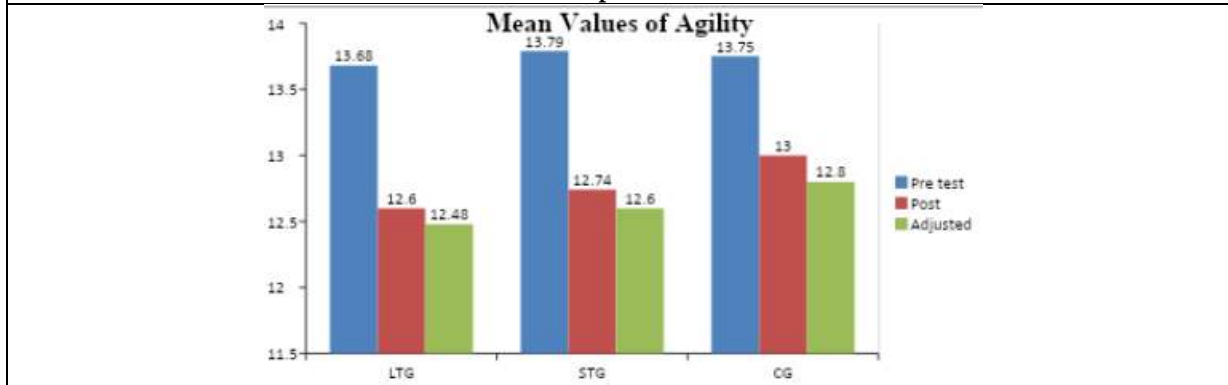


Figure-1I: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Agility.

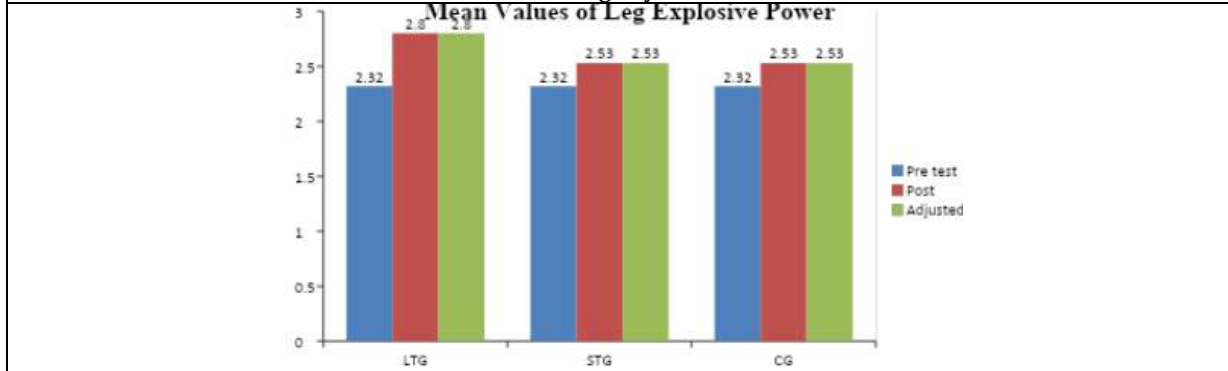


Figure-1II: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Leg Explosive Power.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Isolation of A Novel Antitubercular Dihydrofuranone from *Clausena brevistyla* Fruits

Ganapathy Sankari Subramanian¹, Jeyachandran Malaichamy^{2*} and Ponsadai Lakshmi Subramanian

¹Research Scholar (Reg. No. 19131232032002), Department of Chemistry and Research Centre, Sri Paramakalyani College, Alwarkurichi, Tenkasi (Affiliated to Manonmaniam Sundaranar University, Tirunelveli), Tamil Nadu, India

²Associate Professor, Department of Chemistry and Research Centre, Sri Paramakalyani College, Alwarkurichi, Tenkasi (Affiliated to Manonmaniam Sundaranar University, Tirunelveli), Tamil Nadu, India.

³Professor, Department of Science and Humanities, E.G.S. Pillay Engineering College, Nagapattinam, (Affiliated to Anna University, Chennai), Tamil Nadu, India

Received: 10 Mar 2026

Revised: 11 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

Jeyachandran Malaichamy

Associate Professor,

Department of Chemistry and Research Centre,

Sri Paramakalyani College, Alwarkurichi, Tenkasi

(Affiliated to Manonmaniam Sundaranar University, Tirunelveli),

Tamil Nadu, India.

E.Mail: jeyachandranm@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

An ethanolic extract of *Clausena brevistyla* fruits contains a novel dihydrofuranone, which was isolated and structurally elucidated by using complete spectroscopic analysis. Its molecular structure was unambiguously established through detailed analysis of 1D (¹H, ¹³C, and DEPT-135) and 2D (H-H COSY, HSQC, and HMBC) NMR spectra, supported by high-resolution LC-MS data. HR-LCMS profiling of the fruit extract revealed fifty-three major constituents, including aliphatic acids, aromatic carboxylic acids, phenolic acids, amino acids, flavonoids, and carbohydrates. The isolated dihydrofuranone exhibited antitubercular activity against *Mycobacterium tuberculosis* with a minimum inhibitory concentration of 0.91 µg/mL.

Keywords: *Clausena brevistyla*, Phytochemical profiling, Dihydrofuranone, NMR spectroscopy, HR-LCMS, Antitubercular activity





INTRODUCTION

Natural products have long served as a major source of novel drugs [1]. Of 217 natural product-inspired antibiotics approved between 1943 and September 2025, nearly one fourth of the molecules (52) are natural products, while three fourth (165) are semi-synthetic or synthetic derivatives [2]. Despite these advances, tuberculosis (TB) remains a serious global health concern, with rising mortality, particularly in developing countries. The World Health Organization (WHO) continues to monitor disease trends and support TB research initiatives worldwide [3]. Members of the genus *Clausena* are widely distributed and have been extensively investigated for their phytochemical and pharmacological properties. A number of *Clausena* species are used for conventional medicines [4]. Although, *Clausena* genus consists of approximately 30 species, amongst *Clausena brevistyla* remains relatively underexplored. Remarkably, *C. brevistyla* has been reported to have anti-inflammatory and analgesic properties. It also serves as a food source for the larval stages of certain Australian butterflies [5]. In this context, a comprehensive and systematic analysis is necessary for the identification of secondary metabolites and, to find out the biological applications may provide the improvement of traditional knowledge about the medicinal plants. This prompted us to examine the phytochemicals of *C. brevistyla* and their biological activities. Advanced spectroscopic techniques, including high-resolution LC-MS and one- and two-dimensional NMR, are routinely engaged to define molecular frameworks and connectivity. Such widespread structural study provides perfect support for molecular identity and forms the foundation for correlating chemical structure with biological activity. Accordingly, the present study reports the phytochemical investigation of *Clausena brevistyla* fruits (**Figure 1**), HR-LCMS profiling, isolation and structural elucidation of a novel dihydrofuranone and evaluation of antitubercular activity. Fig. 1 *Clausena brevistyla* fruits

Experimental

Measurements and reagents

1D and 2D NMR spectra were recorded on a Bruker Avance 500 MHz FT-NMR Spectrometer. Silica gel G was used for TLC and preparative TLC. Silica gel 60–120 mesh served as the stationary phase for column chromatography. HRLCMS analyses were performed using an Agilent Technologies 1290 Infinity UHPLC System joined with a 1260 Infinity HPLC with Chip Cube as well as a 6550 iFunnel Q-TOF mass spectrometer.

Plant Material

Clausena brevistyla fruits were collected in January 2023 from Alwarkurichi (8°47'29.4"N, 77°23'40.3"E), Tenkasi district, Tamil Nadu, India. The plant material was authenticated by Dr. K. Petchimuthu, Taxonomist, Sri KGS Arts College, Srivaikundam, and a voucher specimen was deposited for future reference.

Extraction and isolation

Approximately 500 g of *C. brevistyla* fruits were soaked in 1 L of ethanol for one week at room temperature. The mixture was filtered, and the solvent was removed under reduced pressure to yield 63 g of a brown, pasty crude extract (CBE), which was stored at 4 °C for further analysis.

Preliminary Phytochemical Analysis

The ethanolic extract of *Clausena brevistyla* fruits (CBE) was fractionated sequentially using *n*-hexane, chloroform, ethyl acetate, acetonitrile, and methanol. Each fraction was subjected to standard preliminary phytochemical tests to detect the presence of foremost classes of secondary metabolites.

Fractionation and isolation of Novel compound

Slurry was prepared by mixing 30 g of the ethanolic extract (CBE) with 25 mL of hot ethanol and 50 g of silica gel (60–120 mesh) for column chromatography. The dried slurry was re-extracted with increasing polarity of solvents like petroleum ether, chloroform, ethyl acetate, and ethanol by using Soxhlet extractor. The solvents of each re-extracts were removed *in vacuo* and stored at 4 °C for further analysis. A pale yellow spot on TLC was observed from the ethyl acetate re-extract. This extract was dissolved on the same solvent and applied to 41 preparative TLC plates,





Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

which were developed using an ethyl acetate–methanol mixture (9.5:0.5, v/v). After drying, three bands were visually observed, of which 32 plates exhibited the pale yellow band ($R_f = 0.49$). The corresponding silica gel was scraped and extracted with methanol (150 mL) in a Soxhlet apparatus. Removal of the solvent under reduced pressure yielded 23 mg of the purified compound I as a pale yellow powder.

Characterization of novel dihydrofuranone, (Compound I)

Molecular formula : $C_{20}H_{30}O_5$; Molecular weight : 350.46.

IR (KBr) : 3300 (OH str.), 1720 (C=O str). cm^{-1} .

^1H -NMR (DMSO- d_6 , 500 MHz, δ , ppm): 0.65 (s, 3H, C-8a methyl), 1.08 (s, 3H, C-5 methyl), 1.17 (m, 2H, C-4 CH_2), 1.30 (m, 1H, C-4a CH), 1.62 -1.96 (m, 6H) (C-4, C-8 and C-2'' CH_2), 2.30 -2.45 (m, 2H, C-3 CH_2), 3.82 (doublet of doublet, 2H, $J = 3.0$ Hz and $J = 11.0$ Hz, C-5 CH_2 -OH), 4.02, 4.38 (doublet of doublet, 2H, $J = 6.0$ Hz and $J = 10.0$ Hz, C-5' CH_2), 4.13 (doublet of doublet, 1H, $J = 3.0$ Hz and $J = 7.5$ Hz, C-6 CH), 4.62; 4.81 (s, 1H, C-2 C= CH_2), 4.90 (t, 1H, $J = 6.0$ Hz and $J = 6.5$ Hz, C-4' CH -OH), 5.07 (d, 1H, $J = 4.5$ Hz, C-6 OH), 5.72 (d, 1H, $J = 6.5$ Hz, C-5' CH_2), 6.60 (doublet of triplet, 1H, $J = 1.0$ Hz, $J = 1.5$ Hz and $J = 6.5$ Hz, C-1'' CH). ^{13}C -NMR (DMSO- d_6 , 125 MHz, δ , ppm): 15.21 (C-8a methyl carbon), 23.53 (C-5 methyl carbon), 24.41 (C-4 CH_2), 24.44 (C-2' methylene carbon), 28.34 (C-7 methylene carbon), 36.96 (C-8 methylene carbon), 37.96 (C-3 methylene carbon), 40.45 (C-8a quarternary carbon), 42.73 (C-5 quarternary carbon), 54.81 (C-4a methine carbon), 55.93 (C-1), 63.10 (C-5 CH_2 -OH), 64.96 (C-4' methine carbon), 74.80 (C-5' methylene carbon), 78.89 (C-6 methine carbon), 108.72 (C-2 C= CH_2), 129.43 (C-3' quarternary C), 146.78 (C-1'' methine carbon), 148.05 (C-2 C= CH_2) and 170.43 (C-2' C=O). DEPT-135 (δ , ppm): 15.20 (C-8a CH_3), 23.54 (C-5 CH_3), 24.38 (C-4 CH_2), 24.44 (C-2' CH_2), 28.33 (C-7 CH_2), 36.97 (C-8 CH_2), 37.96 (C-3 CH_2), 54.81 (C-4a CH), 55.93 (C-1), 63.10 (C-5 CH_2 -OH), 64.96 (C-4' CH), 74.80 (C-5' CH_2), 78.88 (C-6 CH), 108.75 (C-2 C= CH_2), and 146.79 (C-1'' CH).

Antitubercular activity

Compound I was evaluated for its antimycobacterial behaviour against *Mycobacterium tuberculosis* H37Rv by the MTT-based MABA [6]. The MIC was determined as the lowest concentration of **Compound I** that prohibited the change of colour from blue to pink, demonstrating complete bacterial growth inhibition.

ADMET analysis

The *in silico* absorption, distribution, metabolism, and excretion (ADMET) properties of compound I were predicted using the SwissADME online tool.

RESULTS AND DISCUSSION

Pilot Phytochemical Analysis

The pilot phytochemical screening of *Clausena brevistyla* fruit extracts established that the composition of secondary metabolites is strongly influenced by the polarity of the extraction solvent (**Table 1**). As summarized in **Table 1**, a clear trend is observed in which the number and diversity of phytoconstituents increase with solvent polarity. Specifically, *n*-hexane extract, being non-polar, exhibited the least diversity, contained two major metabolites (triterpenoids and xanthoproteins), chloroform and acetonitrile extracts contained three (triterpenoids, saponins, tannins), ethyl acetate extract contained five (reducing sugars, alkaloids, saponins, xanthoproteins, and aromatic acids), acetonitrile extract contained three (steroids, alkaloids, and flavonoids) and methanol extract contained richest profile of seven metabolites (triterpenoids, reducing sugars, phenolic compounds, saponins, xanthoproteins, flavonoids, and aromatic acids). Despite providing valuable preliminary insights, these qualitative phytochemical tests have limited sensitivity and may not detect minor or trace constituents. Consequently, HR-LCMS analysis was performed to achieve a comprehensive and precise metabolite profiling of *C. brevistyla* fruits, resulting the identification of both major and minor bioactive compounds.

HR-LCMS Analysis

The HR-LCMS analysis (**Figure 2, Table 2**) led to the identification of 53 compounds belonging to miscellaneous compounds, together with 18 aliphatic acids, 4 aromatic carboxylic acids, 23 phenolic acids, 2 amino acids, 3



**Ganapathy Sankari Subramanian and Jeyachandran Malaichamy**

flavonoids, and 3 carbohydrate derivatives. The chromatogram displayed prominent peaks at early retention times (1–3 min), 11 aliphatic carboxylic acids, 2 aromatic carboxylic acids, 9 phenolic acids, 1 flavonoid and a carbohydrate. Mid-range retention times (10–30 min) are conquered by 4 aliphatic carboxylic acids, 1 aromatic carboxylic acid, 8 phenolic acids, 1 amino acid, 2 flavonoids and 2 carbohydrates. Peaks observed at higher retention times (>30 min) correspond to a complex carbohydrate and a phenolic acid. The HR-LCMS results thus confirm that *C. brevistyla* fruits are a rich source of bioactive metabolites, complementing the preliminary phytochemical screening and providing a complete chemical profile.

IR Spectra:

The IR spectrum exhibited characteristic absorption bands at 3300 cm^{-1} is due to the hydroxyl group and 1720 cm^{-1} is due to the carbonyl functionality (**Figure 3**).

¹H NMR Analysis

In the ¹H NMR spectrum of **compound I**, the two isolated methyl groups attached to quaternary carbons at C-8a and C-5 appeared as singlets at δ 0.65 and 1.08 ppm, respectively. Vinylic methylene protons at C-2 (C=CH₂) appeared at δ 4.62 and 4.81 ppm. The C-3 methylene, C-4 methylene and C-5 hydroxy methylene protons of decahydronaphthalene moiety resonated at δ 2.45, 1.17, and 3.82 ppm, respectively. Methylene protons of dihydrofuranone moiety at C-2'' appear δ 4.02 and 4.32 ppm. The tertiary methine protons of decahydronaphthalene moiety C-4a and C-6 resonated at δ 1.30 and 4.13 ppm, respectively, while the tertiary methine protons of dihydrofuranone moiety at C-4' appears at δ 4.90 ppm. The C-1'' methane proton resonates at δ 6.60 ppm (**Figure 4**).

¹³C NMR Analysis

In the ¹³C NMR spectrum of **compound I**, the carbonyl group present in C-2' appears at δ 170.43 ppm. Quaternary carbons C-2, C-5 and C-8a of decahydronaphthalene moiety resonated at δ 148.05, 42.73 and 40.45 ppm, respectively, whereas the quaternary carbon of dihydrofuranone moiety C-3' resonates at δ 129.43 ppm. The two methyl carbons (C-5 and C-8a) appeared at δ 23.53 and 15.21 ppm. Eight methylene carbons C-2 (C=CH₂), C-3, C-4, C-5 (CH₂-OH), C-7, C-8, C-5' and C-2'' were observed δ 108.72, 37.96, 24.41, 63.10, 28.33, 74.80 and 24.44 ppm, respectively. Five methine carbons present at C-1, C-4a, C-6, C-4' and C-1'' resonated at δ 55.93, 54.81, 78.89, 64.96 and 146.78 ppm (**Figure 5**).

DEPT-135 Analysis

In DEPT-135 spectra, positive signals corresponded to the two methyl groups C-5 and C-8a appears at δ 23.54 and 15.20 ppm respectively. The five methine carbons (C-1, C-4a, C-6, C-4', C-1''), while the eight methylene carbons ((C-2 (C=CH₂), C-3, C-4, C-5 (CH₂-OH), C-7, C-8, C-5' and C-2'')) showed negative signals. The nonexistence of quaternary carbons in DEPT confirms earlier ¹³C assignments (**Figure 6**).

HMBC technique

HMBC helps identify long-range connections between "H" and "C" atoms in **compound I**. In the HMBC spectra, the C-8a hydrogen (methyl protons) correlated with the carbons of C-8 (δ 36.96 ppm) and C-4a (δ 54.81 ppm) suggested that two and three bond correlations. The C-5 hydrogen (methyl protons) showed correlations with the carbons of C-5 (δ 42.73 ppm), C-4a (δ 54.81 ppm), C-5 CH₂-OH (δ 63.10 ppm), and C-6 (δ 78.89 ppm), that suggests two, three, two and three bond correlations respectively. The C-5' methylene hydrogens are linked with the carbons of C-2' carbonyl and C-5 hydroxy methine carbon suggests that three and two bond correlations respectively (**Figure 7**). Further correlations of methylene and methine protons are summarized in **Table 3** and illustrated in **Figure 8**. Based on these spectroscopic evidences, the structure of the novel compound was confirmed as 4-Hydroxy-3-(2-(6-hydroxy-5-(hydroxymethyl)-5,8a-dimethyl-2-methylenedeca-hydronaphthalen-1-yl)ethylidene)dihydrofuran-2(3H)-one (**Compound I**) (**Figure 9**).

Fig. 12. HMBC correlation.



**Ganapathy Sankari Subramanian and Jeyachandran Malaichamy****Antitubercular activity**

The in vitro activity of compound I against *Mycobacterium tuberculosis* H37Rv was evaluated using the MABA assay, and the MIC values are summarized in **Table 4** [7]. Compound I exhibited the maximum potency, with an MIC of 0.91 µg/mL, surpassing the activity of standard drugs ethambutol, and ciprofloxacin.

In silico ADMET Analysis

ADMET properties of compound I were predicted using the SwissADME tool. The compound (MW = 350 g/mol, TPSA = 86.99 Å², three rotatable bonds) showed favorable oral bioavailability. A consensus LogP of 2.30 indicated optimal lipophilicity and membrane permeability. Additionally, SwissADME predictions prove that the **compound I** has high gastrointestinal absorption and low risk of drug–drug interactions and also supports the drug-like pharmacokinetic profile.

CONCLUSION

An ethanolic extract of *Clausena brevistyla* fruits contains a novel dihydrofuranone, which was isolated, and completely characterized using 1D and 2D NMR spectra. HR-LCMS profiling revealed 53 major constituents, including aliphatic acids, aromatic carboxylic acids, phenolic acids, amino acids, flavonoids, and carbohydrates. The isolated dihydrofuranone exhibited potent antitubercular activity against *Mycobacterium tuberculosis* (MIC = 0.91 µg/mL). Overall, *C. brevistyla* fruits are a promising source of bioactive compounds with potential applications in biomedical research and sustainable nanotechnology.

ACKNOWLEDGEMENT

The authors thankfully acknowledge the DST-FIST instrumentation facility at Sri Paramakalyani College.

REFERENCES

1. David, J, Newmann., Gordon, M, Cragg. Natural Products as Sources of New Drugs over the Nearly Four Decades from 01/1981 to 09/2019, Journal of Natural Products, 2020, 83 (3), 770-803. <https://doi.org/10.1021/acs.jnatprod.9b01285>
2. Butler, Mark S., Capon, Robert J. Natural product inspired antibiotics approved for human use – 1943 to 2025. Nat Prod Rep. 2026. <https://doi.org/10.1039/D5NP00067J>
3. WHO consolidated guidelines on tuberculosis. Module 4: treatment - drug-susceptible tuberculosis treatment. Geneva: World Health Organization; 2022. Licence: CC BY-NC-SA 3.0 IGO.
4. Ismail A D A M Arab, A review of traditional uses, phytochemical and pharmacological aspects of selected members of *Clausena* genus (Rutaceae). Journal of Medicinal Plants Research, 2012, 6 (38), 5107. <https://doi.org/10.5897/JMPR12.317>
5. Australian Tropical Rainforest Plants, https://apps.lucidcentral.org/rainforest/text/entities/clausena_brevistyla.htm
6. Sarojini, P., Jeyachandran, M., Sriram, D., Ranganathan, P., Gandhimathi, S. Facile microwave-assisted synthesis and antitubercular evaluation of novel aziridine derivatives, Journal of Molecular Structure. 2021, 1233, 130038. <https://doi.org/10.1016/j.molstruc.2021.130038>
7. Jeyachandran, M., Ramesh, P., Sriram, D., Senthilkumar, P., Yogeewari, P. Synthesis and *in vitro* antitubercular activity of 4-aryl/alkylsulfonylmethylcoumarins as inhibitors of *Mycobacterium tuberculosis*. Bioorg. Med. Chem. Lett. 2012, 22, 4807–4819. <https://doi.org/10.1016/j.bmcl.2012.05.054>





Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

Table 1: Primary phytochemical analysis of *C. brevistyla* Fruits

Phyto constituents	Results for different extracts				
	<i>n</i> -Heaxane	CHCl ₃	EtOAc	CH ₃ CN	MeOH
Steriods	--	--	--	--	--
Triterpenoids	++	++	--	++	++
Reducing sugar	--	--	++	--	++
Alkaloids	--	--	++	++	--
Phenolic compound	--	--	--	--	++
Saponin	--	--	--	--	++
Xanthoproteins	++	--	++	--	++
Tannins	--	++	--	--	--
Flavonoids	--	--	--	++	++
Aromatic acids	--	++	++	--	++

Table 2: HRLCMS Analysis of ethanolic extract of *C. brevistyla* Fruits

Compound type	Name of the compounds	M.F.	RT	m/z
Aliphatic acids	Azelaic acid	C ₉ H ₁₆ O ₄	11.258	188.10
	Suberic acid	C ₈ H ₁₄ O ₄	1.246	174.09
	Oleic Acid	C ₁₈ H ₃₄ O ₂	1.585	282.26
	Palmitic Acid	C ₁₆ H ₃₂ O ₂	1.402	256.24
	<i>trans</i> -Petroselinic Acid	C ₁₈ H ₃₄ O ₂	21.302	282.26
	Linoleic acid	C ₁₈ H ₃₂ O ₂	10.562	280.24
	Methylsuccinic acid	C ₅ H ₈ O ₄	10.429	132.04
	9,10-dihydroxy-12-octadecenoic acid	C ₁₈ H ₃₄ O ₄	4.882	132.04
	6-Hydroxycaproic acid	C ₆ H ₁₂ O ₃	3.375	180.04
	DL-Mandelic acid	C ₈ H ₈ O ₃	1.767	138.03
	16- Hydroxyhexadecanoic acid	C ₁₆ H ₃₂ O ₃	1.15	138.03
	Ethylmalonic acid	C ₅ H ₈ O ₄	1.315	138.03
	16 -Hydroxyhexadecanoic acid	C ₁₆ H ₃₂ O ₃	1.761	154.03
	Ethylmalonic acid	C ₅ H ₈ O ₄	1.306	170.02
	Linolenic Acid	C ₁₈ H ₃₀ O ₂	1.678	138.03
	Citric acid	C ₆ H ₈ O ₇	1.623	152.05
	D-(-)-Quinic acid	C ₇ H ₁₂ O ₆	29.573	153.04
	Itaconic acid	C ₅ H ₆ O ₄	22.707	270.05
Aromatic Carboxylic acids	Benzoic acid	C ₇ H ₆ O ₂	1.762	286.05
	Caffeic acid	C ₉ H ₈ O ₄	1.534	153.04
	4-Anisic acid	C ₈ H ₈ O ₃	29.13	9.9
	3-Hydroxypicolinic acid	C ₆ H ₅ NO ₃	1.76	10
Phenolic acids	3-Hydroxybenzoic acid	C ₇ H ₆ O ₃	1.651	76.1
	Salicylic acid	C ₇ H ₆ O ₃	29.919	10
	2,5- Dihydroxybenzaldehyde	C ₇ H ₆ O ₃	1.765	9
	3,5- Dihydroxybenzoic acid	C ₇ H ₆ O ₄	2.129	83.4





Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

	4-Hydroxybenzoic acid	C ₇ H ₆ O ₃	8.299	9.9
	Gallic acid	C ₇ H ₆ O ₅	3.249	70.2
	1- Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	1.576	10
	2- Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	1.327	9.1
	Homogentisic acid	C ₈ H ₈ O ₄	1.369	98.7
	Gentisic acid	C ₇ H ₆ O ₄	2.128	9
	Isovanillic acid	C ₈ H ₈ O ₄	1.97	10
	4-Hydroxymandelic acid	C ₈ H ₈ O ₄	23.507	8.3
	3-Hydroxymandelic acid	C ₈ H ₈ O ₄	31.171	47.3
	Vanillic acid	C ₈ H ₈ O ₄	25.177	9.9
	Protocatechuic acid	C ₇ H ₆ O ₄	20.105	9.3
	5-Methoxysalicylic acid	C ₈ H ₈ O ₄	20.862	94.3
	3,4-Dihydroxyphenylpropionic acid	C ₉ H ₁₀ O ₄	29.358	69.6
	Isoferulic acid	C ₁₀ H ₁₀ O ₄	1.875	35
	Ferulic acid	C ₁₀ H ₁₀ O ₄	10.57	9.9
	3 Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	9.053	47.1
	Homovanillic acid	C ₉ H ₁₀ O ₄	18.129	8.3
Amino acids	3- Hydroxyanthranilic acid	C ₇ H ₇ NO ₃	8.8	8.3
	Xanthurenic acid	C ₁₀ H ₇ NO ₄	32.577	8.1
Flavanoids	Genistein	C ₁₅ H ₁₀ O ₅	1.399	9.9
	Apigenin	C ₁₅ H ₁₀ O ₅	29.169	8.4
	Luteolin	C ₁₅ H ₁₀ O ₆	25.368	7.8
Carbohydrates	(3β-9ξ)-3-(β D-Glucopyranosyloxy)-14-hydroxycard20(22)-enolide	C ₂₉ H ₄₄ O ₉	1.762	9.3
	Quercetin-3β-Dglucoside	C ₂₁ H ₂₀ O ₁₂	23.596	8.4
	3-(β-D-Glucopyranosyloxy) -14-hydroxycarda-5,20(22)-dienolide	C ₂₉ H ₄₂ O ₉	31.095	9.8

Table 3: Correlation spectra

Position	HMBC
0.65 (s, 3H, C-8a $\underline{\text{CH}}_3$)	36.96 (C-8), 54.81 (C-4a)
1.08 (s, 3H, C-5 $\underline{\text{CH}}_3$)	42.73 (C-5), 54.81 (C-4a), 63.10 (C-5 hydroxy methylene), 78.89 (C-6)
3.82 (dd, 2H, J= 3.0 Hz and J=11.0 Hz, C-5 $\underline{\text{CH}}_2$ -OH)	23.53 (C-5 $\underline{\text{CH}}_3$), 54.81 (C-4a), 78.89 (C-6)
4.02, 4.38 (dd, 2H, J= 6.0 Hz and J=10.0 Hz, C-5' $\underline{\text{CH}}_2$)	170.43 (C-2' C=O), 63.10 (C-5 $\underline{\text{CH}}_2$ OH)
4.13 (dd, 1H, J= 3.0 Hz and J=7.5 Hz, C-6 $\underline{\text{CH}}$)	63.10 (C-5 $\underline{\text{CH}}_2$ OH), 42.73 (C-5 quarternary C)
4.62; 4.81 (s, 1H, C-2 C= $\underline{\text{CH}}_2$)	55.93 (C-1), 37.96 (C-3)
4.90 (t, 1H, J=6.0 Hz and J=6.5Hz, C-4' $\underline{\text{CH}}$ -OH)	170.43 (C-2' C=O)
5.07 (d, 1H, J=4.5 Hz, C-6 $\underline{\text{OH}}$)	78.89 (C-6 $\underline{\text{CH}}$), 63.10 (C-5 $\underline{\text{CH}}_2$ OH), 42.73 (C-4a quarternary C), 28.33 (C-7 $\underline{\text{CH}}_2$)



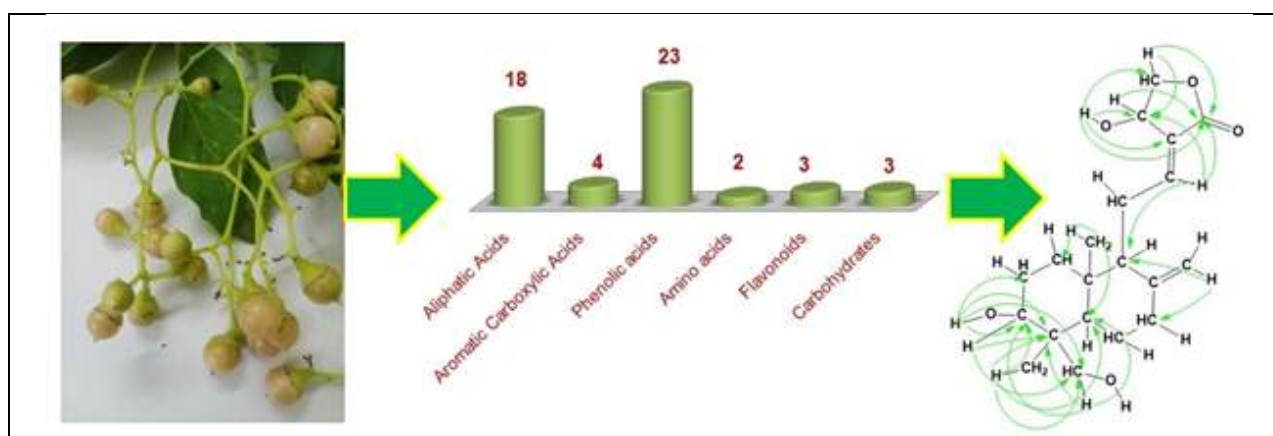


Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

5.72 (d, 1H, J=6.5 Hz, C-5' $\underline{\text{CH}}_2$)	170.43 (C-2' C=O), 129.43 (C-3' quarternary C), 64.96 (C-4' $\underline{\text{CH}}$)
6.60 (dt, 1H, J= 1.0 Hz, J= 1.5 Hz and J= 6.5 Hz, C-1'' $\underline{\text{CH}}$)	170.43 (C-2' C=O), 64.96 (C-4' $\underline{\text{CH}}$), 55.93 (C-1)

Table 4: Antitubercular activity of compound I

Compound	MIC($\mu\text{g/mL}$)
Compound I	0.91
Isoniazid	0.15
Rifampicin	0.25
Ethambutol	1.50
Ciprofloxacin	1.52



Graphical Abstract

Fig. 1 *Clausena brevistyla* fruits

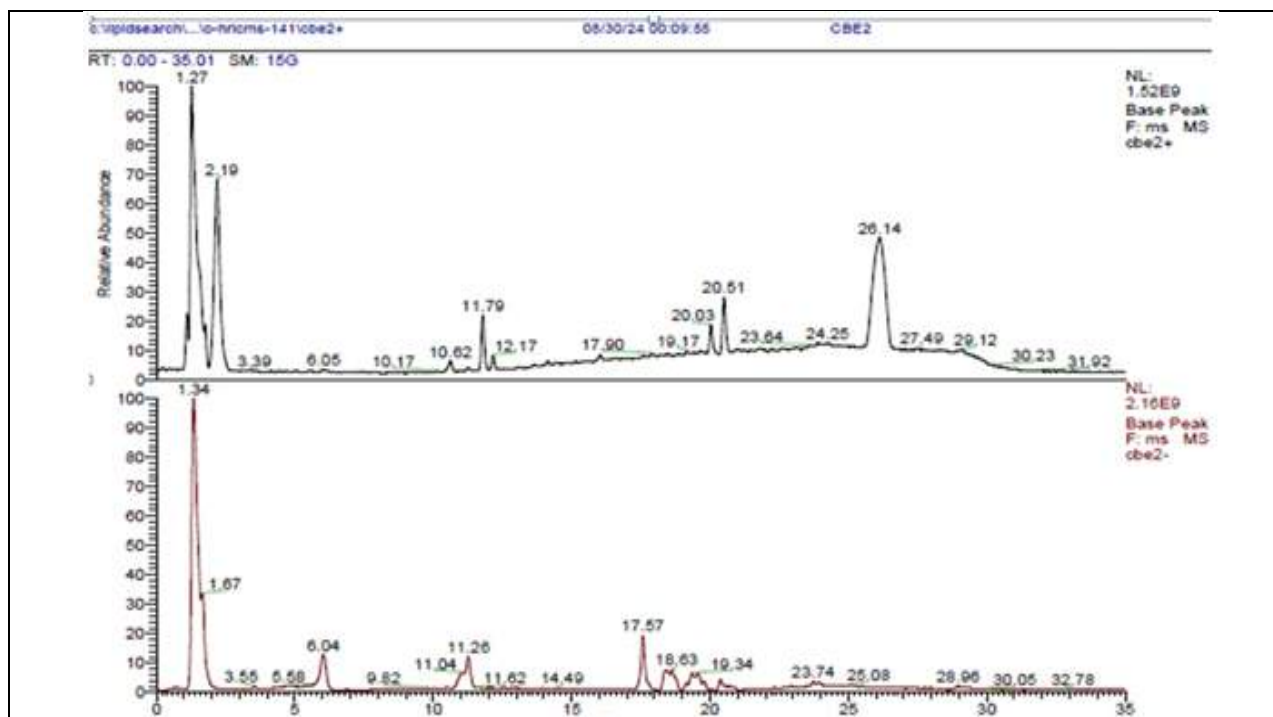


Fig. 2 HPLCMS chromatogram

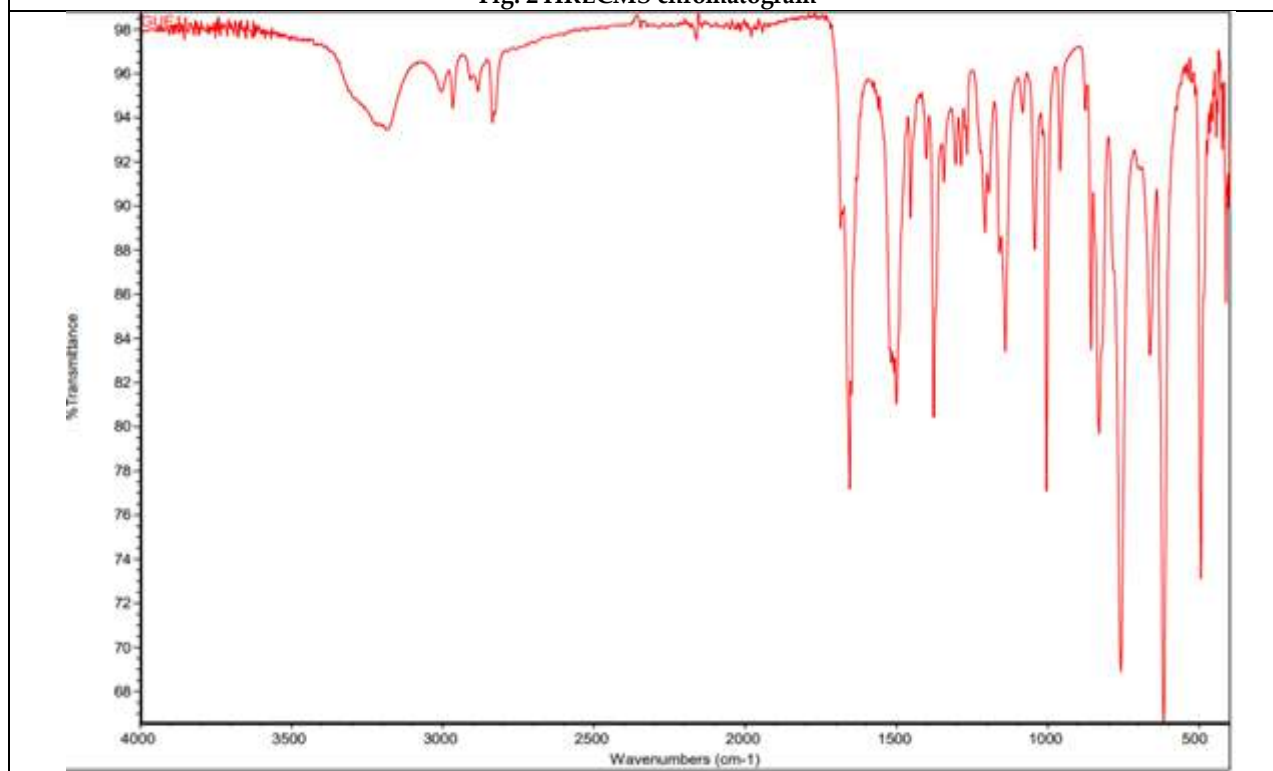


Fig. 3IR Spectra for compound I



Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

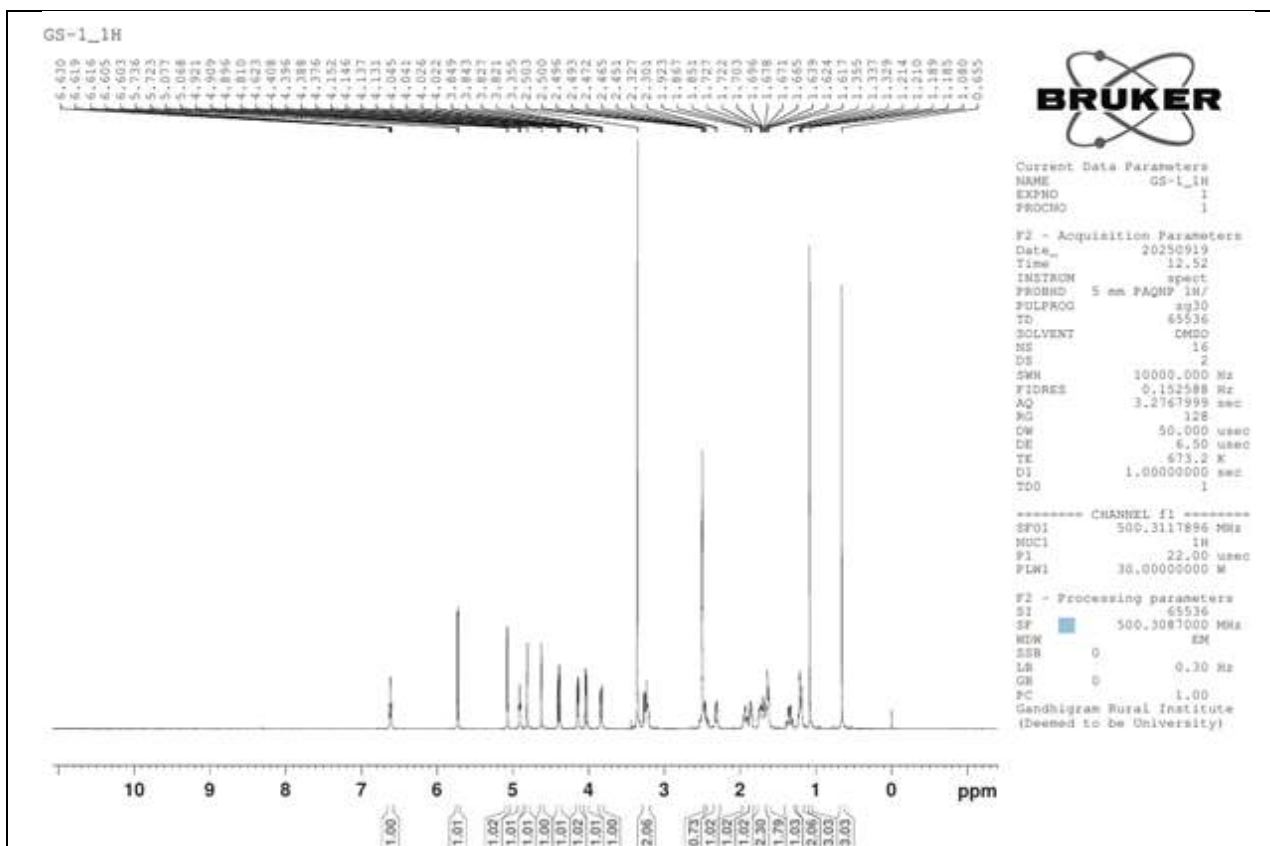


Fig. ^1H -NMR for compound I

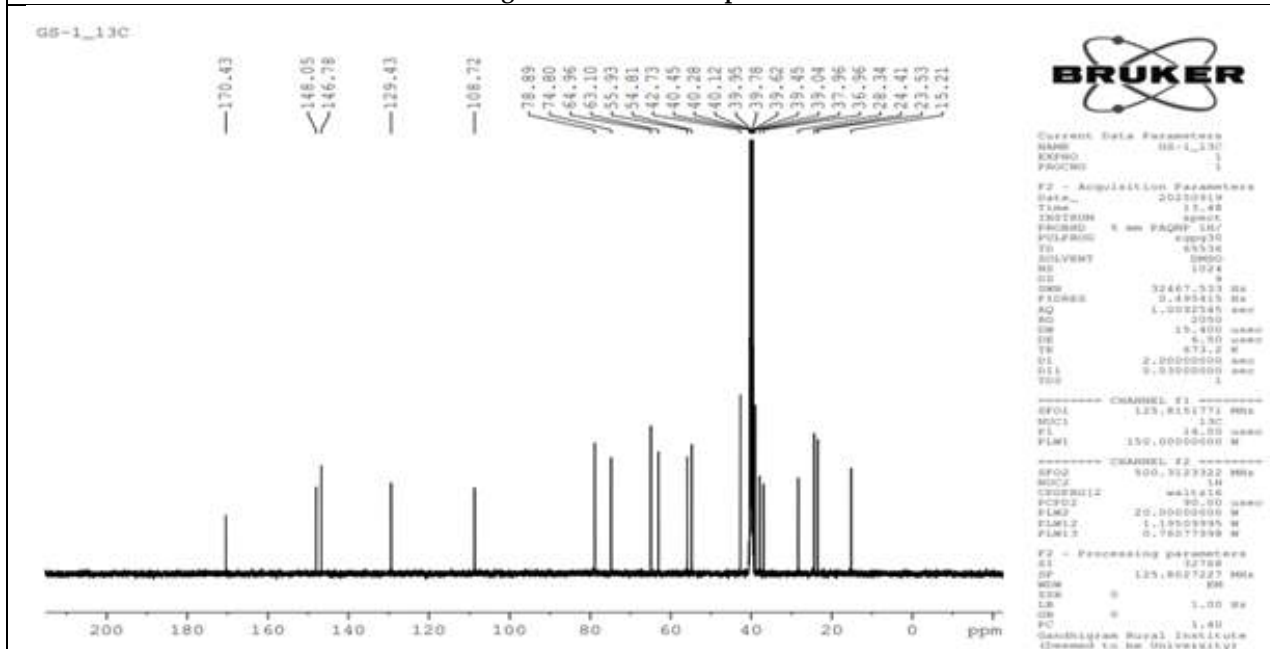


Fig. ^{513}C -NMR for compound I





Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

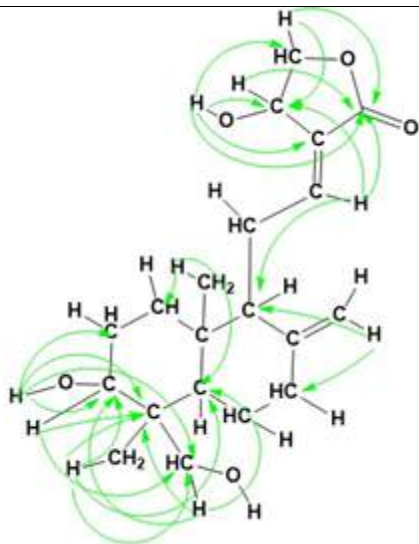


Fig. 8 HMBC correlation for compound I

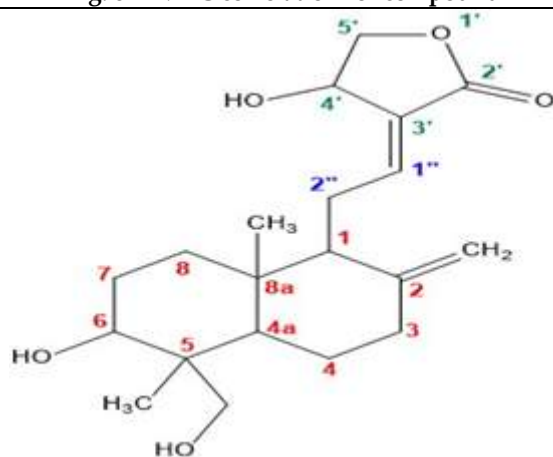


Fig.9. Compound I

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Effectiveness of Tissue Glue and Silk Sutures After Periodontal Flap Surgery : A Split - Mouth Clinical Study

Shweta Vikhe^{1*}, Shivani Sachdeva², Amit Mani³ and Sakshi Takale¹

¹PG Student, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

²Professor, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

³Professor and HOD, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

Received: 10 Mar 2026

Revised: 12 Apr 2026

Accepted: 22 May 2026

*Address for Correspondence

Shweta Vikhe

PG Student,

Department of Periodontology,

Rural Dental College,

Pravara Institute of Medical Sciences,

Loni, Maharashtra, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Primary wound closure after periodontal flap surgery is critical for optimal healing and patient comfort. Traditionally, silk sutures have been used for flap approximation. However, tissue adhesives such as isoamyl 2-cyanoacrylate have emerged as promising alternatives due to their haemostatic, bacteriostatic, and patient-friendly properties. To compare the effectiveness of tissue glue (isoamyl 2-cyanoacrylate) and silk sutures in periodontal flap closure with respect to healing, pain, bleeding, and clinical outcomes.

A split-mouth randomized controlled clinical trial was conducted on 30 patients (13 males, 17 females) aged 31–60 years with Stage III periodontitis indicated for periodontal flap surgery. Each patient received tissue glue closure on one side (test group) and silk sutures on the contralateral side (control group). Clinical parameters assessed were Plaque Index (PI), Gingival Index (GI), Healing Index (HI), Probing Pocket Depth (PPD), Clinical Attachment Level (CAL), post-operative pain and bleeding (VAS scale), and time taken for flap closure. Data were statistically analysed using paired and unpaired Student's *t*-tests at 5% and 1% significance levels. Both groups demonstrated significant improvement in clinical parameters from baseline to follow-up. Test group showed significantly superior healing at 3 days and 1 week ($p=0.0001$). Post-operative pain was significantly lower in the test group on day 2 ($p=0.0001$). No significant difference between groups, though minimal bleeding was observed with tissue glue. PPD and Both groups showed significant reduction from baseline to 3 months ($p=0.0001$), with no intergroup difference. Significantly less in the test group (2.38 ± 0.78 mins) than control (7.09 ± 1.40 mins) ($p=0.0001$).



**Shweta Vikhe et al.,**

Isoamyl 2-cyanoacrylate tissue adhesive is an effective, faster, and less painful alternative to silk sutures for flap closure following periodontal surgery. It offers excellent early wound healing and superior patient comfort without compromising clinical outcomes.

Keywords: tissue, wound, clinical, parameters, surgery

INTRODUCTION

Periodontal flap surgery is a fundamental procedure in the treatment of periodontitis aimed at gaining access for thorough debridement and root surface management. Achieving primary wound closure and favourable healing are essential determinants of surgical success.ⁱ Traditionally, sutures such as silk have been employed to approximate flap margins; however, their use is often associated with patient discomfort, plaque accumulation, and delayed healing.ⁱⁱ Tissue adhesives like cyanoacrylates, on the other hand, provide a rapid, painless, and bacteriostatic means of wound closure, forming a strong bond within seconds of application.ⁱⁱⁱ Isoamyl 2-cyanoacrylate, a biocompatible adhesive, has shown promising results in various surgical fields. This study was undertaken to clinically compare the effectiveness of tissue glue and silk sutures following periodontal flap surgery using a split-mouth design.^{iv} The aim of the present study was to compare the effectiveness of tissue glue (Iso Amyl 2-Cyanoacrylate) and silk sutures after periodontal flap closure.

MATERIALS AND METHODS

Study Design and Population

This experimental, split-mouth, randomized controlled clinical trial was conducted in the Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni. The study protocol received ethical approval (Ref: PMT/DR/RDC/2022/514) and was registered under CTRI/2023/07/055464.

A total of 30 patients (13 males, 17 females; aged 31–60 years) diagnosed with Stage III periodontitis (AAP 2017 classification) were included.

Inclusion Criteria

- Adults aged 31–60 years
- Probing pocket depth (PPD) ≥ 5 mm
- Willingness to provide informed consent and attend follow-ups

Exclusion Criteria

- Systemic illness affecting periodontal healing
- Allergy to cyanoacrylate
- Pregnancy or lactation
- Tobacco use or smoking
- Bleeding disorders or anticoagulant therapy
- Periodontal treatment within the past year

Randomization

A lottery method was used for random allocation. The selected side for tissue glue was considered the **test site (Group B)**, while the contralateral side with silk sutures served as the **control site (Group A)**. Figure 1 depicts flow chart of the study





Surgical Procedure

After Phase I therapy (scaling and root planing), flap surgery was performed under local anesthesia. Full-thickness mucoperiosteal flaps were reflected, debridement was carried out, and the flaps were repositioned.

- **Group A:** Flap margins approximated with 3-0 silk sutures.
- **Group B:** Flap margins sealed using isoamyl 2-cyanoacrylate applied dropwise until a thin film formed.

Patients were prescribed antibiotics and 0.12% chlorhexidine rinses and followed up at 3 days, 7 days, 14 days, 1 month, and 3 months.

Clinical Parameters

- Plaque Index (Silness and Loe, 1964) – Baseline, 7 days, and 1 month
- Gingival Index (Loe and Silness, 1963) – Baseline to 1 month
- Healing Index (Landry et al., 1988) – 3 days to 1 month
- Probing Pocket Depth (PPD) – Baseline and 3 months
- Clinical Attachment Level (CAL) – Baseline and 3 months
- Post-operative pain and bleeding – VAS at days 1–5 and 1–3 respectively
- Time for flap closure – Measured in minutes

FIGURE 2 : (2a) & (2b): Pre-Operative Clinical Photograph: Assessment of Probing Pocket Depth at Baseline, (2c): Clinical Photograph of Periodontal Flap Reflection and Debridement, (2d): Cyanoacrylate Application on the Test Site, (2e): Clinical Photograph: Periodontal Flap Closure with Silk Sutures on Control Site and Cyanoacrylate on Test Site, (2f) & (2g): Post-Operative Clinical Photograph: Assessment of Probing Pocket Depth at 3 Months

Statistical Analysis

Data were analyzed using SYSTAT version 12. Student's paired *t*-test was used for intragroup comparison, and unpaired *t*-test for intergroup analysis. A *p*-value ≤ 0.05 was considered statistically significant.

RESULTS

Demographics

The study included 30 participants (13 males, 17 females) with a mean age of 38.13 ± 6.23 years.

Plaque Index

Plaque index increased at 1 week and reduced significantly by 1 month. Comparison of mean values of Plaque Index at baseline, 1 week and 1 month post-operatively are depicted in **graph 1**.

Gingival Index

There was a significant reduction in GI from baseline (1.99 ± 0.59) to 1 month (0.47 ± 0.26). Comparison of mean values of Gingival Index at baseline, 3 days, 1 week, 2 weeks and 1 month post-operatively are depicted in **graph 2**.

Healing Index

Group B (tissue glue) showed significantly higher Healing Index at 3 days (3.43 ± 0.50) and 1 week (4.23 ± 0.43) compared to Group A. No significant difference was observed at 2 weeks and 1 month. Comparison of mean values of Healing Index in Group A and Group B at 3 days, 1 week, 2 weeks and 1 month post-operatively are depicted in **graph 3**.

Probing Pocket Depth

Both groups showed significant reduction from baseline to 3 months, but intergroup difference was not significant. Comparison of mean values of Probing Pocket Depth in Group A and Group B at baseline and 3 months post-operatively are depicted in **graph 4**.

Clinical Attachment Level

Significant gain in CAL from baseline to 3 months was observed in both groups, with no intergroup difference. Comparison of mean values of Clinical Attachment Level in Group A and Group B at baseline and 3 months post-operatively are depicted in **graph 5**.



Shweta Vikhe *et al.*,**Post-operative Pain**

Pain scores were significantly lower in the test group on day 2. No significant difference was noted on other days.

Post-operative Bleeding

Minimal bleeding was observed on day 1 in the control group (0.23 ± 0.43), while no bleeding occurred in the test group. The difference was not statistically significant.

Time for Flap Closure

Closure time was significantly shorter with tissue glue (2.38 ± 0.78 min) compared to sutures (7.09 ± 1.40 min).

DISCUSSION

The results of the present study demonstrate that isoamyl 2-cyanoacrylate is a reliable alternative to silk sutures for flap closure in periodontal surgery. The faster healing and reduced post-operative discomfort observed with tissue glue can be attributed to its rapid polymerization and hemostatic properties.^v Comparable improvements in PPD and CAL between the two groups indicate that use of tissue adhesive does not compromise the clinical outcome. Similar findings were reported by Khurana *et al.*^{vi} (2016), who also noted better early healing with cyanoacrylate compared to silk sutures. Additionally, the significant reduction in operative time and improved patient comfort highlight the clinical advantages of tissue glue, particularly in multiple quadrant surgeries or patients with limited tolerance for lengthy procedures. Ashoka *et al.*^{vii} (2005) employed Octyl cyanoacrylate to close neck incisions in cancer patients and discovered it to be an effective alternative to sutures. Babu *et al.*^{viii} (2005) discovered that isoamyl cyanoacrylate outperformed butyl cyanoacrylate in the healing of surgical incisions over the neck. S. Kondoh *et al.*^{ix} (2003) applied this material impregnated in gauze as a treatment on alveolopalatal wounds following alveolar bone grafting. Rewainy, Osman and El-Prince^x (2015) found a substantial reduction in hemostasis when standard silk sutures and soft tissue glue cyanoacrylate were used to close the mucoperiosteal flap after surgical extraction of mandibular impacted third molars. Vaaka *et al.*^{xi} (2018) found that patients treated with cyanoacrylate had a lower incidence of wound infection than individuals whose wounds were closed with 3-0 black braided silk suture. When it comes to intraoral wound coaptation following open flap debridement, Kaur *et al.*^{xii} (2020) compared cyanoacrylate to braided silk sutures and discovered that the cyanoacrylate was superior to the silk sutures due to its reduced tissue reaction, immediate hemostasis, relative painlessness, and ability to prevent wound infection and dehiscence.

CONCLUSION

Isoamyl 2-cyanoacrylate tissue adhesive provides:

- Faster wound closure,
- Superior early healing,
- Reduced post-operative pain, and
- Comparable long-term periodontal outcomes to silk sutures.

Hence, from the present study it can be concluded that iso-amyl cyanoacrylate tissue adhesive is an effective and reliable alternative to conventional silk sutures as it is easy to apply, less time-consuming, causes less inflammatory response to tissues, provides immediate hemostasis, lessens the post-operative pain and discomfort, and above all has high patient satisfaction. Tissue glue can be considered a simple, efficient, and patient-friendly alternative to conventional sutures for flap closure following periodontal surgery. Perhaps, one disadvantage of using cyanoacrylate is its high cost. However, the benefits of reduced effort and improved post-operative outcomes outweigh this drawback.



**Shweta Vikhe et al.,****REFERENCES**

1. Newman MG, Takei H, Klokkevold PR, Carranza FA. Carranza's clinical periodontology. Elsevier health sciences; 2011 Feb 14.
2. Ananda BB, Vikram J, Ramesh BS, Khan HM. A comparative study between conventional skin sutures, staples adhesive skin glue for surgical skin closure. International Surgery Journal. 2019 Feb 25;6(3):775-82.
3. Kulkarni S, Dodwad V, Chava V. Healing of periodontal flaps when closed with silk sutures and N-butyl cyanoacrylate: a clinical and histological study. Indian Journal of Dental Research. 2007 Apr 1;18(2):72-7
4. Suthar P, Shah S, Wankar P, Limaye G, Saha A, Sathe P. Comparing intra-oral wound healing after alveoloplasty using silk sutures and n-butyl-2-cyanoacrylate. Journal of the Korean Association of Oral and Maxillofacial Surgeons. 2020 Feb;46(1):28.
5. Kumar VR, Rai AB, Priyayadav. Comparative evaluation of n-butyl cyanoacrylate and silk sutures in intra oral wound closure-a clinical study. Journal of Advanced Oral Research. 2010 Oct;1(1):37-42.
6. 1. Khurana JV, Mali AM, Mali RS, Chaudhari AU. Comparative evaluation of healing after periodontal flap surgery using isoamyl 2-cyanoacrylate (bioadhesive material) and silk sutures: A split-mouth clinical study. Journal of Indian Society of Periodontology. 2016 Jul 1;20(4):417-22.
7. Ashoka CA. Evaluation of octyl-2-cyanoacrylate tissue adhesive as an acceptable alternative to sutures in head & neck surgery [Ph. D. dissertation]. India: Rajiv Gandhi University of Health Sciences Karnataka. 2005.
8. Babu L. A comparative clinical study of isoamyl-2-cyanoacrylate & butyl-2 cyanoacrylate on healing of surgical wounds [Ph. D. dissertation]. India: Rajiv Gandhi University of Health Sciences Karnataka. 2005.
9. Kondoh S, Matsuo K, Yuzuriha S, Kikuchi N, Ban R. Dressing for alveolopalatal wounds after alveolar bone grafting. Annals of plastic surgery. 2003 Sep 1;51(3):290-3.
10. Rewainy M, Osman S, El-Prince N. The use of n-butyl cyanoacrylate adhesive in the closure of mucoperiosteal flap after the surgical extraction of impacted mandibular third molar. Alexandria dental journal. 2015 Dec 1;40(2):152-9.
11. Vaaka PH, Patlolla BR, Donga SK, Ganapathi AK, Kurapati V. Cyanoacrylate: An alternative to silk sutures: A comparative clinical study. Journal of Dr. NTR University of Health Sciences. 2018 Apr 1;7(2):108-14.
12. Kaur G, Kaur S, Singh ST, Sharma A, Prashar P. A clinical study to compare and evaluate the potency of isoamyl 2 cyanoacrylate (Amcrylate)® in contrast to braided silk sutures in intraoral wound coaptation after open flap debridement. Baba Farid University Dental Journal. 2020;10(2):19-24





Shweta Vikhe et al.,

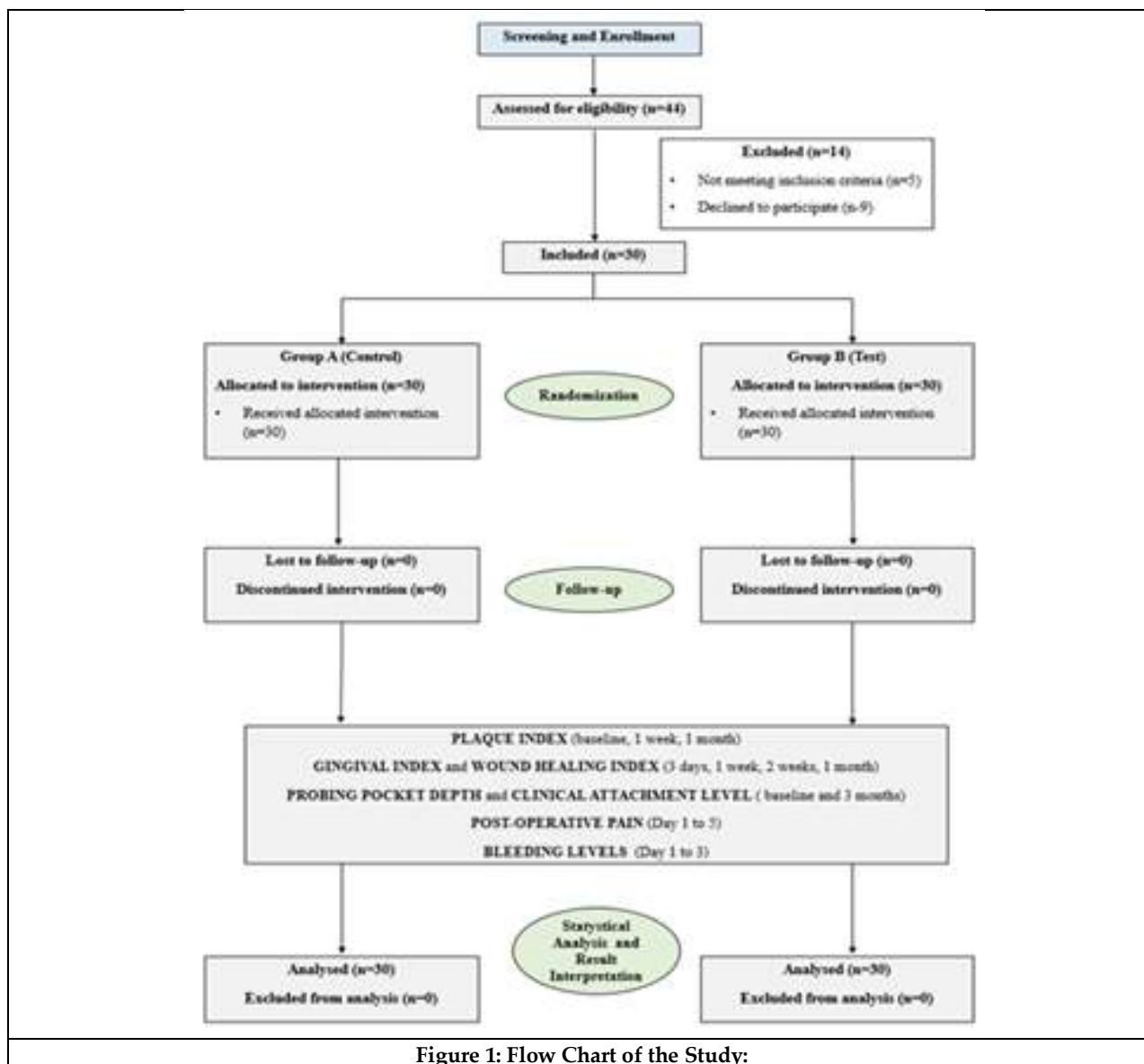


Figure 1: Flow Chart of the Study:





Shweta Vikhe et al.,



Figure 2 depicts the clinical photographs showing flap closure with silk sutures and using isoamyl 2-cyanoacrylate.





Shweta Vikhe et al.,

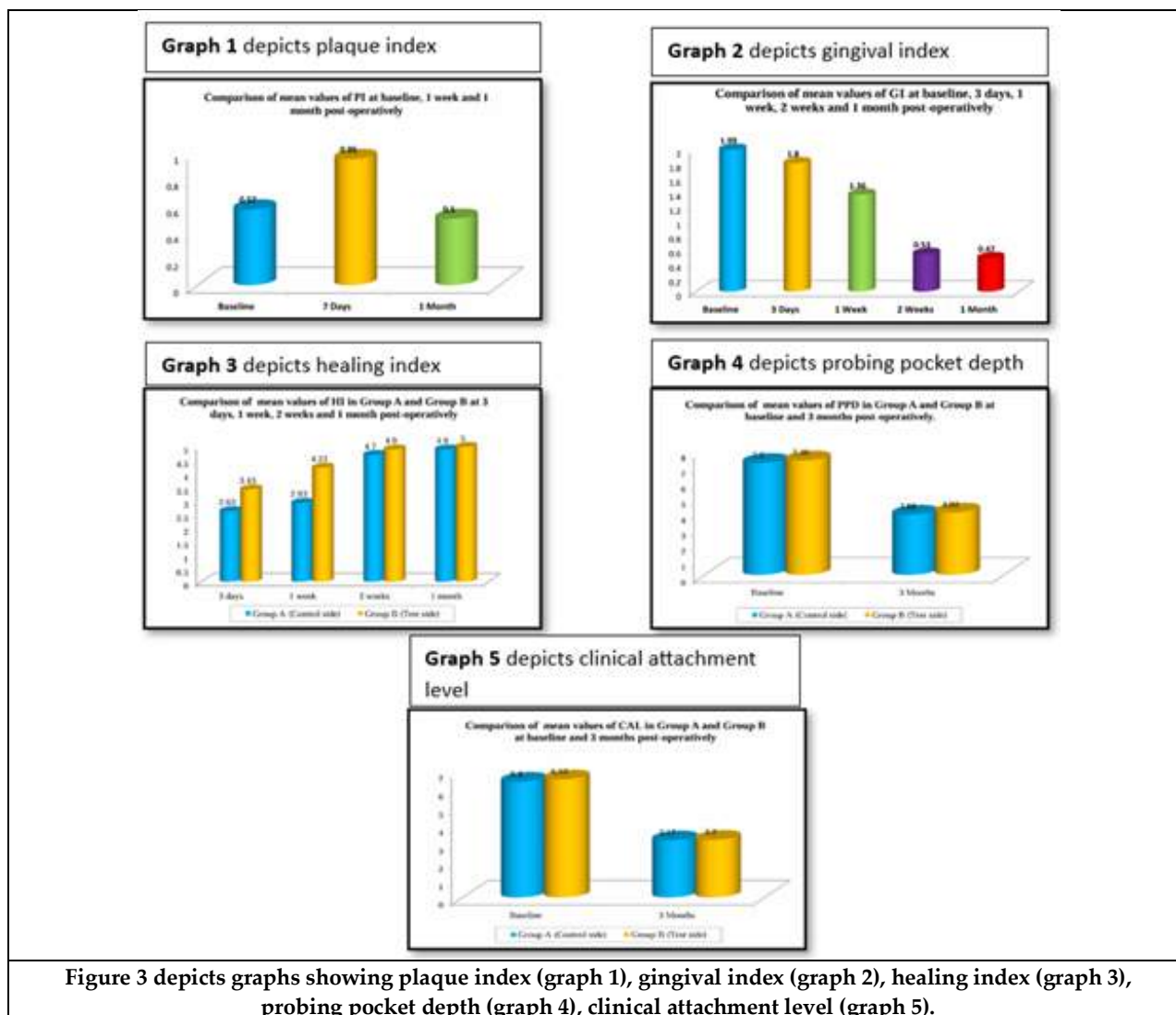


Figure 3 depicts graphs showing plaque index (graph 1), gingival index (graph 2), healing index (graph 3), probing pocket depth (graph 4), clinical attachment level (graph 5).

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Paradigm Shift in Periodontology: Integrating Holistic Modalities and the Oral-Systemic Axis in the Management of Periodontal Disease

Raju Anarthe¹, Prabhavati Dive^{2*} and Amit Mani³

¹Professor, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

²PG Student, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

³Professor and HOD, Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni, Maharashtra, India

Received: 21 Mar 2026

Revised: 20 Apr 2026

Accepted: 23 May 2026

*Address for Correspondence

Prabhavati Dive

PG Student,

Department of Periodontology,

Rural Dental College,

Pravara Institute of Medical Sciences,

Loni, Maharashtra, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Periodontitis is a chronic, globally prevalent inflammatory disorder triggered by a complex interplay of plaque biofilms, host immune responses, and environmental variables. Traditional therapies—primarily mechanical scaling, antimicrobial use, and corrective surgery—excel at managing local etiological factors but frequently overlook the patient's systemic health, psychological state, and daily habits. This paper examines the integration of holistic and biological strategies into periodontal care, supported by the latest 2024 and 2025 clinical evidence. By blending targeted dietary counseling (including probiotics and Vitamin D), herbal supplements (such as curcumin, matcha green tea, and neem), and stress-management practices (like yoga and mindfulness), practitioners can actively regulate the host's inflammatory cascade. Adopting this whole-body perspective not only helps halt periodontal tissue breakdown and combats the rise of antimicrobial resistance but also fosters systemic well-being and lasting oral health.

Keywords: Holistic Dentistry, Periodontitis, Host Modulation, Curcumin, Green Tea, Oral Microbiome, Mind-Body Medicine, Periodontal Treatment.



**Raju Anarthe et al.,**

INTRODUCTION

Periodontitis is a multifactorial inflammatory disease driven by a complex interplay between dysbiotic microbial biofilms, host immune responses, genetic predisposition, and environmental risk factors [1]. Affecting a significant proportion of the global adult population, the pathogenesis is initiated by gram-negative anaerobic consortia predominantly *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* [2,3]. However, the subsequent progression and severity of connective tissue degradation and alveolar bone resorption are fundamentally dictated by a dysregulated and hyper-responsive host immunoinflammatory profile. Historically, periodontal management has relied on a mechanistic paradigm emphasizing mechanical debridement, targeted antimicrobial pharmacotherapy, and surgical intervention [4]. While these modalities remain foundational, contemporary periodontology is transitioning toward a comprehensive bio-psychosocial model. It is now unequivocally recognized that oral homeostasis is inextricably linked to systemic health. A holistic framework synergizes conventional mechanical therapies with lifestyle modifications, nutritional interventions, smoking cessation, stress management, and natural adjunctive therapeutics to achieve optimal host immunomodulation.

The Oral-Systemic Axis

The pathophysiology of periodontitis involves a sustained inflammatory response triggered by plaque accumulation, leading to the local overexpression of matrix metalloproteinases (MMPs) and pro-inflammatory cytokines, notably Interleukin (IL)-1 β , IL-6, and Tumor Necrosis Factor-alpha (TNF- α). Crucially, this chronic inflammatory burden is not confined to the periodontium; it disseminates systemically [5]. A bidirectional relationship between periodontitis and chronic systemic pathologies, particularly diabetes mellitus, is well documented [6]. In diabetic cohorts, chronic hyperglycemia exacerbates the formation of advanced glycation end-products (AGEs), which amplifies oxidative stress and severely compromises periodontal collagen integrity [7]. Furthermore, transient bacteremias allow pathogens such as *P. gingivalis* to enter the systemic circulation, contributing to endothelial dysfunction and the atherogenic processes implicated in cardiovascular diseases [8]. Recent 2025 meta-analyses have elucidated further systemic ramifications, establishing strong pathogenic associations between periodontitis and autoimmune disorders, such as rheumatoid arthritis [9], as well as identifying elevated risks for prostate cancer mediated by circulating periodontal pathogens [10].

Conventional Therapy: Foundation and Limitations

Non-surgical mechanical debridement—primarily scaling and root planing (SRP) remains the gold standard and initial phase of periodontal therapy. In cases of refractory deep periodontal pockets, surgical interventions—including flap debridement, resective procedures, or guided tissue regeneration using osseous grafts and barrier membranes are indicated to re-establish a physiologic architecture. Although traditional mechanical modalities are highly efficacious in disrupting localized biofilm and removing calculus, they do not intrinsically address the systemic or behavioral determinants of host inflammation. Moreover, the escalating global threat of antimicrobial resistance precludes the long-term empirical use of systemic antibiotics in periodontitis, thereby necessitating the integration of safer, sustainable, and holistic immunomodulatory adjuncts.

Adjunctive Holistic and Integrative Modalities

To optimize tissue regeneration and actively modulate the host immune response, contemporary clinical protocols should incorporate the following adjunctive holistic strategies during both active therapy and supportive periodontal maintenance.

Nutritional Therapy, Microbiome Modulation, and Lifestyle Modifications

Nutritional deficiencies impair immune surveillance, delay wound healing, and precipitate shifts toward oral dysbiosis.



**Raju Anarthe et al.,**

Micronutrients (Vitamins C and D): Ascorbic acid (Vitamin C) is indispensable for collagen biosynthesis; systemic deficits directly compromise periodontal structural integrity. Vitamin D regulates bone metabolism and exhibits potent immunomodulatory and anti-inflammatory properties crucial for alveolar bone preservation.

Omega-3 Polyunsaturated Fatty Acids (PUFAs): Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) serve as essential substrates for specialized pro-resolving lipid mediators (SPMs), such as resolvins and protectins, which actively drive the resolution of inflammation [11].

Probiotic Therapy: The targeted modulation of the oral microbiome represents a critical frontier in adjunctive therapy. A 2024 systematic review demonstrated that the administration of *Lactobacillus* and *Bifidobacterium* species, delivered via lozenges, significantly attenuates the repopulation of periopathogens following SRP [12].

Behavioral Interventions: Smoking cessation remains the most critical behavioral intervention for improving periodontal prognosis [13]. Concurrently, optimizing sleep hygiene has been shown to significantly reduce circulating systemic inflammatory markers.

Phytotherapeutics and Traditional Medicine

Plant-derived pharmacotherapeutics offer biocompatible and cost-effective alternatives with established anti-inflammatory and antimicrobial profiles. Recent literature robustly supports their clinical utility:

Curcumin (Turmeric): A comprehensive 2025 review affirmed that topical curcumin applications significantly reduce plaque indices and bleeding on probing. Its clinical efficacy is comparable to standard chlorhexidine gluconate, notably devoid of adverse effects such as extrinsic tooth discoloration [14].

Epigallocatechin Gallate (Green Tea): A 2024 randomized clinical trial concluded that daily prophylactic use of matcha green tea extract mouthwash significantly suppresses the proliferation of *P. gingivalis* and other obligate anaerobes, largely attributable to its high concentration of EGCG catechins [15].

Azadirachta indica (Neem): A prominent agent in Ayurvedic medicine, a 2024 clinical analysis validated that neem-formulated mouthrinses effectively disrupt bacterial cell membranes, demonstrating high efficacy in the maintenance of gingival homeostasis [16].

Oil Pulling Therapeutics: Traditional therapies utilizing virgin coconut or sesame oil have consistently demonstrated clinical value in the saponification of bacterial toxins, resulting in significant reductions in both plaque accumulation and gingival bleeding indices.

Psychoneuroimmunology and Mind-Body Interventions

Chronic psychological stress precipitates the dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, resulting in elevated cortisol and catecholamine levels. This neuroendocrine shift suppresses immune surveillance, diminishes salivary flow, and exacerbates periodontal tissue degradation. A landmark 2025 study established that patients with severe periodontitis exhibit significantly elevated systemic cortisol, which not only impairs local mucosal immunity but actively enhances periopathogenic virulence [17]. Mind-body interventions, including Yoga and Mindfulness-Based Stress Reduction (MBSR), have been empirically proven to mitigate these effects by downregulating salivary cortisol, attenuating systemic inflammation, and promoting enhanced tissue oxygenation through controlled autonomic breathing practices (Pranayama).

CONCLUSION

The trajectory of modern periodontology is firmly oriented toward predictive, preventive, personalized, and participatory (P4) medicine. The integration of holistic modalities into standard periodontal protocols provides a customized therapeutic model that aligns seamlessly with contemporary integrative healthcare. By systematically addressing underlying risk factors such as nutritional deficiencies, chronic psychological stress, microbiome dysbiosis, sleep disturbances, and detrimental oral habits, these interventions significantly enhance intrinsic host immunomodulation. While the standardization of these biological protocols warrants continued clinical investigation, the adoption of this comprehensive, evidence-based paradigm represents a critical advancement in the longitudinal management of lifestyle-driven, oral-systemic diseases.





REFERENCES

1. Page, R. C., & Schroeder, H. E. (1976). Pathogenesis of inflammatory periodontal disease. A summary of current work. *Laboratory Investigation*, 34(3), 235-249.
2. Socransky, S. S., Haffajee, A. D., Cugini, M. A., Smith, C., & Kent, R. L. (1994). Microbial complexes in subgingival plaque. *Journal of Clinical Periodontology*, 25(2), 134-144.
3. Hajishengallis, G., Darveau, R. P., & Curtis, M. A. (2012). The keystone-pathogen hypothesis. *Nature Reviews Microbiology*, 10(10), 717-725.
4. Axelsson, P., Nyström, B., & Lindhe, J. (2004). The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults: results after 30 years of maintenance. *Journal of Clinical Periodontology*, 31(9), 749-757.
5. D'Aiuto, F., Parkar, M., Andreou, G., Suvan, J., Brett, P. M., Ready, D., & Tonetti, M. S. (2004). Periodontitis and systemic inflammation: control of the local infection is associated with a reduction in serum inflammatory markers. *Journal of Dental Research*, 83(2), 156-160.
6. Preshaw, P. M., Alba, A. L., Herrera, D., Jepsen, S., Kraigher, A., McGaw, T., & Taylor, G. W. (2012). Periodontitis and diabetes: a two-way relationship. *Diabetologia*, 55(1), 21-31.
7. Loe, H. (1993). Periodontal disease: the sixth complication of diabetes mellitus. *Diabetes Care*, 16(1), 329-334.
8. Sanz, M., et al. (2020). Periodontitis and cardiovascular diseases: Consensus report. *Journal of Clinical Periodontology*, 47(3), 268-288.
9. Martinez, C., et al. (2025). Periodontal disease and prostate cancer: a systematic review and meta-analysis. *Urologia Colombiana*, 34(1).
10. Van Dyke, T. E., & Serhan, C. N. (2003). Resolution of inflammation: a new paradigm for the pathogenesis of periodontal diseases. *Journal of Dental Research*, 82(2), 82-90.
11. Zhao, Y., et al. (2024). Efficacy of probiotics as an adjunct to non-surgical periodontal therapy: A systematic review. *Journal of Periodontal Research*, 59(2), 214-228.
12. Haber, J., & Kent, R. L. (1992). Cigarette smoking in a periodontal practice. *Journal of Periodontology*, 63(2), 100-104.
13. Sharma, A., et al. (2025). Curcumin in oral health: mechanisms, clinical evidence, and delivery strategies. *Frontiers in Pharmacology*, 16.
14. Nakao, R., et al. (2024). Inhibitory effects of matcha green tea extract mouthwash on periodontopathogens: A randomized clinical trial. *Microbiology Spectrum*, 12(3).
15. Gupta, R., et al. (2024). Antimicrobial efficacy of *Azadirachta indica* in periodontal management. *Journal of Ayurveda and Integrative Medicine*, 15(1).
16. Smith, J., et al. (2025). The impact of psychological stress and elevated cortisol levels on the progression of severe periodontitis. *Journal of Clinical Medicine*, 14(3).



Figure 1: Clinical presentation of chronic periodontitis exacerbated by systemic conditions such as diabetes.





Figure 2: Pre- and post-operative presentation of mechanical debridement

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Site Secure Vision : An AI - Based Industrial Safety and Security Compliance Monitoring System

Kamana Laina Amoomo^{1*}, Udesang K. Jaliya², Hinaxiben M. Patel² and Sanjay Dabhi³

¹Student, Department of Computer Engineering, Birla Vishvakarma Mahavidyalaya Engineering College, Anand, (Affiliated to Gujarat Technological University), Gujarat, India

²Assistant Professor, Department of Computer Engineering, Birla Vishvakarma Mahavidyalaya Engineering College, Anand, (Affiliated to Gujarat Technological University), Gujarat, India

³Founder and CEO, Invisible Fiction Company, Pooja Estate, Anand, Gujarat, India

Received: 24 Mar 2026

Revised: 26 Apr 2026

Accepted: 25 May 2026

*Address for Correspondence

Kamana Laina Amoomo

Student,

Department of Computer Engineering,

Birla Vishvakarma Mahavidyalaya Engineering College,

(Affiliated to Gujarat Technological University),

Anand, Gujarat, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Critical industries such as mechanical, manufacturing, chemical, marine and construction rely on traditional surveillance systems for monitoring and securing industrial sites. This approach present several challenges as they are not proactive and safety violations can occur without real-time enforcement of safety protocols. This leads to accidents within industrial environments and may cause operational interruptions when safety regulations are not followed. The major causes of safety violations include improper use of Personal Protective Equipment (PPE), fire or smoke outbreaks, intruders, and worker falls. This paper presents SiteSecureVision, a product developed by Invisible Fiction Company, which is an on-premises industrial safety compliance and security monitoring platform using Artificial Intelligence (AI) that transforms existing CCTV feeds into a real-time intelligent safety monitoring platform. The system performs identity-aware monitoring across 1080p RTSP and USB camera streams using machine learning models such as InsightFace for face detection and recognition and YOLOv8 for PPE detection, fire/smoke detection, license plate recognition, and fall detection. It also incorporates zone-based access control and a night-mode security mechanism. A single GPU batched inference pipeline is decouples from CPU-bound tasks such as tracking, MongoDB logging, and WhatsApp/SMS alert generation. The proposed approach demonstrates a stable operation for an AI-based industrial safety monitoring solution capable of detecting safety violations and emergency hazards in real time on across 10 -50 camera streams that achieved 15 – 25 FPS.

Keywords: Industrial safety monitoring, computer vision, YOLOv8, PPE detection, face recognition, multi-camera surveillance, AI-based monitoring



**Kamana Laina Amoomo et al.,**

INTRODUCTION

Industrial personnel are exposed to a variety of safety hazards like falling objects, electrical faults, temperature extremes, chemical exposure, and accidents. Occupational safety regulations strictly implemented the usage of Personal Protective Equipment (PPE) and restricted access to areas that are dangerous, thereby reducing safety risks [1]. However, it is a challenge for many industries that are operating on traditional CCTV monitoring systems, which are based on manual monitoring by security personnel. Manual monitoring is very inefficient, as the monitoring of safety violations by humans may be due to distractions and simultaneous safety violations happening at the same time. These are the drawbacks of traditional monitoring systems, resulting in unnoticed safety violations, accidents, and financial risks. Recently, with the advancement of Artificial Intelligence (AI) and computer vision technologies, it is now possible for intelligent monitoring systems to automatically detect safety violations and continuously monitor multiple areas with minimal involvement of humans [2], [3]. YOLO family of algorithms is one of the modern object detection frameworks that demonstrated a strong real-time performance in visual detection[4], [5], [6], [7], [8].

Several studies have explored AI-based PPE detection in industrial safety monitoring: Karlsson et al. proposed method of PPE detection using Histogram of Oriented Gradients (HOG) and YOLOv4 PPE detectors in finding helmets and safety vests [9]; Lema et al. implemented a real-time PPE detection using edge devices (Jetson Nano and Raspberry Pi), and the results shows that the proposed method using Jetson Nano works efficiently because of the support of a GPU[10]. Sanjeevani et al. developed a PPE detection system using SSD MobileNet V2 and YOLOv5 models loaded onto AI-enabled cameras to find people wearing or not wearing PPE. It demonstrated high accuracy using a YOLOv5 detector, but heavy on the edge device[11]. Recently, Makandar and Naik developed a real-time PPE detection using yolov8 and computer vision for industrial safety compliances[12] that has most of the gaps that are addressed in this paper. The proposed paper, Site Secure Vision, is an intelligent industrial safety monitoring system, which uses multi-camera PPE detection with identity-aware monitoring through face recognition Technology addresses the above mentioned challenges. This is because the proposed system not only expands PPE detection to twelve categories but also incorporates other safety modules such as fire/smoke detection, Automatic License Plate Recognition (ALPR), fall detection, zone control, and alongside there is night security mode system that works after hours. These are all done through a single GPU inference pipeline that improves the existing passive CCTV system and enables the system to detect any violations in real-time.

MATERIALS AND METHODS

SiteSecureVision framework utilizes several deep learning architectures in one unified computer vision pipeline to enable real time monitoring of industrial safety. The modularity of the architecture acquires video streams from various cameras [13]. Once acquired, the video streams undergo identity aware compliance verification at GPU accelerated inference. Batch processing is utilized during the inference process and the CPU is utilized for event driven processing [14], [15]. This is accomplished by using multithreading

Acquisition of multi-camera video

The platform can operate on multiple cameras such as IP cameras (RTSP) or USB cameras using processed using Open CV to process video streams acquired on the industrial environment that is being monitored in real-time[13]. Video streams from each camera are captured on a single thread and continuously update a common frame buffer that is managed by the camera manager. A desktop application is used for visualization and this system is a local solution for industrial monitoring that preserves privacy. Synchronization of the most recent frames that are processed from all active cameras occurs.

Real-time batched inference



**Kamana Laina Amoomo et al.,**

SiteSecureVision works in real-time using GPU batched inference that maximizes utilization the resources and maintains stable real-time performance in multiple cameras streams. It takes the latest frames from live streams of all active cameras, and combine them into a batched tensor processed on GPU for face detection, face recognition, PPE detection, fire/smoke detection, license plate recognition, person and person fall detection. To maintain real-time responsiveness, GPU inference is separated from CPU-based application logic. The inference outputs are queued on the CPU thread that will carry out other tasks such as attendance logging, violation logging, alert triggering and visualization updates. This queue-based architecture decouples GPU inference from CPU processing so that both pipelines operate asynchronously without blocking each other. As a result, the system can process multiple camera streams simultaneously while maintaining stable frame rates and efficient use of computing resources.

Face detection and recognition

The identification of an individual through identity aware recognition use Buffalo-L model of the InsightFace framework for the identification task[16]. A person's face is localized by the SCRFD detector that performs well with varying degrees of illumination, pose and partial occlusion. It use iResNet-100 backbone for the ResNet architecture, an ArcFace 512 dimensional embedding is then generated for each localized face[17]. The generated embeddings are then compared with the registered worker embeddings in the database using cosine similarity to determine if a match existed. If the cosine similarity exceeded a predetermined threshold, the corresponding worker identity will be assigned to the individual; if the similarity did not exceed the threshold, the individual will be identified as a visitor (unknown) with a temporary identifier. Temporal smoothing over 5 frames reduced the rate of identity flicker.

PPE detection

PPE detection is done using a custom-trained YOLOv8m model object detection model [8] that is capable of detecting twelve classes of PPEs, namely apron, boots, face mask, gloves, hearing muff, reflective vest, safety goggles, safety harness, safety helmet, safety jacket, suit, and welding mask. Batched frame processing is employed to allow concurrent execution of PPE detection on multiple camera feeds without FPS dropping and attain maximum GPU throughput. In addition to PPE and hazard detection, the system includes Automatic License Plate Recognition (ALPR) by applying object detection and OCR techniques, as well as pose estimation models for fall detection by skeletal key point analysis [18], [19], [20] that are all using YOLOv8n detection models.

Spatial PPE verification

Spatial verification is applied to reduce false positive by filtering detected PPEs from background or held items. Therefore only worn PPE will be considered by putting the detected persons' bounding boxes with respect to the bounding box of the detected face using geometric rules to determine area of interest.

Identity-aware tracking

Identity anchors are used to perform tracking instead of a deep learning-based tracking algorithm like Deep SORT or ByteTracker. Overlap and temporal smoothing are used to ensure the tracking of a person's bounding box from frame to frame. Identity of a person is then used to perform tracking (worker ID or visitor ID). Tracks are automatically removed when a person go out of frame using a time-to-live mechanism.

Compliance evaluation

An Individual is evaluated against their respective role's PPE compliance criteria retrieved from the database. If all required PPEs are present, then the individual is considered to be in compliance. Otherwise, a list of missing PPEs is recorded as a violation with a snapshot. The following formula calculate PPE detected based on the role of an individual. Missing PPE = required PPE - verified PPE.

Alert generation

In MongoDB, violation incidents are recorded along with violation types, identity details, camera ID, zone, and timestamps along with evidence snapshots or a short video. A cooldown mechanism is set per individual per camera to prevent repetitive alerts. Alerts notification is sent to the supervisor via WhatsApp using the WS Panel API, along



**Kamana Laina Amoomo et al.,**

with automatic SMS support in the absence of internet connection. In the presence of emergency hazards such as fire and smoke, high-priority alerts are sent, halting all other alerts.

Fire and smoke detection

In the proposed system, there is a separate module for fire and smoke detection using the YOLOv8n model for detecting fire, sparks, and smoke from videos captured in real-time[8], through surveillance cameras. In the presence of fire and smoke, the violation is categorized as a high-priority emergency, overriding all other violation alerts. The system records the emergency, takes a snapshot and short video, and sends alerts to the supervisor. In addition to mobile alerts, there is also a buzzer alarm that immediately goes off to notify persons present in the zone with fire do evacuate the place.

Night mode security monitoring

A night mode security monitoring mechanism is provided alongside PPE compliance system to monitor the industrial area after work hours, which can be done in automatic or manual mode to activate it. When night mode is active, a lightweight YOLOv8n model is activated to detect persons in the area, while the PPE compliance system is disabled, and any person detected in the area is considered a violation (intruder).

Zone management and access control

A zone-based security monitoring mechanism is also provided in this system to restrict access of unauthorized personnel to hazardous areas in the industrial area. Each camera is assigned to a specific industrial area (zone), which is stored in the database. Each worker's permission to work in a specific area is also provided in this system's configuration. When a person is detected in a monitored area, it is checked whether that person is allowed to work in that area or not.

RESULTS AND DISCUSSION

Experimental setup

The implementation and evaluation of SiteSecureVision was done on a workstation equipped with an AMD Ryzen 7 7445HS processor, 16 GB RAM, and an NVIDIA RTX 4050 GPU with 6 GB VRAM for accelerated deep learning inference. RTSP-based IP cameras and USB webcam devices operating at 1080p resolution were used to test the multiple camera system. Experiments were carried out in simulated industrial environments (videos from different industrial areas) under both indoor and outdoor conditions, different scenarios with varying illumination levels to assess system robustness on all functions. The system real-time capabilities and scalability was evaluated during the experiment by continuously using multiple camera feeds with different environment scenes. A total of 7 deep learning models used in the experiments were YOLOv8 for PPE detection, InsightFace for biometric identification, person detection for night security mode, and pose for falling person, YOLOv8 for fire/smoke detection and EasyOCR for license plate character detection. The performance of the system was evaluated by executing benchmarking tests that measured parameters, size, latency, frame rate, and system response time.

For the experimental deployment phase, SiteSecureVision system was distributed as a standalone .exe installer for ease of workstation deployment. In order to ensure robust security and software integrity, the system utilizes a hardware-bound licensing mechanism, which is secured using RSA-2048 digital signatures. The system is no longer depending on a locally generated file but instead verifies the vendor-supplied license, i.e., .lic, that cryptographically binds the software to a unique workstation MAC address via a salted SHA-256 hash algorithm. The application verifies the license's authenticity via a public RSA key, which is embedded in the software package, to ensure that the configuration is not modified or moved to another workstation without permission. The installer now also automates the initialization of a MongoDB compass database and the creation of all required data structures, including personnel, cameras, and audit logs."

3.2 Model performance evaluation

Deep learning models integrated into SiteSecureVision system's performance was assessed and considered inference latency as well as frame rate



**Kamana Laina Amoomo et al.,**

processing. Table 1 presents a summary of the runtime performance of the used models within the system. The results for latency and FPS indicate that it is possible to perform different deep learning models concurrently by using a GPU acceleration approach. Pytorch (.pt) trained models such as PPE detection, person detection, fire & smoke detection, fall detection and license plate detection were converted to Open Neural Network Exchange (ONNX) format to improve inference performance and independent deployment out of Pytorch[21],[22].

Real-time system performance

The system architecture employs batched GPU inference, along with asynchronous CPU processing, to support simultaneous video streams coming from multiple cameras. The experimental evaluation results indicate that it offers an overall stable performance. The system attain 25-30 FPS when processing a single camera feed and 10-25 FPS when processing 10- 50 cameras continuously, which indicated a stable rate as Invisible Fiction Company target 15 camera per deployment. The system design decouples CPU from GPU inference such that CPU-based processing, including database logging, compliance checking, and graphical visualization, does not affect the performance of GPU-based inference processing.

Compliance monitoring and alert reliability

The occurrence of duplicate violation of the same incident can cause a lot of alerts to be triggered. Therefore a cooldown mechanism of 30 seconds is employed to minimize the repetition of alerts by 85% for continuous monitoring. This is achieved by identity-aware as face recognition is linked to PPE detection for evaluation of PPE. The system successfully monitored different industrial safety and security violations such as the absence of PPE such as helmets, vests, and unauthorized entry into certain zones. The emergency hazards module for fire, smoke detection, fall detection and intruders after working hours security also worked successfully and sent instant alerts. The instant alerts were sent via WhatsApp and SMS for emergency hazards. The system activate a buzzer in case of fire/smoke outbreak to evacuate people in the zone or nearby zone with fire incident. This shows that the modular architecture can be used for safety monitoring while ensuring real-time response with smooth video streaming.

Comparison with existing systems

Comparing SiteSecureVision provides several additional capabilities compared to existing PPE monitoring system reviewed. This includes covering a wide range of PPE categories, multi-camera monitoring, person identification, role based PPE rules, zone based access control, fire and smoke detection, falling detection and night security monitoring resulting in an integrated operational workflow. Some studies primarily focused on dataset-level detection accuracy, while this system emphasizes operational deployment and real-time monitoring in industrial environments. It integrate multiple safety monitoring modules in a single GPU inference pipeline enabling the system to function as a comprehensive real-time industrial safety management platform.

Limitations

The performance of the system is dependent on the position of the camera, lighting conditions, distance and the availability of hardware resources. In addition, cases of occlusions or camera angles may affect the face recognition or PPE detection for a certain period of time or certain people. Moreover, SiteSecureVision implementation does not allow re-identification for a person moving between non-overlapping camera views.

Practical implications

The experimental deployment shows that existing CCTV infrastructure can be transformed to create an intelligent safety enforcement system with the help of AI-based computer vision. It helps to achieve identity-based compliance monitoring, automated notifications, and surveillance to achieve active safety management in an industrial setup.

CONCLUSION



Kamana Laina Amoomo et al.,

The safety monitoring system, SiteSecureVision presented, is a smart industrial safety compliance solution that is developed to upgrade existing CCTV infrastructure using AI technologies. It uses deep learning algorithms such as YOLOv8 for PPE detection and hazard monitoring, InsightFace for face recognition, and EasyOCR for license plate monitoring. Batched GPU inference pipeline with asynchronous CPU processing is used to enable efficient multi-camera monitoring while maintaining real-time responsiveness even after the number of cameras increases. The experimental results indicated a consistent frame rate between 18-25 FPS, achieved in real-time processing on different industrial scenes. This system is capable of identifying persons, monitoring spatial PPE, and real time alerting for industrial safety violations. This system presents effective techniques for safety management that allow for flexibility in industrial environments, minimizing conventional monitoring techniques while facilitating instant violation alerts. The architecture follows a modular design that employs spatial PPE verification and links violations directly to responsible individuals while allowing additional modules to be integrated easily. The future work will aim on improving the person re-identification across cameras, enhancing the system for edge environments, and extending the system to monitor other industrial safety hazards such as unsafe lifting and behavioural safety.

REFERENCES

1. ISO, *ISO 45001: Occupational Health and Safety Management Systems—Requirements with Guidance for Use*. Geneva, Switzerland: International Organization for Standardization, 2018.
2. M. S. Islam, M. Karray, and R. Alhajj, "Vision-based worker safety monitoring: A survey," *Comput. Vis. Image Underst.*, vol. 208, 2021.
3. A. Nath, S. Mishra, and P. K. Sa, "Deep learning techniques for workplace safety: A review," *Saf. Sci.*, vol. 148, 2022.
4. J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, "You Only Look Once: Unified, real-time object detection," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR)*, 2016, pp. 779–788.
5. J. Redmon and A. Farhadi, "YOLO9000: Better, faster, stronger," in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit. (CVPR)*, 2017, pp. 6517–6525.
6. J. Redmon and A. Farhadi, "YOLOv3: An incremental improvement," *arXiv preprint arXiv:1804.02767*, 2018.
7. A. Bochkovskiy, C.-Y. Wang, and H.-Y. M. Liao, "YOLOv4: Optimal speed and accuracy of object detection," *arXiv preprint arXiv:2004.10934*, 2020.
8. G. Jocher et al., "YOLOv8: Ultralytics real-time object detection," *arXiv preprint arXiv:2305.09972*, 2023.
9. J. Karlsson, F. Strand, J. Bigun, F. Alonso-Fernandez, K. Hernandez-Diaz, and F. Nilsson, "Visual detection of personal protective equipment and safety gear on industry workers," in *Proc. Int. Conf. Pattern Recognit. Appl. Methods (ICPRAM)*, 2022, pp. 1–8.
10. D. G. Lema, R. Usamentiaga, and D. F. García, "Low-cost system for real-time verification of personal protective equipment in industrial facilities using edge computing devices," *J. Real-Time Image Process.*, vol. 20, no. 2, pp. 1–14, 2023.
11. P. Sanjeevani, G. Neuber, J. Fitzgerald, N. Chandrasena, S. Potums, A. Alavi, and C. Lane, "Real-time personal protective equipment non-compliance recognition on AI edge cameras," *Electronics*, vol. 13, no. 15, Art. no. 2990, 2024.
12. A. Makandar and R. Naik, "Real-time personal protective equipment detection using YOLOv8 and computer vision for industrial safety compliance," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 14, no. 8, pp. 303–306, Aug. 2025.
13. G. Bradski, "The OpenCV Library," *Dr. Dobbs's Journal*, 2000.
14. D. Kirk and W. Hwu, *Programming Massively Parallel Processors*, Morgan Kaufmann, 2016.
15. T. Mattson et al., *Patterns for Parallel Programming*, Addison-Wesley, 2004.
16. J. Guo and J. Deng, "InsightFace: 2D and 3D face analysis project," *arXiv preprint arXiv:2002.04264*, 2020.
17. J. Deng, J. Guo, N. Xue, and S. Zafeiriou, "ArcFace: Additive angular margin loss for deep face recognition," in *Proc. IEEE/CVF Conf. Comput. Vis. Pattern Recognit. (CVPR)*, Long Beach, CA, USA, 2019, pp. 4690–4699.
18. J. Baek et al., "What Is Wrong With Scene Text Recognition Model Comparisons?" *ICCV*, 2019.





Kamana Laina Amoomo et al.,

19. J. JaiedAI, "EasyOCR: Ready-to-use OCR with Deep Learning," 2020.
20. Z. Cao et al., "OpenPose: Realtime Multi-Person 2D Pose Estimation," IEEE TPAMI, 2021.
21. A. Bai et al., "ONNX: Open Neural Network Exchange," *arXiv preprint* arXiv:1905.04245, 2019.
22. S. Narang et al., "ONNX Runtime: A production-grade inference engine for deep learning," Microsoft Research, Tech. Rep., 2019.
23. S. Szeliski, *Computer Vision Applications*, Springer.
24. A. Krizhevsky et al., "ImageNet Classification with Deep CNNs," *NIPS*, 2012.

Table 1. Runtime performance of deep learning models used in SiteSecureVision system

SINo	Model	Task	Latency	Throughput (FPS)	Accuracy metrics
Trained					
1	YOLOv8m (best.onnx)	PPE detection	266 ms CPU 25.7 ms GPU	3.4 FPS CPU, 38.9 FPS GPU	Precision 0.88, Recall 0.88, mAP@0.5 = 0.92
2	YOLOv8n (best.onnx)	Person detection	131 ms	7.6 FPS	Precision: 0.92, Recall = 0.84, mAP@0.5 = 0.89
3	YOLOv8n (best.onnx)	Fire & smoke detection	50 ms	19.7 FPS	Precision 0.91, Recall 0.78, mAP@0.5 ≈ 0.88
Pre- trained					
4	SCRFD det_10g	Face detection	80 ms	12.4 FPS	High-accuracy face localization
5	ArcFace w600k_r50	Face recognition	48 ms	20.6 FPS	Recognition accuracy ≈ 92.9%
6	YOLOv8n-Pose	Fall detection	56 ms	17.8 FPS	Pose-based fall detection
7	ALPR YOLOv8n	License plate detection	51 ms	19.3 FPS	Runtime detection validated



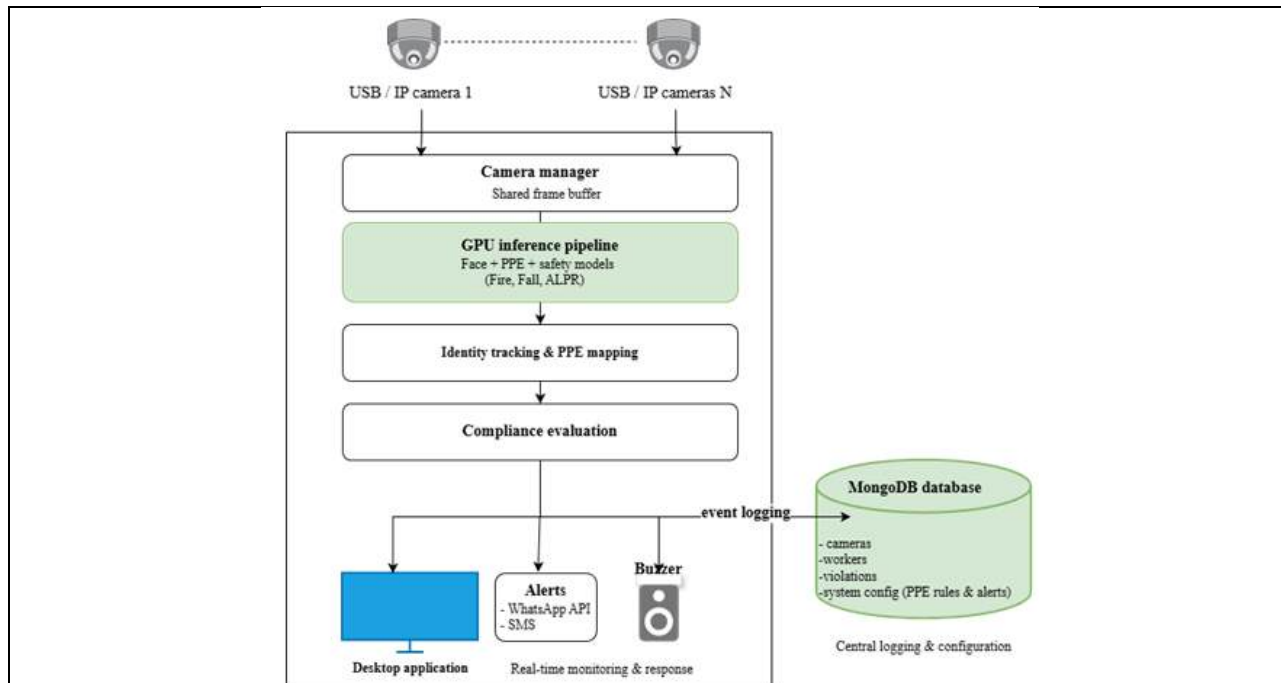


Fig. 1. Architecture of SiteSecureVision System illustrating acquisition of multi-camera video, the inference pipeline of the GPU, evaluation of identity compliant video and event log with alerting mechanisms.

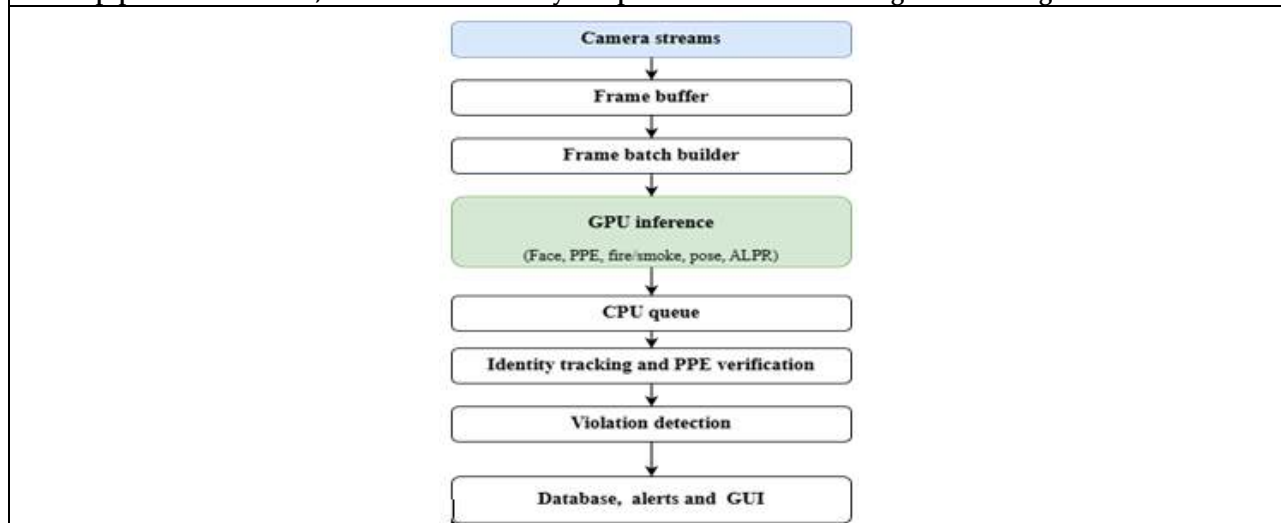


Fig. 2. Real-time inference pipeline showing batched GPU processing and asynchronous CPU post-processing for violation detection and event logging.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

High Resolution-Liquid Chromatography Mass Spectrometry (HR-LCMS) - Based Phytochemical Profiling of *Pogonatum neesii* (Mull.Hal.) Dozy

Sarath Ramesan V. V.¹ and Pradeesh S^{2*}

¹Research Scholar, PG Department and Research Centre of Botany, Mahatma Gandhi College (Affiliated to University of Kerala), Thiruvananthapuram, Kerala, India.

²Assistant Professor, PG Department and Research Centre of Botany, Mahatma Gandhi College (Affiliated to University of Kerala), Thiruvananthapuram, Kerala, India.

Received: 16 Mar 2026

Revised: 23 Apr 2026

Accepted: 25 May 2026

*Address for Correspondence

Pradeesh S

Assistant Professor,

PG Department and Research Centre of Botany,

Mahatma Gandhi College (Affiliated to University of Kerala),

Thiruvananthapuram, Kerala, India.

E.Mail: pradeeshnair10@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Plant-based therapeutics have gained increasing attention due to their perceived safety, reduced toxicity and demonstrated pharmacological efficacy compared with many synthetic compounds. A significant number of contemporary drugs currently used in clinical practice are derived from natural sources, particularly medicinal plants. Therefore, integrating traditional ethnomedicinal knowledge with modern drug discovery approaches is essential for the identification of novel bioactive compounds. In this context, the present study aimed to screen and identify, potential bioactive constituents from the ethyl acetate extract of *Pogonatum neesii*. The investigation focused on the phytochemical profiling of the ethyl acetate extract using advanced analytical techniques. Liquid Chromatography-Mass Spectrometry (LC-MS) was employed to detect and characterize the phytoconstituents present in the plant extract. This analytical method enables sensitive and accurate identification of secondary metabolites based on their mass spectral patterns and chromatographic behavior. The LC-MS analysis results provide valuable insights into the chemical composition of the *Pogonatum neesii* extract and may inform the discovery of pharmacologically active compounds for future drug development. Among them, Chamaemeloside, Madasiatic acid, Genistein 8-C-glucoside, Ohioensin-A, Ferulic acid 4-O-glucuronide, Kaempferol 3-(2",6"-di-(E)-p-coumarylglucoside), Cichoriin, Tectorigenin, Esculetin, 2,6-dihydroxybenzoic acid, Grossamide, Isolimononic acid, Pretazettine, Dihydrocapsaicin, Cajanin, Sarmentosin, Ruspolinone, Sphagnum acid, Scoparone, Vanillic acid etc. are major compounds having reported diverse pharmacological activities. This is the first report of these active compounds from this plant. Extracted





information is useful for future perspectives in drug development and understanding of its pharmacological actions.

Keywords: HR-LCMS, Chamaemeloside, Ruspolinone, Sphagnum acid, Scoparone, Vanillic acid

INTRODUCTION

Plants are significant sources of natural medicine. However, the availability of these plant resources is limited and often insufficient to meet the growing global demand driven by the increasing human population [1]. Plant-derived natural products have long served as valuable therapeutic resources and have been used for centuries in the treatment of numerous diseases. In recent years, the use of bioactive compounds obtained from plants has increased significantly, largely due to concerns about the adverse effects associated with many synthetic drugs, which may sometimes pose greater risks than the conditions they are intended to treat. In contrast, plant-based medicines contain naturally occurring compounds that can support health and aid in the management of various illnesses. These herbal remedies are often considered safer, better tolerated by patients, relatively cost-effective and widely accepted across the globe. Consequently, recognizing the therapeutic potential of medicinal plants and promoting a renewed reliance on natural remedies has become increasingly important in both present and future healthcare system [2,3,4].

Mosses are a group of plants widely distributed worldwide. Currently, it is estimated that there are approximately 22,000-25,000 of these organisms all over the World [5,6]. However, only a small percentage of these minute, photosynthetic, terrestrial, green spore-producing plants have been chemically investigated to date [7,8]. In this study, we used *Pogonatum neesii*, which belongs to the family Polytrichaceae in the order Polytrichales. The genus *Pogonatum* P. Beauv. is the most species-rich genus in the Polytrichaceae family, comprising more than 50 species [9]. Phytochemicals are broadly classified into primary and secondary metabolites. Primary metabolites include essential compounds such as chlorophyll, proteins and simple sugars that are directly involved in plant growth and metabolism. In contrast, secondary metabolites comprise diverse groups such as terpenoids, alkaloids and phenolic compounds, which often play protective and ecological roles in plants. Among these, terpenoids are known to exhibit a wide range of pharmacological activities, including anti-inflammatory, antimalarial, antiviral, antibacterial effects and the ability to inhibit cholesterol synthesis. Alkaloids, another important class of secondary metabolites, are widely distributed in medicinal plants and possess significant therapeutic properties. Many alkaloids are utilized in medicine as anesthetic agents and contribute substantially to the pharmacological value of medicinal plants [10,11,12,13]. High Resolution-Liquid Chromatography Mass Spectrometry (HR-LCMS) is one such powerful analytical technique used for separation, identification and quantification of both unknown and known compounds, small molecules, as well as to elucidate the structure and chemical properties of different molecules, multicomponent containing substances [14]. This study focused on the identification of active compounds in *Pogonatum neesii* through HR-LCMS.

MATERIALS AND METHODS

Plant materials and sample preparation

Pogonatum neesii were collected from Kodaikanal, Tamil Nadu and authenticated by the Bryology Division, Department of Botany, University of Calicut. Voucher specimen (Collection number 195032) was deposited in the Calicut University herbarium (CALI). The collected material was thoroughly washed, shade-dried at room temperature and then ground into fine powder using a mechanical blender. The powdered samples were stored in a zip-lock bag for further analysis.



**Sarath Ramesan and Pradeesh**

Preparation of Plant Extracts

The plant material was subjected to sequential solvent extraction using hexane, petroleum ether, chloroform, ethyl acetate, methanol and distilled water. The resulting extracts were concentrated using a rotary evaporator and stored in sealed containers at 4 °C for future use.

HR-LCMS

The HR-LCMS analysis is conducted using a TOF/Q-TOF mass spectrometer (model G6550A) equipped with a Dual AJS ESI source operating at Sophisticated Analytical Instrument Facility (SAIF) Bombay. The acquisition mode is Auto MS/MS, covering an m/z range of 120 to 1200, with a scan rate of 1 spectrum per second for both MS and MS/MS scans. Collision energy is ramped based on precursor ion charge, with specific slope and offset values of -2.643, -2.662 and -2.681. Chromatographic separation is performed with a binary solvent system, where solvent A is 0.1% formic acid in water and solvent B is acetonitrile. The gradient starts with 5% solvent B, increasing linearly to 100% by 25 minutes, holding at 100% until 30 minutes, then ramping back to 5% by 31 minutes with a re-equilibration phase lasting until 35 minutes. The flow rate is maintained at 0.300 ml/min, with the column compartment temperature set at 40°C. The injection volume is 3 µl and needle washing is enabled at the flush port with a wash time of 3 seconds. Source conditions include a sheath gas flow of 11 l/min at 300°C, a drying gas flow of 13 l/min at 250°C and a nebulizer pressure of 35 psig. The capillary voltage is set at 3500 V, while the nozzle voltage is maintained at 1000 V. MS/MS isolation width is approximately 4 amu and dynamic precursor selection is based on abundance, with a purity cutoff of 30% and strict stringency at 100%. Active exclusion is enabled, with excluded precursors released after 0.2 minutes or excluded after one spectrum. A maximum of 10 precursors is selected per cycle, targeting 25,000 counts per spectrum.

RESULTS AND DISCUSSION

HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* in negative ionisation mode enabled the tentative identification of 39 secondary metabolites belonging to diverse phytochemical classes, including flavonoids, phenolic compounds, terpenoids, saponins, coumarins, fatty acids, oxylipins, glycosides and esters. The presence of these metabolites indicates the chemical diversity of the extract and suggests its potential pharmacological relevance.

Phenolic compounds are one of the major and diverse groups found in plants. They contain at least one aromatic ring and one or more hydroxyl groups in their structure, with the simplest form of phenol being C₆H₅OH [31,32]. Phenolic compounds may also be used in several fields like antioxidant, anti-inflammatory, antimicrobial, antiviral, antipyretic and analgesic [33]. The abundance of phenolics in the extract supports its potential role as a natural antioxidant source. Several phenolic compounds and phenolic glycosides were identified, including ferulic acid 4-O-glucuronide, 1-O-sinapoylglucose, 1-caffeoyl-β-D-glucose, 2,6-dihydroxybenzoic acid and shoyuflavones A and B. Rotenonone used as an insecticide and pesticide [24]. Ferulic acid 4-O-glucuronide has significant antioxidant activity [26]. And 2,6-dihydroxybenzoic acid also shows Antioxidant properties [30]. HR-LCMS analysis revealed the presence of flavonoid compounds such as Kaempferol 3-(2'',6''-di-(E)-p-coumarylglucoside), 2,3-dihydroamentoflavone, Genistein 8-C-glucoside, Ohioensin-A and Tectorigenin were identified. Flavonoids are the most abundant and broadly distributed class of phenolic compounds found in plants [34].

Flavonoids are well known for their various biological activities, including anti-allergic, anti-inflammatory, antiviral, anti-proliferative and anti-carcinogenic effects and they also influence certain aspects of mammalian metabolism [35]. Kaempferol 3-(2'',6''-di-(E)-p-coumarylglucoside) is reported to possess strong antioxidant and antibacterial properties [15]. Similarly, 2,3-dihydroamentoflavone has been associated with antidiabetic activity [22], while Genistein 8-C-glucoside exhibits hepatoprotective and antioxidant properties [36]. The presence of these flavonoids may contribute significantly to the biological activity of the extract. Coumarin is a naturally occurring compound found in many plants and essential oils. From a pharmacological perspective, it is classified as a flavonoid, along with several other related compounds [37]. Coumarins have also been shown to inhibit lipid peroxidation and to neutralize reactive species such as hydroxyl radicals, superoxide radicals and hypochlorous acid [38], soybean



**Sarath Ramesan and Pradeesh**

lipoxygenase/or 5-lipoxygenase [39] and to possess anti-inflammatory and anticoagulant abilities [40]. Coumarins and coumarin glycosides such as esculetin, cichoriin, 5-hydroxy-6-methoxycoumarin-7-glucoside and furocoumarinic acid glucoside were also present in the ethyl acetate extract. Esculetin has been reported to exhibit antioxidant, antidiabetic and anti-inflammatory activities [29], while cichoriin has demonstrated antioxidant, antidiabetic and cardioprotective properties [27]. These compounds are known to contribute to free-radical scavenging and metabolic regulation.

Terpenes are a large and diverse group of organic compounds produced by various plants [41,42]. Terpenes are hydrocarbons that often have a strong odor. They may help protect the plants that produce them by attracting predators and parasites of herbivores, as well as by deterring herbivores [43,44]. Terpenes perform several roles in plants, including signaling functions, acting as pigments, solvents and flavoring agents and they also have various medicinal applications [45]. Terpenes possess various therapeutic properties, including antimicrobial, antiviral, antifungal, analgesic, antihyperglycemic, antiparasitic and anti-inflammatory activities. They are also used to enhance skin penetration and help prevent inflammatory diseases. In medicine, terpenes are utilized in the development of several pharmaceutical drugs [46]. Terpenoid compounds, including Madasiatic acid and Kessyl glycol were also detected. Madasiatic acid is widely recognized for its anti-inflammatory, antioxidant, antimicrobial and wound-healing properties [21]. These compounds may play a crucial role in mediating therapeutic effects related to inflammation and tissue repair. In addition, sesquiterpene lactone glycosides such as "Chamaemeloside" were identified and are known for their anti-inflammatory effects [19]. The presence of 12-hydroxyamoorastatin, a terpene with reported antileukemic activity [20] Triterpenoid saponins were also detected, including Cyclopasifloside II. Cyclopasifloside II has been reported to exhibit anti-inflammatory activity through inhibition of inducible nitric oxide synthase [16].

The analysis also revealed the presence of iridoid glycosides. Iridoids are oxygenated monoterpenes that commonly occur as glycosides attached to glucose. They have been reported in several plant families and have shown a broad spectrum of biological activities [47,48]. Iridoid glycosides represented by Kanokoside C, which has been reported to show neuroprotective and nerve growth factor (NGF) potentiating activity [17]. Such compounds are often associated with neuroprotective and anti-inflammatory effects, indicating potential neurological benefits of the plant extract. The HR-LCMS analysis also identified a saponin, Notoginsenoside T2. Saponins are defined as triterpenoid or steroid glycosides produced by some bacteria, lower marine animals and plants [49]. Saponins have antioxidant activity [49] and antimicrobial activity [50]. Notoginsenoside T2 has no reported activities. Chlorophyll a complex green pigment found in plants, algae and certain bacteria, plays a crucial role in the process of photosynthesis by absorbing light energy and converting it into chemical energy [51]. Chlorophyll derivatives exhibit a range of beneficial effects, including antioxidant, antigenotoxic and anti-obesogenic properties [52]. Chlorophyll derivatives such as phaeophorbide b were detected, which have been reported to possess antioxidant activity [18]. Fatty acids, including omega-hydroxy behenic acid, (2S)-2-hydroxyphytanic acid, 16-hydroxyhexadecanoic acid, 8S-HODE and 9-HOTE, along with several oxylipins such as 9,10-dihydroxy-12,13-epoxyoctadecanoate and corchorifatty acid F. Other detected compounds included esters (dioctyl hexanedioate, diethyl succinate), fatty alcohol derivatives (avocadene 4-acetate) and sugars (hamamelose). Although their biological activities are not reported, more studies are needed.

The HR-LCMS analysis of the ethyl acetate extract in positive ionisation mode revealed the presence of 30 secondary metabolites belonging to diverse phytochemical classes such as alkaloids, flavonoids, terpenoids, phenolic compounds, coumarins, cyanogenic glycosides, carotenoids and amino acid derivatives. The detection of these compounds highlights the chemical complexity of the extract and provides insight into its potential pharmacological properties. Several phenolic compounds are detected, including feruloyl C1-glucuronide, Lucidin omega-methyl ether, sphagnum acid, vanillic acid and (E)-3-(2-hydroxyphenyl)-2-propenal. For instance, vanillic acid has demonstrated antibacterial and anti-inflammatory activities [69,70]. Similarly, sphagnum acid has been reported to possess antibacterial properties [66]. Phenyl propanoids such as methoxyeugenol are also reported, but their activity has not been reported yet. Flavonoids and isoflavonoids were also detected. These compounds are widely recognized for their antioxidant, antibacterial, antifungal and anti-inflammatory activities. For example, cajanin has been



**Sarath Ramesan and Pradeesh**

reported to exhibit antibacterial and antioxidant properties [59], along with antifungal activity [60] and anti-inflammatory effects [61]. Coumarin derivatives such as scoparone and 8-hydroxy-7-methoxy-2H-1-benzopyran-2-one were also identified. Scoparone, in particular, has been reported to exhibit anti-inflammatory activity [67] as well as antibacterial effects [68]. The presence of lignanamides, represented by grossamide, is noteworthy due to their well-documented anti-inflammatory activity [53]. The extract also contained cyanogenic glycosides, lotaustralin, which are naturally occurring plant defense compounds. Although these compounds are primarily known for their role in plant defense [71]. Similarly, sarmentosin has been associated with anti-inflammatory and antioxidant activities [63]. Several terpenoid compounds were also identified in the extract, including physalin O, isolimonic acid, D-linalool 3-(6"-malonylglucoside) and antheraxanthin

A. Carotenoid derivatives such as antheraxanthin A play an important role in plants by protecting photosynthetic systems against photooxidative damage through the xanthophyll cycle [54]. Terpenoids such as isolimonic acid have demonstrated antibacterial properties [55], suggesting their potential contribution to the antimicrobial activity of the extract. Among the identified metabolites, chlorophyll derivatives, including red chlorophyll catabolite, phaeophorbide a and phaeophorbide b. phaeophorbide a and phaeophorbide b are degradation products of chlorophyll and have been reported to exhibit significant antioxidant activity [18]. The LC–MS profile also revealed the presence of several alkaloids, including pretazettine, (S)-neolitsine, dihydrocapsaicin, (±)-clausenamide and ruspolinone. Alkaloids are the main secondary metabolites that have medical properties. Alkaloids can help avoid several degenerative diseases by scavenging free radicals or binding with a catalyst to the oxidative reaction. Several studies indicated that the alkaloids from several plants have a wide range of pharmaceutical applications [72]. Pretazettine has demonstrated antiviral activity [56], while (S)-neolitsine has shown strong cytotoxic activity against cancer cell lines such as MCF-7 and B16-F10 [57]. Dihydrocapsaicin has been reported to possess antioxidant and anti-inflammatory properties [58]. Additionally, clausenamide has been studied for its anti-lipid peroxidation and neuroprotective effects [62]. In addition to the major constituents, several other compounds were also identified, including organic acids such as 2,6-diamino-7-hydroxy-azelaic acid, amino acid derivatives like N-acetyl-L-phenylalanine, fatty acid esters such as isobutyl 2-furanpropionate, carboxylic acid derivatives including methyl 2,3-dihydro-3,5-dihydroxy-2-oxo-3-indoleacetic acid and polyketides such as ornaline. However, the biological or pharmacological activities of these compounds have not yet been reported in the literature, indicating the need for further investigation to determine their potential significance.

SUMMARY AND CONCLUSION

HR-LCMS analysis of the ethyl acetate extract in both negative and positive ionisation modes revealed a diverse array of phytochemicals, highlighting the complex chemical composition of the extract. A total of 69 secondary metabolites were tentatively identified, comprising 39 compounds in negative ionisation mode and 30 compounds in positive ionisation mode. These metabolites belong to several important phytochemical classes, including flavonoids, phenolic compounds, terpenoids, saponins, coumarins, alkaloids, lignanamides, carotenoids, cyanogenic glycosides, fatty acids, oxylipins and amino acid derivatives. Flavonoids and phenolic compounds represented a major portion of the detected constituents. Compounds such as kaempferol derivatives, genistein glycosides, tectorigenin, liquiritin apioside, cajanin and vanillic acid are well known for their antioxidant, anti-inflammatory, antimicrobial and antidiabetic activities. Coumarin derivatives, including esculetin, cichoriin and scoparone, further contribute to the antioxidant and anti-inflammatory potential of the extract. Several terpenoids and carotenoids, such as Madasiatic acid, physalin O, isolimonic acid and antheraxanthin, were also detected and are associated with antimicrobial, cytoprotective and anti-inflammatory effects.

Additionally, the presence of alkaloids including pretazettine, (S)-neolitsine, dihydrocapsaicin and clausenamide suggests possible antiviral, anticancer and neuroprotective activities. Other metabolites such as saponins, lignanamides, cyanogenic glycosides, fatty acids and oxylipins may further contribute to the biological properties of the extract. Overall, the LC–MS profiling demonstrates that the ethyl acetate extract is a rich source of bioactive





compounds, supporting its potential pharmacological significance and providing a chemical basis for its therapeutic applications.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Manoj G. S., Assistant Professor, Department of Botany, Mahatma Gandhi College, Kesavadasapuram, Thiruvananthapuram, for valuable suggestions and encouragement. We gratefully acknowledge Dr. Manju C. Nair, Associate Professor, Department of Botany, University of Calicut, for authentication of plant material. We also extend our sincere thanks to SAIF IIT Bombay for providing the HR-LCMS analysis facilities and also acknowledge UGC-CSIR, New Delhi, for financial support.

REFERENCES

1. Vignesh A, Veerakumari KP, Selvakumar S, Rakkiyappan R, Vasanth K. Nutritional assessment, antioxidant, anti-inflammatory and antidiabetic potential of traditionally used wild plant, *Berberis tinctoria* Lesch. Trends in Phytochemical Research. 2021;5(2):71-92.
2. Tarnam YA, Ilyas MM, Begum TN. Biological potential and phytopharmacological screening of *Gomphrena* species. International Journal of Pharma Research & Review. 2014; 3(1):58-66.
3. Ayyanar M, Ignacimuthu S. Plants used for non-medicinal purposes by the tribal people in Kalakad Mundanthurai Tiger Reserve, Southern India. Indian Journal of Traditional Knowledge. 2009; 9(3):515-518.
4. Moura RM, Pereira PS, Januario AH, França SD, Dias DA. Antimicrobial screening and quantitative determination of benzoic acid derivative of *Gomphrena celosioides* by TLC-densitometry. Chemical and Pharmaceutical Bulletin. 2004;52(11):1342-1344.
5. Frahm JP. A new contribution to the moss flora of Baltic and Saxon amber. Review of Palaeobotany and Palynology. 2004;129(1-2):81-101.
6. Asakawa Y, Ludwiczuk A. Bryophytes: liverworts, mosses and hornworts: extraction and isolation procedures. In Metabolomics tools for natural product discovery: Methods and protocols. Totowa, NJ: Humana Press. 2013;1-20.
7. Ando H, Matsuo A. Applied bryology. Advances in bryology. 1984;2:133-224.
8. Inoue H. Bryophytes as an indicator of continental drift (Gondwana land). Kagakuasahi. 1988;8:116-121.
9. Hyvonen J. A synopsis of genus *Pogonatum* (Polytrichaceae, Musci). Acta Botanica Fennica, 1989,138:1-87.
10. Yamuna P, Abirami P, Sharmila M, Vijayashalini P. Qualitative phytochemical analysis of *Gomphrena globosa* Linn. and *Gomphrena decumbens* Jacq. International Journal of Biology Research. 2017; 2(3):20-22.
11. Krishnaiah D, Sarbatly R, Bono A; Phytochemical antioxidants for health and medicine: A move towards nature. Biotechnology and Molecular Biology Review. 2007;1:97-104.
12. Mahato SB, Sen S. Advances in triterpenoid research. Phytochemistry. 1997;44(7):1185-1236.
13. Herouart D, Sangwan RS, Fliniaux MA, Sangwan-Norreel BS. Variations in the leaf alkaloid content of androgenic diploid plants of *Datura innoxia*. Planta Medica. 1988;54(01):14-17.
14. Mukherjee PK. LC-MS: A rapid technique for understanding the plant metabolite analysis. Quality Control and Evaluation of Herbal Drugs; Elsevier: Amsterdam, The Netherlands. 2019;459-479.
15. Begum T, Arzmi MH, Uddin AH, Rofiee MS, Shah SA, Parveen H, Mukhtar S, Ahmed QU. Unveiling comparative bioactivities of Kratom leaf extracts obtained via maceration and ultrasonic techniques: Antioxidant, antimicrobial and antibiofilm effects with molecular docking of Q-ToF-LCMS identified compounds and ADMET prediction. Journal of King Saud University-Science. 2025;37(10): 1-11.
16. Sandhiutami NM, Desmiaty Y, Ningsih FN, Dewi RS, Pratami DK, Syahirah S, Zahara WN, Xavier F. *Passiflora edulis* Sims leaves nanoparticle alleviates inflammation and osteoarthritis by suppressing pro-inflammatory cytokines production and matrix metalloproteinase-9: A combined in-silico, in-vitro and in-vivo models. Journal of Pharmaceutical Innovation. 2026;21(3):1-23.





Sarath Ramesan and Pradeesh

17. Guo Y, Xu J, Li Y, Watanabe R, Oshima Y, Yamakuni T, Ohizumi Y. Iridoids and sesquiterpenoids with NGF-potentiating activity from the rhizomes and roots of *Valeriana fauriei*. Chemical and Pharmaceutical Bulletin. 2006;54(1):123-125.
18. Lanfer-Marquez UM, Barros RM, Sinnecker P. Antioxidant activity of chlorophylls and their derivatives. Food Research International. 2005;38(8-9):885-91.
19. Liu MH, Sun JS, Tsai SW, Sheu SY, Chen MH. Icariin protects murine chondrocytes from lipopolysaccharide-induced inflammatory responses and extracellular matrix degradation. Nutrition Research. 2010;30(1):57-65.
20. Polonsky J, Varon Z, Marazano C, Arnoux B, Pettit GR, Schmid JM, Ochi M, Kotsuki H. The structure of amoorastatone and the cytotoxic limonoid 12-hydroxyamoorastatin. Experientia. 1979;35(8):987-989.
21. Gohil KJ, Patel JA, Gajjar AK. Pharmacological review on *Centella asiatica*: a potential herbal cure-all. Indian journal of pharmaceutical sciences. 2010;72(5):546-556.
22. Laishram S, Sheikh Y, Moirangthem DS, Deb L, Pal BC, Talukdar NC, Borah JC. Anti-diabetic molecules from *Cycas pectinata* Griff. traditionally used by the Maiba-Maibi. Phytomedicine. 2015;22(1):23-26.
23. Rucinska A, Kirko S, Gabryelak T. Effect of the phytoestrogen, genistein-8-C-glucoside, on Chinese hamster ovary cells *in vitro*. Cell Biology International. 2007;31(11):1371-1378.
24. Colpo GD, Ribeiro FM, Rocha NP, Teixeira AL. Animal models for the study of human neurodegenerative diseases. In Animal Models for the Study of Human Disease. Academic Press. 2017;1109-1129.
25. Chandra S, Chandra D, Khajuria AK. Ohioensins: A Potential Therapeutic Drug for Curing Diseases. In Bryophytes. Intech Open. 2019;1-8.
26. Salau VF, Erukainure OL, Ibeji CU, Olasehinde TA, Koorbanally NA, Islam MS. Ferulic acid modulates dysfunctional metabolic pathways and purinergic activities, while stalling redox imbalance and cholinergic activities in oxidative brain injury. Neurotoxicity research. 2020;37(4):944-955.
27. Sishu NK, Selvaraj CI. Cichoriin, a coumarin glycoside with antidiabetic effect and cardioprotective activity against H₂O₂ induced oxidative stress in H9c2 cells: *in-vitro* and *in-silico* study. Free Radical Biology and Medicine. 2025;671-688.
28. Pan CH, Kim ES, Jung SH, Nho CW, Lee JK. Tectorigenin inhibits IFN- γ /LPS-induced inflammatory responses in murine macrophage RAW 264.7 cells. Archives of Pharmacal Research. 2008;31(11):1447-1456.
29. Garg SS, Gupta J, Sahu D, Liu CJ. Pharmacological and therapeutic applications of esculetin. International Journal of Molecular Sciences. 2022;23(20):1-29.
30. Sappey C, Boelaert JR, Legrandpoels S, Grady RW, Piette J. NF- κ B transcription factor activation by hydrogen peroxide can be decreased by 2, 3-Dihydroxybenzoic acid and its ethyl ester derivative. Archives of Biochemistry and Biophysics. 1995;321(1):263-2670.
31. da Silveira JS, Mertz C, Morel G, Lacour S, Belleville MP, Durand N, Dornier M. Alcoholic fermentation as a potential tool for coffee pulp detoxification and reuse: Analysis of phenolic composition and caffeine content by HPLC-DAD-MS/MS. Food Chemistry. 2020;319:1-7.
32. Gharaati S, Kargar H, Falahati AM. Tetrahydropyranylation of alcohols and phenols catalyzed by a new multi-wall carbon nanotubes-bound tin (IV) porphyrin. Journal of the Iranian Chemical Society. 2017;14(6):1169-1178.
33. Cheynier V. Phenolic compounds: from plants to foods. Phytochemistry Reviews. 2012;11(2):153-77.
34. Harborne JB. The Flavonoids: (1988). Advances in research since 1980, Chapman and Hall Ltd, New York.121.
35. Middleton Jr E, Kandaswami C. Effects of flavonoids on immune and inflammatory cell functions. Biochemical Pharmacology. 1992;43(6):1167-1179.
36. Zhang W, Song Q, Bi X, Cui W, Fang C, Gao J, Li J, Wang X, Qu K, Qin X, An X. Preparation of *Pueraria lobata* root-derived exosome-like nanovesicles and evaluation of their effects on mitigating alcoholic intoxication and promoting alcohol metabolism in mice. International Journal of Nanomedicine. 2024;4907-4921.
37. Egan D, O'kenney R, Moran E, Cox D, Prosser E, Thornes RD. The pharmacology, metabolism, analysis and applications of coumarin and coumarin-related compounds. Drug Metabolism Reviews. 1990;22(5):503-529.
38. Laughton MJ, Evans PJ, Moroney MA, Hoult JRS and Halliwell B. Inhibition of mammalian 5-lipoxygenase and cyclooxygenase by flavonoids and phenolic dietary additives. Biochemical Pharmacology. 1991;42:1673-1681.





Sarath Ramesan and Pradeesh

39. Yoshiyuki K, Hiromichi O, Shigeru A, Kimiye B, Mitsugi K. Inhibition of the formation of 5-hydroxy-6, 8, 11, 14-eicosatetraenoic acid from arachidonic acid in polymorphonuclear leukocytes by various coumarins. *Biochimica et Biophysica Acta (BBA)-Lipids and Lipid Metabolism*. 1985;834(2):224-229.
40. [40] Khan MS, Sharma P. Synthesis of New α -Pyroneflavones and Related Products. Part 2. *Chem Inform*. 1993;32: 817-821.
41. Breitmaier E. Hemi- and Monoterpenes. In *Terpenes: Flavors, Fragrances, Pharmaca, Pheromones*; John Wiley and Sons: Hoboken, NJ, USA, 2006;10-23.
42. Davis EM, Croteau R. Cyclization enzymes in the biosynthesis of monoterpenes, sesquiterpenes and diterpenes. In *Biosynthesis: Aromatic polyketides, isoprenoids, alkaloids*. Berlin, Heidelberg: Springer Berlin Heidelberg. 2000;53-95.
43. Martin DM, Gershenzon J, Bohlmann J. Induction of volatile terpene biosynthesis and diurnal emission by methyl jasmonate in foliage of Norway spruce. *Plant Physiology*. 2003;132(3):1586-1599.
44. Pichersky E, Noel JP, Dudareva N. Biosynthesis of plant volatiles: nature's diversity and ingenuity. *Science*. 2006;311(5762):808-811.
45. Yang J, Xian M, Su S, Zhao G, Nie Q, Jiang X, Zheng Y, Liu W. Enhancing production of bio-isoprene using hybrid MVA pathway and isoprene synthase in *E. coli*. *PloS One*. 2012;7(4):1-7.
46. Franklin LU, Cunningham GD, Young DE, inventors; Ximed Group PLC, assignee. Terpene based pesticide treatments for killing terrestrial arthropods including, amongst others, lice, lice eggs, mites and ants. United States patent US 6,130,253. 2000.
47. Widyowati R, Tezuka Y, Miyahara T, Awale S, Kadota S. Alkaline phosphatase (ALP) enhancing iridoid glucosides from the Indonesian medicinal plant *Barleria lupulina*. *Natural Product Communications*. 2010;5(11), 1711-1716.
48. Zhang W, Bai Y, Qiao Y, Wang J, Li MY, Wang JW, Jia N, Chen T, Li YQ, Wen AD. 8-O-Acetyl shanzhiside methylester from *Lamiophlomis rotata* reduces neuropathic pain by inhibiting the ERK/TNF- α pathway in spinal astrocytes. *Frontiers in Cellular Neuroscience*. 2018;12:1-12.
49. Yoshiki Y, Kudou S, OKuBo K. Relationship between chemical structures and biological activities of triterpenoid saponins from soybean. *Bioscience, biotechnology and Biochemistry*. 1998;62(12):2291-2299.
50. Tschesche VR, Wulff G. Chemie und biologie der saponine. In *Fortschritte Der Chemie Organischer Naturstoffe: Progress in the Chemistry of Organic Natural Products*. Vienna: Springer Vienna. 1973;461-606.
51. Bjorn LO, Papageorgiou GC, Blankenship RE, Govindjee. A viewpoint: why chlorophyll a?. *Photosynthesis Research*. 2009;99(2):85-98.
52. [52] Martins T, Barros AN, Rosa E, Antunes L. Enhancing health benefits through chlorophylls and chlorophyll-rich agro-food: A comprehensive review. *Molecules*. 2023;28(14):1-21.
53. Luo Q, Yan X, Bobrovskaya L, Ji M, Yuan H, Lou H, Fan P. Anti-neuroinflammatory effects of grossamide from hemp seed via suppression of TLR-4-mediated NF- κ B signaling pathways in lipopolysaccharide-stimulated BV2 microglia cells. *Molecular and Cellular Biochemistry*. 2017;428(1):129-37.
54. Niyogi KK, Björkman O, Grossman AR. The roles of specific xanthophylls in photoprotection. *Proceedings of the National Academy of Sciences*. 1997;94(25):14162-14167.
55. Vikram A, Jesudhasan PR, Pillai SD, Patil BS. Isolimonc acid interferes with *Escherichia coli* O157: H7 biofilm and TTSS in QseBC and QseA dependent fashion. *BMC Microbiology*. 2012;12(1):1-13.
56. Gabrielsen B, Monath TP, Huggins JW, Kefauver DF, Pettit GR, Groszek G, Hollingshead M, Kirsi JJ, Shannon WM, Schubert EM, DaRe J. Antiviral (RNA) activity of selected Amaryllidaceae isoquinoline constituents and synthesis of related substances. *Journal of Natural Products*. 1992;55(11):1569-1581.
57. Salleh WM, Ahmad F. Phytochemistry and biological activities of the genus *Ocotea* (Lauraceae): A review on recent research results (2000-2016). *Journal of Applied Pharmaceutical Science*. 2017;7(5):204-218.
58. Thongin S, Den-Udom T, Uppakara K, Sriwantana T, Sibmooh N, Laolob T, Boonthip C, Wichai U, Muta K, Ketsawatsomkron P. Beneficial effects of capsaicin and dihydrocapsaicin on endothelial inflammation, nitric oxide production and antioxidant activity. *Biomedicine & Pharmacotherapy*. 2022;154:113521.
59. Bravo RK, Angelia MR, Uy LY, Garcia RN, Torio MA. Isolation, purification and characterization of the antibacterial, antihypertensive and antioxidative properties of the bioactive peptides in the purified and

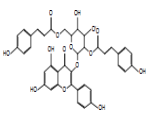




Sarath Ramesan and Pradeesh

- proteolyzed major storage protein of pigeon pea (*Cajanus cajan*) seeds. Food Chemistry: Molecular Sciences. 2022 Jul 30;4:100062.
60. Marley PS, Hillocks RJ. The role of phytoalexins in resistance to *Fusarium* wilt in pigeon pea (*Cajanus cajan*). Plant Pathology. 1993;42(2):212-218.
 61. Hong SJ, Kwon OK, Hwang D, Goo SH, Kim DY, Kim MH, Kim SY, Jang HJ, Oh SR. Anti-inflammatory activity of Cajanin, an isoflavonoid derivative isolated from *Canavalia lineata* pods. International Journal of Molecular Sciences. 2022;23(16):9492.
 62. Liu Y, Shi CZ, Zhang JT. Anti-lipidperoxidation and cerebral protective effects of clausenamide. Acta Pharmaceutica Sinica. 1991;26(3):166-170.
 63. Lee YT, Mohd Yunus MH, Abdul Rani R, Ng CY, Yazid MD, Ugusman A, Law JX. Bioactive-Rich *Piper sarmentosum* Aqueous Extract Mitigates Osteoarthritic Pathology by Enhancing Anabolic Activity and Attenuating NO-Driven Catabolism in Human Chondrocytes. Biomedicines. 2026;14(1):1-21.
 64. Roeder E, Wiedenfeld H. Plants containing pyrrolizidine alkaloids used in the traditional Indian medicine--including ayurveda. Pharmazie. 2013;68(2):83-92.
 65. Bhat C, Tilve SG. Recent advances in the synthesis of naturally occurring pyrrolidines, pyrrolizidines and indolizidine alkaloids using proline as a unique chiral synthon. RSC Advances. 2014;4(11):5405-5452.
 66. H. Mellegard, T. Stalheim, V. Hormazabal, P.E. Granum, S.P. Hardy, Antibacterial activity of sphagnum acid and other phenolic compounds found in *Sphagnum papillosum* against food-borne bacteria. Letters in Applied Microbiology. 2009;49(1):85-90.
 67. Lu C, Li Y, Hu S, Cai Y, Yang Z, Peng K. Scoparone prevents IL-1 β -induced inflammatory response in human osteoarthritis chondrocytes through the PI3K/Akt/NF- κ B pathway. Biomedicine and Pharmacotherapy. 2018;106:1169-1174.
 68. Luo Y, Zhang S, Ou S, Shen C, Xiao Q, Chen W, Pu J, Zeng J, Zheng D, Huang B, Chen C. Scopoletin and Scoparone from *Viola philippica* Attenuate the Virulence of *Pseudomonas aeruginosa* by Inhibiting Quorum Sensing-Related Genes. Infection and Drug Resistance. 2025;3891-3906.
 69. Adekola HA, Adeleye AO, Adesetan TO, Folorunso JB, Odeyemi FA. Antibacterial activity of vanillic acid against *Staphylococcus aureus*, *Salmonella typhi* and *Proteus mirabilis*. Microbes, Infection and Chemotherapy. 2022;2:1-6.
 70. Calixto-Campos C, Carvalho TT, Hohmann MS, Pinho-Ribeiro FA, Fattori V, Manchope MF, Zarpelon AC, Baracat MM, Georgetti SR, Casagrande R, Verri Jr WA. Vanillic acid inhibits inflammatory pain by inhibiting neutrophil recruitment, oxidative stress, cytokine production and NF κ B activation in mice. Journal of Natural Products. 2015;78(8):1799-1808.
 71. Moller BL, Seigler DS. In BK Singh, ed, Plant Amino Acids, Biochemistry and Biotechnology. Marcel Dekker, New York, 1999;563-609.
 72. Roy A. A review on the alkaloids an important therapeutic compound from plants. International Journal of Plant Biotechnology. 2017;3(2):1-9.

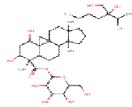
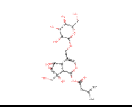
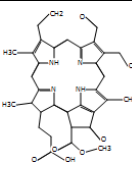
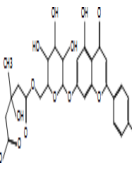
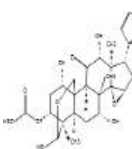
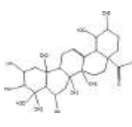
Table 1 HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* and identification of compounds with their biological uses using negative ionization mode

Sl. No.	Name of the compound	Molecular formula	RT	Mass	M/Z	Class	Structure	Activities
1	Kaempferol 3-(2",6"-di-(E)-p-coumarylglucoside)	C ₃₉ H ₃₂ O ₁₅	3.973	740.1834	739.1764	Flavonoids		Antioxidant and Antibacterial properties [15].





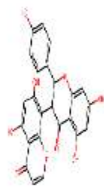
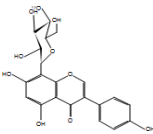
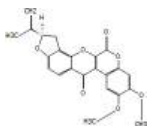
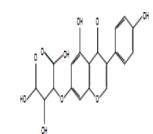
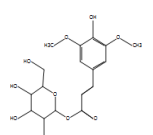
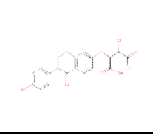
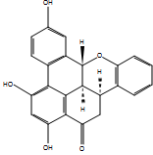
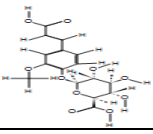
Sarath Ramesan and Pradeesh

2	Cyclopassifloside II	$C_{37}H_{62}O_{11}$	23.46 4	682.42 25	681.41 55	Triterpenoid Saponins		Anti-inflammatory Activity (iNOS Inhibition) [16].
3	Notoginsenoside T2	$C_{37}H_{62}O_{10}$	23.92 3	666.42 82	665.42 12	Saponins		Not reported
4	Kanokoside C	$C_{27}H_{42}O_{17}$	15.47 5	638.24 86	683.24 71	Iridoid glycosides		Neuroprotective and NGF-Potentiating Activity [17].
5	Phaeophorbide b	$C_{35}H_{34}N_4O_6$	18.87 8	606.25 04	605.24 3	Chlorophyll		Antioxidant activity [18].
6	Chamaemeloside	$C_{27}H_{28}O_{14}$	7.649	576.15 13	575.14 41	Flavonoid		Anti-inflammatory effects [19].
7	12-alpha hydroxyamoorastatin	$C_{28}H_{36}O_{10}$	10.94 6	532.23 43	531.22 73	Terpenes		Antileukemic Activity [20].
8	Madasiatic acid	$C_{30}H_{48}O_5$	17.27 6	488.35 27	487.34 59	Terpenes		Anti-inflammatory, Antioxidant, Antimicrobial properties and wound healing properties [21].
9	2,3-Dihydro-5,5',7,7'-tetrahydroxy-2-(4-hydroxyphenyl)[3,8'-bi-4H-1-benzopyran]-4,4'-dione or 2,3-dihydroamentoflav	$C_{24}H_{16}O_9$	5.913	448.07 79	447.07 27	Flavonoid		Anti-diabetic activity [22].





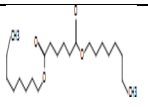
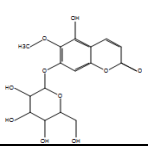
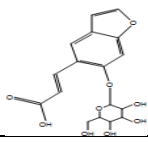
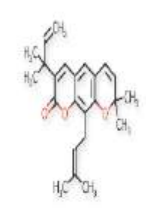
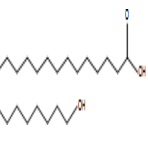
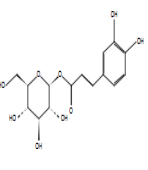
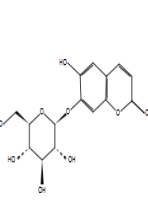
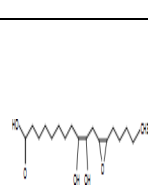
Sarath Ramesan and Pradeesh

	one							
10	Genistein 8-C-glucoside	$C_{21}H_{20}O_{10}$	6.554	432.1077	431.1005	Flavonoids		Antioxidant properties [23].
11	Rotenonone	$C_{23}H_{18}O_7$	7.969	406.1076	405.1006	Phenolic compound		Used as an insecticide and pesticide [24].
12	Shoyuflavone B	$C_{19}H_{14}O_{10}$	8.046	402.061	401.0539	Phenolic compound		Not reported
13	1-O-Sinapoylglucose	$C_{17}H_{22}O_{10}$	4.961	386.1228	385.1158	Phenolic compound		Not reported
14	Shoyuflavone A	$C_{19}H_{14}O_9$	10.388	386.0658	385.0586	Phenolic compound		Not reported
15	Ohioensin-A	$C_{23}H_{16}O_5$	13.479	372.102	371.0943	Flavonoids		Antioxidant, Anti-inflammatory and Anticancer properties [25].
16	Ferulic acid 4-O-glucuronide	$C_{16}H_{18}O_{10}$	3.974	370.0919	415.0903	Phenolic compound		Antioxidant properties [26].
17	Diocetyl hexanedioate	$C_{22}H_{42}O_4$	20.598	370.31	369.3028	Esters		Not reported





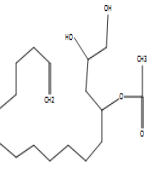
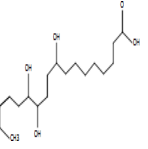
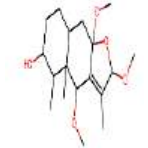
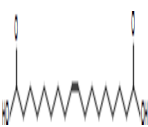
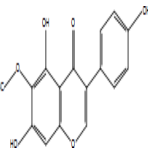
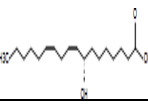
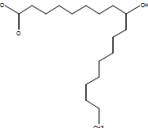
Sarath Ramesan and Pradeesh

								
18	5-Hydroxy-6-methoxycoumarin 7-glucoside	$C_{16}H_{18}O_{10}$	3.971	370.09 21	369.08 5	Coumarin glycosides		Not reported
19	Furocoumarinic acid glucoside	$C_{17}H_{18}O_9$	5.508	366.09 69	411.09 52	Coumarin glycosides		Not reported
20	3-(1,1-Dimethyl-2-propenyl)-8-(3-methyl-2-butenyl) xanthyletin	$C_{24}H_{28}O_3$	10.08 9	364.20 13	363.19 56	Pyrano coumarins		Not reported
21	omega-hydroxy behenic acid	$C_{22}H_{44}O_3$	24.96 3	356.33 07	355.32 34	Fatty acid		Not reported
22	1-Caffeoyl-beta-D-glucose	$C_{15}H_{18}O_9$	11.81	342.09 18	387.09 03	Phenolic glycoside		Not reported
23	Cichoriin	$C_{15}H_{16}O_9$	4.388	340.08 12	339.07 38	Polyphenolic coumarin glycoside		Antioxidant, Antidiabetic and Cardioprotective Activity [27].
24	9,10-Dihydroxy-12,13-epoxyoctadecanoate	$C_{18}H_{34}O_5$	10.70 5	330.24 28	329.23 55	Oxylipins		Not reported
25	(2S)-2-	$C_{20}H_{40}O_3$	23.22	328.29	327.29	Fatty acid		Not reported





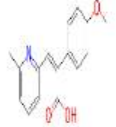
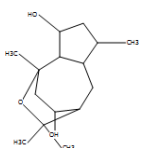
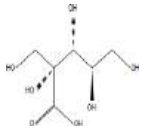
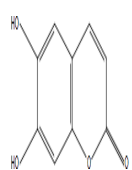
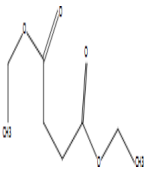
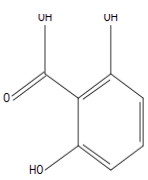
Sarath Ramesan and Pradeesh

	hydroxyphytanic acid		6	93	21			
26	Avocadene 4-acetate	C ₁₉ H ₃₆ O ₄	19.16 2	328.26 31	327.25 58	Fatty alcohols		Not reported
27	Corchorifatty acid F	C ₁₈ H ₃₂ O ₅	10.00 7	328.22 67	327.21 94	Oxylipins		Not reported
28	(3b,6b,8a,12a)-8,12-Epoxy-7(11)-eremophilene-6,8,12-trimethoxy-3-ol	C ₁₈ H ₃₀ O ₅	10.10 1	326.20 99	325.20 28	Naphthofurans		Not reported
29	9Z-Octadecenedioic acid	C ₁₈ H ₃₂ O ₄	13.14 4	312.23 2	311.22 48	Dicarboxylic acid		Not reported
30	Tectorigenin	C ₁₆ H ₁₂ O ₆	8.259	300.06 52	299.05 8	Flavonoid		Anti-inflammatory activity [28].
31	8S-HODE	C ₁₈ H ₃₂ O ₃	15.86 5	296.23 71	295.23	Fatty acid		Not reported
32	9-HOTE	C ₁₈ H ₃₀ O ₃	15.13 5	294.22 12	293.21 4	Fatty acids		Not reported
33	16-Hydroxy hexadecanoic acid	C ₁₆ H ₃₂ O ₃	19.41 8	272.23 66	271.22 94	Fatty acids		Not reported





Sarath Ramesan and Pradeesh

34	alpha-(p-Methoxyphenyl)-6-methyl-2-pyridineacrylic acid	$C_{16}H_{15}NO_3$	10.01 2	269.10 67	268.09 95	Carboxylic acid		Not reported
35	Kessyl glycol	$C_{15}H_{26}O_3$	11.21 3	254.18 96	299.18 8	Terpenes		Not reported
36	Hamamelose	$C_6H_{12}O_7$	1.201	196.05 9	195.05 17	Sugars		Not reported
37	Esculetin	$C_9H_6O_4$	5.192	178.02 75	177.02 02	Coumarin		Antioxidant property, Antidiabetic and Antiinflammatory activities [29].
38	Diethyl succinate	$C_8H_{14}O_4$	6.166	174.09	173.08 27	Dicarboxylic acid esters		Not reported
39	2,6-dihydroxybenzoic acid	$C_7H_6O_4$	3.059	154.02 71	153.01 98	Phenolic compounds		Antioxidant properties [30].





Sarath Ramesan and Pradeesh

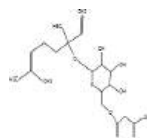
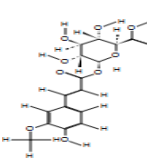
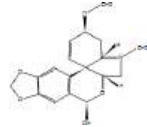
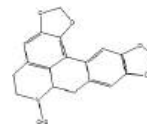
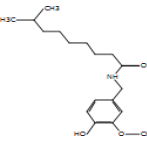
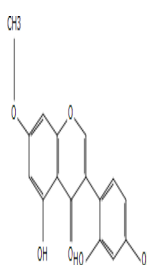
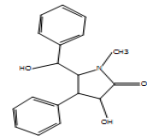
Table 2. HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* and identification of compounds with their biological uses using positive ionization mode

Sl. No.	Name of the compound	Molecular formula	RT	Mass	M/Z	Class	Structure	Activities
1	Red chlorophyll catabolite	C ₃₅ H ₃₈ N ₄ O ₇	14.25	626.2691	627.2764	Linear tetrapyrrole		Not reported
2	Grossamide	C ₃₆ H ₃₆ N ₂ O ₈	19.916	624.2542	625.2617	Lignanamides		Anti-inflammatory properties [53].
3	Phaeophorbide b	C ₃₅ H ₃₄ N ₄ O ₆	18.778	606.2437	607.251	Chlorophyll		Antioxidant activity [18].
4	Phaeophorbide a	C ₃₅ H ₃₆ N ₄ O ₅	21.1	592.2652	593.2725	Chlorophyll		Antioxidant activity [18].
5	Antheraxanthin A	C ₄₀ H ₅₆ O ₃	23.189	584.4161	585.4234	Carotenoids / Terpenoids		Protect plants from photooxidative damage [54].
6	Liquiritin apioside	C ₂₆ H ₃₀ O ₁₃	1.818	550.1752	276.0949	Flavonoid glycosides		Not reported
7	Physalin O	C ₂₈ H ₃₂ O ₁₀	15.19	528.1989	529.2063	Terpenoids		Not reported





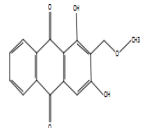
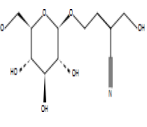
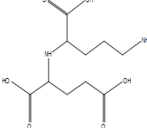
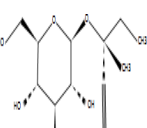
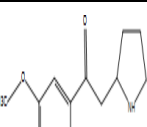
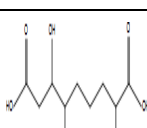
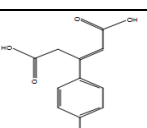
Sarath Ramesan and Pradeesh

8	Isolimononic acid	$C_{26}H_{34}O_{10}$	15.18 7	506.21 73	507.22 45	Terpenoids		Antibacterial properties [55].
9	D-Linalool 3-(6''-malonylglucoside)	$C_{19}H_{30}O_9$	11.77 6	402.19 12	403.19 86	Terpenoids		Not reported
10	Feruloyl C1-glucuronide	$C_{16}H_{18}O_{10}$	3.79	370.08 72	371.09 45	Phenolic compounds		Not reported
11	Pretazettine	$C_{18}H_{21}NO_5$	14.08 2	331.13 88	332.14 61	Alkaloid		Antiviral activity [56].
12	(S)-Neolitsine	$C_{19}H_{17}NO_4$	5.236	323.11 86	324.12 61	Alkaloid		The most cytotoxic alkaloid to MCF-7 and B16-F10 cells [57].
13	Dihydrocapsaicin	$C_{18}H_{29}NO_3$	8.631	307.21 13	308.21 96	Alkaloids		Antioxidant and Anti-inflammatory activities [58].
14	Cajanin	$C_{16}H_{12}O_6$	8.154	300.06 03	301.06 76	Isoflavonoids		Antibacterial and Antioxidant properties [59] Antifungal activity [60] Anti-inflammatory activity [61].
15	(±)-Clausenamide	$C_{18}H_{19}NO_3$	11.48 7	297.13 38	298.14 07	Alkaloids		Anti-lipidperoxidation and cerebral protective effects [62].





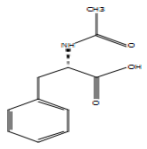
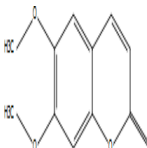
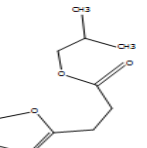
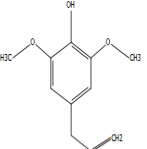
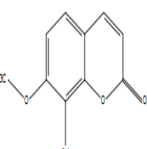
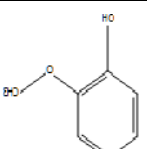
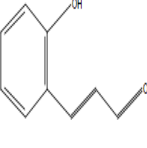
Sarath Ramesan and Pradeesh

16	Lucidin omega-methyl ether	$C_{16}H_{12}O_5$	8.084	284.06 56	285.07 27	Phenolic compounds		Not reported
17	Sarmentosin	$C_{11}H_{17}NO_7$	2.223	275.09 81	276.10 55	Cyanogenic glycosides		Anti-inflammatory and antioxidant activities [63].
18	Ornaline	$C_{10}H_{18}N_2O_6$	5.753	262.11 77	263.12 49	Polyketides		Not reported
19	Lotaustralin	$C_{11}H_{19}NO_6$	5.061	261.11 79	262.12 61	Cyanogenic glycosides		Not reported
20	Ruspolinone	$C_{14}H_{19}NO_3$	6.4	249.13 41	250.14 13	Alkaloid		Organocatalysts and building blocks in organic synthesis [64,65].
21	Methyl 2,3-dihydro-3,5-dihydroxy-2-oxo-3-indoleacetic acid	$C_{11}H_{11}NO_5$	1.434	237.06 15	238.06 88	Indolyl carboxylic acid		Not reported
22	2,6-Diamino-7-hydroxy-azelaic acid	$C_9H_{18}N_2O_5$	6.705	234.12 25	235.13 03	Organic acid		Not reported
23	Sphagnum acid	$C_{11}H_{10}O_5$	7.077	222.05 05	223.05 77	Phenolic compounds		Antibacterial activity [66].





Sarath Ramesan and Pradeesh

24	N-Acetyl-L-phenylalanine	$C_{11}H_{13}NO_3$	1.471	207.0873	208.0946	N acyl alpha aminoacids		Not reported
25	Scoparone	$C_{11}H_{10}O_4$	7.916	206.0554	207.0626	Coumarins		Anti-inflammatory activity [67]. Antibacterial activity [68].
26	Isobutyl 2-furanpropionate	$C_{11}H_{16}O_3$	6.55	196.1079	197.1152	Fatty acid ester		Not reported
27	Methoxyeugenol	$C_{11}H_{14}O_3$	6.64	194.0922	195.0995	Phenyl propanoids		Not reported
28	8-Hydroxy-7-methoxy-2H-1-benzopyran-2-one	$C_{10}H_8O_4$	6.342	192.0404	193.0477	Hydroxy coumarins		Not reported
29	Vanillic acid	$C_8H_8O_4$	3.792	168.0406	169.0476	Phenolic acid		Antibacterial activity [69]. Anti-Inflammatory activity [70].
30	(E)-3-(2-Hydroxyphenyl)-2-propenal	$C_9H_8O_2$	14.046	148.0508	149.0581	Phenyl propanoids		Not reported



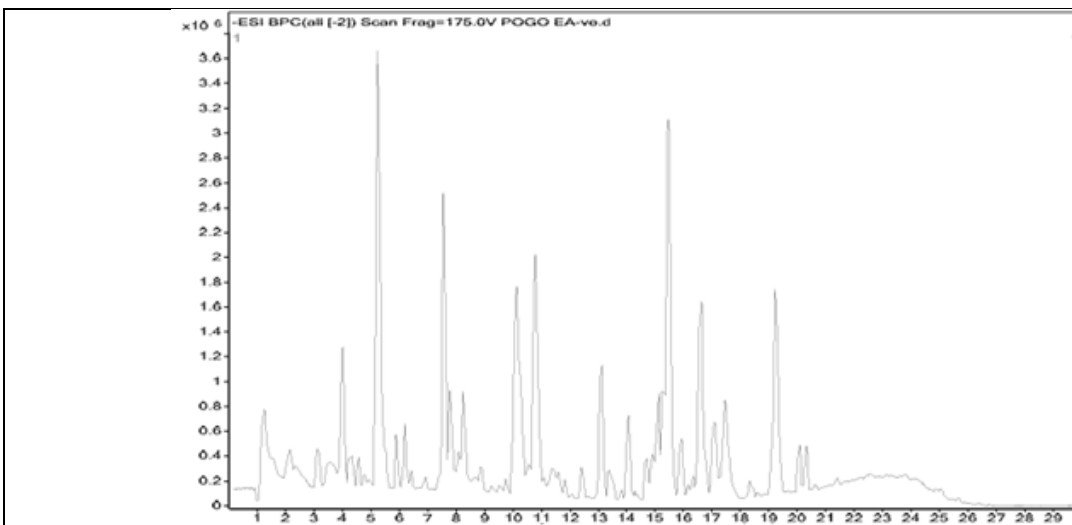
**Sarath Ramesan and Pradeesh**

Fig. 1. Chromatogram showing different peaks corresponding to various compounds in the negative ionization mode.

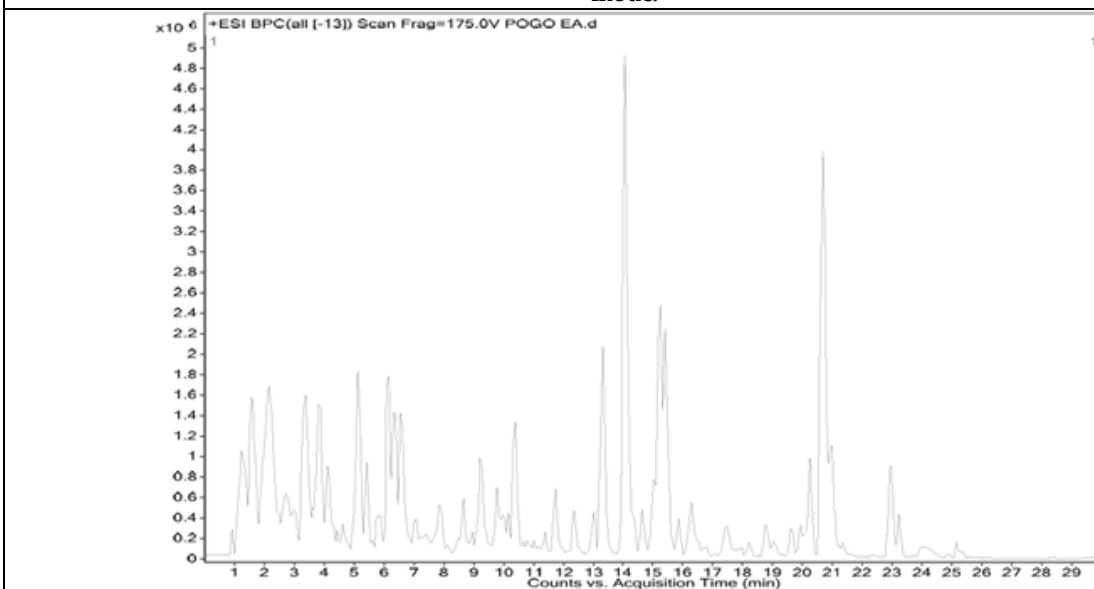


Fig. 2. Chromatogram showing different peaks corresponding to various compounds in the positive ionization mode.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Thymidine Oxidation by the Sodium Chromate – Hydrogen Peroxide System: Kinetic and Mechanistic Insights, and the Modulating Roles of Ascorbic Acid and Riboflavin

M.Sudha Swaraga*

Assistant Professor, Department of Chemistry, St.Pious X Degree and PG College for Women (Affiliated to Osmania University), Hyderabad, Telangana, India.

Received: 21 Mar 2026

Revised: 22 Apr 2026

Accepted: 25 May 2026

*Address for Correspondence

M.Sudha Swaraga

Assistant Professor,
Department of Chemistry,
St.Pious X Degree and PG College for Women
(Affiliated to Osmania University),
Hyderabad, Telangana, India
E.Mail: drsudhaswaraga@stpiouscollege.org



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The oxidation of Thymidine with sodium chromate and hydrogen peroxide ($\text{Cr(VI)} - \text{H}_2\text{O}_2$) system in presence of ascorbic acid at pH 8 has been carried in tris HCl buffer. The reactions are followed by measuring the absorbance of Thymidine at λ_{max} of 267nm. The rates of oxidation of Thymidine increased with increase in [chromate], [hydrogen peroxide] and [ascorbic acid]. The plot $\log$ (initial rate) versus $\log$ [chromate], and $\log$ (initial rate) versus $\log$ [ascorbic acid] was found to be linear with slope less than one indicating fractional order dependence on [chromate] and [ascorbic acid]. The fractional order dependence of reaction rate on [ascorbic acid] and [chromate] indicates that reaction might be proceeding through the initial formation of a complex between ascorbic acid and Cr(VI) . The first order dependence of rate of oxidation on $[\text{H}_2\text{O}_2]$ suggests that Chromium-Ascorbate complex might react with H_2O_2 in the rate determining step via Fenton like mechanism to generate OH radicals. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no significant increase of rate of oxidation suggests that OH radicals react with Thymidines in a fast step to form product. It has been found that riboflavin protects Thymidine to the extent of 78.9% at $64\mu\text{M}$ concentration of riboflavin from OH radicals.

Keywords: Oxidation of Thymidine, Chromium (VI), Hydrogen peroxide, ascorbic acid, Chromium-Ascorbate complex, Protection by riboflavin



**Sudha Swaraga**

INTRODUCTION

Chromate, Cr(VI), as a human carcinogen has been established, although its mechanism of action has not been clearly defined [1,2]. The reaction of DNA with chromate causes a number of putative lesions in cellular systems including oxidized nucleic acid bases, abasic sites, DNA strand breaks, inter- and intrastrand cross-linked adducts and DNA–protein cross-links [3-7]. The tetrahedral structure of anionic conformation of +6 oxidation state of chromium facilitates active transport into cell systems through the phosphate and sulfate cellular transport systems [8]. Cr(VI) does not directly react with isolated DNA; rather, its genotoxic effects are mediated through reduction by cellular reductants, producing Cr(V) species that are considered key intermediates in DNA damage [8,9]. Various biological systems contribute to this reduction, including microsomes [10,11], mitochondria [12], superoxide radicals [13], flavin-containing enzymes [14–16], mitochondrial electron transport chain complexes [17], ascorbate [18,19], and thiol- or diol-containing molecules [8,20–22]. Jennette [10] proposed that Cr(V) represents the ultimate carcinogenic form of chromium.. Earlier studies by Kawanishi et al. [23] suggested that Cr(V)(O₂)₄³⁻ mediates hydroxyl radical (•OH) formation from a mixture of 40 mM Na₂CrO₄ and 400 mM H₂O₂ at pH 8.

However, these concentrations exceed physiological levels, as noted by Aiyar et al. [24]. Subsequent ESR and spin-trapping studies revealed that Cr(V)(O₂)₄³⁻ is not formed in significant amounts with biologically relevant reductants. Instead, Cr(V) forms complexes with reductant-derived ligands, which generate hydroxyl radicals from H₂O₂ through Fenton-like reactions [25–27]. Chromium(VI)-induced DNA damage also exhibits tissue specificity. In animal models, DNA-protein and DNA interstrand crosslinks are observed in the livers of chick embryos treated with Cr(VI), whereas in red blood cells, damage manifests mainly as strand breaks [28]. This indicates that Cr(VI) reduction follows different metabolic pathways depending on the tissue type. The present study investigates the mechanism of DNA constituent damage induced by hydroxyl radicals generated from the Cr(VI)-H₂O₂ system, both in the presence and absence of naturally occurring antioxidants. By analyzing the reaction products of chromate with nucleosides and nucleic acid bases, we aim to gain deeper insights into the oxidative pathways involved in DNA damage.

Experimental

Thymidine, sodium chromate and ascorbic acid were from sigma and used as such. The solutions were prepared afresh with double distilled water, standardized and de-aerated by bubbling nitrogen. The Hydrogen peroxide solution was standardized using the method described in the literature [29]. The concentration of thymidine was determined by measuring the absorbance at λ_{max} of 267nm from the known absorption coefficient values. In a typical reaction required amounts of thymidine and H₂O₂ solution were then injected as aqueous solution into the mixture of ascorbic acid and sodium chromate solutions present in a 1-cm path length quartz cuvette suitable for absorbance measurements. The progress of the reactions were followed by measuring the absorbance at λ_{max} of thymidine on double beam UV-visible Spectrophotometer model T60U of Lab India at different time intervals from which rate of oxidation of thymidine were calculated.

The HPLC system used for analysis of products includes shimadzu LC-10AT equipment with dual piston pump system, a solvent programmer and Reodhyne injector model 7725 fitted with 20 μ l loop. A prepacked octadecylsilyl silica gel ODS hypersil column 25cm $\times$ 0.46cm, mean particle size 5 μ m was used. The column effluents were monitored at 280nm, using variable wavelength SPD-10A UV-Visible detector equipped with 8 μ l flow cell and attached to C-R7Ae plus chromatographic integrator. Samples were eluted with aqueous solutions containing 5% (v/v) methanol and buffered with 10mM KH₂PO₄ solution adjusted to pH 8. Before use the phosphate buffer was filtered through Millipore type HA 0.45 μ m membrane filter. All mobile phases were degassed using a vacuum pump. The solvent flow rate was kept at 0.5ml/min and all the HPLC runs were carried out at ambient temperatures.





Sudha Swaraga

RESULTS AND DISCUSSION

The oxidation of Thymidine with sodium chromate and hydrogen peroxide (Cr(VI) - H_2O_2) system in presence and absence of ascorbic acid at pH 8 has been carried in tris HCl buffer. Thymidine is not oxidized even with highest concentration of sodium chromate (1×10^{-4} M) and hydrogen peroxide (5×10^{-3} M) system in the absence of ascorbic acid but in presence of ascorbic acid (1×10^{-5} M), thymidine is oxidized even with concentration as low as of sodium chromate (1×10^{-8} M) and hydrogen peroxide (5×10^{-3} M). The oxidation of thymidine with Cr(VI) - H_2O_2 system in presence of ascorbic acid were carried out (Spectra 1). The oxidation of Thymidine with Cr(VI) - H_2O_2 system in presence of ascorbic acid were carried out at different [chromate] varying from 2×10^{-4} to 1×10^{-8} M keeping [ascorbic acid], [Thymidine] and [H_2O_2] constant. The plot of log (initial rate) versus log [chromate] was found to be linear with slope less than one indicating fractional order dependence on chromate (Figure 1). The effect of [ascorbic acid] varying between 1×10^{-5} – 4×10^{-5} M was studied keeping [H_2O_2], [Thymidine] and [chromate] constant. The plot of log (initial rate) versus log [ascorbic acid] was found to be linear with slope less than one indicating fractional order dependence on ascorbic acid (Figure 2).

An increase in [H_2O_2] was found to increase the rate of oxidation and order with respect to [H_2O_2] has been found to be unity from the slopes of log (initial rate) versus log [H_2O_2]. The concentration of H_2O_2 was varied between 1×10^{-3} – 1×10^{-2} M. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no significant effect on rate of oxidation of Thymidine. In the present work, the fractional order dependence of reaction rate on [ascorbic acid] and [chromate] indicates that reaction might be proceeding through the initial formation of complex between ascorbic acid and Cr (VI) to give Cr(V)-ascorbate complex. Reduction of Cr(VI) by biological reductants such as ascorbic acid is well established to proceed via Cr(V) intermediates, which are highly reactive and play a key role in oxidative damage. Jennette demonstrated that Cr(V) species are crucial intermediates in chromium-induced carcinogenic processes[10]. Shi al confirmed the formation of Cr(V) during reduction of Cr(VI) by biological reductants using ESR spectroscopy[11]. These studies support $\text{Cr(VI)} + \text{ascorbate} \rightarrow \text{Cr(V)}\text{-ascorbate complex}$.

The first order dependence of rate of oxidation Thymidine on [H_2O_2] suggests that Cr(V)-Ascorbate complex reacts with H_2O_2 in the rate determining step via Fenton like mechanism to generate OH radicals. Cr(V) complexes are known to react with hydrogen peroxide to generate hydroxyl radicals through Fenton-like chemistry. Kawanishi et al. reported hydroxyl radical formation in Cr(VI)- H_2O_2 systems[23]. Aiyar et al. clarified that under biologically relevant conditions, Cr(V) forms ligand-bound complexes that mediate $\bullet\text{OH}$ generation rather than free peroxo species [24]. Shi et al. further demonstrated that Cr(V)-ligand complexes catalyze H_2O_2 decomposition to produce $\bullet\text{OH}$ radicals [25].

This supports the step: $\text{Cr(V)}\text{-ascorbate} + \text{H}_2\text{O}_2 \rightarrow \text{Cr(VI)} + \bullet\text{OH}$

With the addition of ethanol, oxidation of Thymidine decreased indicating that OH radicals are generated in our system. The rate constant of OH radical with ethanol is reported to be $1.8 \pm 0.2 \times 10^9 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$ [29]. The rate constant of OH radical with thymidine are calculated using equation (1) and found to be $4.2 \times 10^9 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$. Hence in this system there might be a competition between Thymidine and ethanol for OH radicals. The relative amounts of OH radicals reacting with Thymidine decreases with increasing [ethanol]. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no effect on rate of oxidation suggests that OH radicals react with Thymidine in the fast step to form product. In order to understand the site of attack of OH radical on thymidine i.e, at the base/sugar moiety, a quantitative estimation of the base and sugar moieties present in the Thymidine has been made simultaneously and independently under same kinetic conditions at different times. The results indicated that the sugar moiety is not significantly affected during the oxidation either in the absence or presence of riboflavin [Table.1]. The rate of oxidation of D-ribose by OH radicals is lower than the rate of oxidation of Thymidine under the same experimental conditions. Further, the rates of oxidation of Thymidine by OH radicals are comparable to those of the rates of oxidation of Thymine (Table.1). These results indicate that it is the base moiety





Sudha Swaraga

that is preferentially attacked by OH radicals. Therefore protection offered by riboflavin is thought to be mainly against base moiety oxidation.

Effect of pH : With increase in pH, rate of oxidation of Thymidine have been found to increase with Cr(VI)-H₂O₂ system in presence of ascorbic acid. Increase in rate of oxidation of Thymidine with pH clearly shows that oxidation occurs by OH radicals generated by reaction of H₂O₂ with Cr(V)-ascorbate complex via Fenton reaction (Table 2).

Anti oxidant activity of Riboflavin : The initial rates of oxidation of Thymidine by Cr (VI) - H₂O₂ system in presence of ascorbic acid have been found to decrease with increase in [Riboflavin] indicating that riboflavin is protecting the Thymidine from OH radicals generated with Cr (V)-ascorbate complex reaction with H₂O₂ via Fenton like mechanism [Table 3] & [Figure 3].

In this system there is a competition between Thymidine and riboflavin for OH radicals. The relative amounts of OH radicals reacting with Thymidine decreases with increasing [riboflavin]. The rate constant of riboflavin with hydroxyl radical has been reported to be $1.2 \pm 0.05 \times 10^{10} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ over the pH range 1–11 [30]. The rate constant of hydroxyl radical with ascorbic acid at physiological pH has been reported to be $2.7 \times 10^5 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ [31]. This indicates that ascorbic acid is not specific hydroxyl radical scavenger at physiological pH. Since the rate constant of OH radical with riboflavin is much higher than rate constant of OH radical with ascorbic acid, it is understood that ascorbic acid does not compete for OH radicals under the experimental conditions. The rate constant of the reaction of the OH radical with thymidine has been calculated by the Thymidine competition method at pH 8 in tris HCl buffer, which is very similar to the one chosen by Akhalaq et al [32] to determine the rate constant for the reaction of OH radicals with polyhydric alcohols in competition with KSCN[33,34]. Solutions containing thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid and in the absence and also presence of varying amounts of riboflavin were made to react for 4 minutes and decrease of absorbance of Thymidine was measured. The decrease of absorbance of thymidine reflects the number of OH radicals that have reacted with thymidine. From the reported rate constant of riboflavin with OH radicals at pH 8 ($k_{\text{riboflavin} + \text{OH}} = 1.23 \times 10^{10} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$) by Sudha et al [35], the rate constant of OH radical with Thymidine can be calculated using equation (1).

$$\frac{[\text{Absorbance of Thymidine}]_0}{[\text{Absorbance of Thymidine}]_{\text{riboflavin}}} = 1 + \frac{k_{(\text{OH} + \text{Riboflavin})} [\text{Riboflavin}]}{k_{(\text{OH} + \text{Thymidine})} [\text{Thymidine}]} \quad (1)$$

Where $[\text{Absorbance of Thymidine}]_0$ and $[\text{Absorbance of Thymidine}]_{\text{riboflavin}}$ indicate the decrease in the absorbance of Thymidine in the absence and presence of riboflavin respectively, in the same interval of time. Experiments of this kind can be carried out with great accuracy. The rate constant for the reaction of OH radical with thymidine has been calculated with five different concentrations of Thymidine and average value obtained is $4.2 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. The probability of OH radicals reacting with Thymidine $\{p(\text{OH} + \text{Thymidine})\}$ is calculated using the following equation.

$$p(\text{OH} + \text{Thymidine}) = \frac{[\text{Thymidine}] k_{\text{Thymidine}}}{[\text{Thymidine}] k_{\text{Thymidine}} + [\text{Riboflavin}] k_{\text{Riboflavin}}} \quad (2)$$

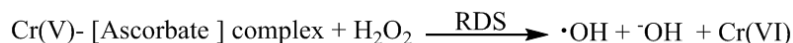
$k_{\text{Thymidine}}$ and $k_{\text{riboflavin}}$ are the rate constants of OH radical with Thymidine and riboflavin respectively. From the rate constant of OH radical with riboflavin and Thymidine (Equation (2)), the fraction of OH radicals scavenged by riboflavin (Percentage scavenged = $(1 - p) \times 100$) at different [riboflavin] were calculated (Table.3). These values were a measure of protection of Thymidine due to scavenging of OH radicals by riboflavin. It has been found that riboflavin is protecting thymidine to the extent of 78.9% at 64 μM concentration of riboflavin from OH radicals. Based on the above results and discussion the following mechanism has been proposed in scheme 1





Sudha Swaraga

Scheme 1



CONCLUSIONS

The present study exhibit that under biologically relevant conditions, mixture of Cr(VI) and H₂O₂ does not oxidize Thymidine by OH radicals generated in this system but Cr(VI) Concentration as low as 1×10⁻⁸ M and H₂O₂ 5×10⁻³ M could oxidize Thymidine in presence of ascorbic acid. It has been found that riboflavin protects Thymidine to the extent of 78.9% at 64μM concentration of riboflavin from OH radicals.

ACKNOWLEDGEMENT

The author express sincere gratitude to the University Grants Commission (UGC) for awarding the Minor Research Project, under which the present study has been carried out. The financial assistance provided by UGC is gratefully acknowledged. The author also extend heartfelt thanks to St. Pious X Degree and PG College for Women, Nacharam, Hyderabad, Telangana, for providing the necessary infrastructure and facilities to successfully complete this research work.

REFERENCES

1. International Agency for Research on Cancer. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Chromium, Nickel and Welding*. Lyon: IARC; 1990. Vol. 48, pp. 49–508.
2. R. B. Hayes. Carcinogenic effects of chromium. In: Langard S, editor. *Biological and Environmental Aspects of Chromium*. New York: Elsevier Biomedical Press; 1982. pp. 221–248.
3. C. A. Miller, M. Costa. *Mol Carcinog*. 1988;1:125.
4. O. Cantoni, M. Costa. *Carcinogenesis*. 1984;5:1207.
5. D. Y. Cupo, K. E. Wetterhahn. *Cancer Res*. 1985;45:1146.
6. J. W. Hamilton, K. E. Wetterhahn. *Carcinogenesis*. 1986;7(12):2085.
7. S. H. Robison, O. Cantoni, M. Costa. *Mutat Res*. 1984;131:173.
8. P. H. Connett, K. E. Wetterhahn. *Struct Bonding*. 1983;54:93.
9. M. J. Tsapakos, K. E. Wetterhahn. *Chem Biol Interact*. 1983;46(2):265.
10. K. W. Jennette. *J Am Chem Soc*. 1982;104:874–875.
11. X. Shi, N. S. Dalal, V. Vallyathan. *Arch Biochem Biophys*. 1991;290(2):381.
12. S. C. Rossi, N. Gorman, K. E. Wetterhahn. *Chem Res Toxicol*. 1988;1(2):101.
13. X. Shi, N. S. Dalal. *Arch Biochem Biophys*. 1992;292(1):323.
14. X. Shi, N. S. Dalal. *Biochem Biophys Res Commun*. 1989;163(1):627.
15. X. Shi, N. S. Dalal. *J Inorg Biochem*. 1990;40(1):1.
16. X. Shi, N. S. Dalal. *FEBS Lett*. 1990;276(1–2):189.





Sudha Swaraga

17. S. C. Rossi, K. E. Wetterhahn. Carcinogenesis. 1989;10(5):913.
18. A. M. Standeven, K. E. Wetterhahn. Carcinogenesis. 1991;12(9):1733.
19. D. M. L. Goodgame, A. M. Joy. Inorg Chim Acta. 1987;135(2):115.
20. X. Shi, N. S. Dalal. Arch Biochem Biophys. 1990;277(2):342.
21. X. Shi, N. S. Dalal. Biochem Biophys Res Commun. 1988;156:137.
22. P. O'Brien, J. Barrett, F. Swanson. Inorg Chim Acta. 1985;108:L19.
23. S. Kawanishi, S. Inoue, S. Sano. J Biol Chem. 1986;261:5952.
24. J. Aiyar, K. M. Borges, R. A. Floyd, K. E. Wetterhahn. Toxicol Environ Chem. 1989;22:135.
25. X. Shi, N. S. Dalal. Environ Health Perspect. 1994;102(Suppl 3):231.
26. M. Sugiyama, A. Ando, R. Ogura. Biochem Biophys Res Commun. 1989;159(3):1080.
27. M. Sugiyama et al. Cancer Lett. 1987;38:1.
28. J. W. Hamilton, K. E. Wetterhahn. Carcinogenesis. 1986;7(12):2085.
29. S. Steenken. Chem Rev. 1989;89:503–520.
30. K. Kishore, P. N. Moorthy, K. N. Rao. Radiat Phys Chem. 1982;20(4):241.
31. Subcellular Biochemistry Volume 25: Ascorbic Acid. Edited by J. Robin Harris.
32. M. S. Akhalaq, S. Al-Baghdad, C. von Sonntag. Carbohydr Res. 1987;164:71.
33. A. J. C. S. Vieira, S. Steenken. J Am Chem Soc. 1990;112:6986–6994.
34. D. G. E. Lemaire et al. Int J Radiat Biol. 1984;45:351–358.
35. M. Sudha Swaraga et al. Int J Chem Sci. 2016;14(4):2420–2432.

Table 1 : Rates of oxidation of thymine, thymidine , and D-ribose with Cr(VI)-H₂O₂ system in presence of ascorbic acid

Substrate	10 ⁸ × initial rate (mol dm ⁻³ s ⁻¹)
Thymine	19.50
Thymidine	9.032
D-ribose	0.249

[H₂O₂] = 5.0 × 10⁻³ mol dm⁻³, [substrate] = 5.00 × 10⁻⁵ mol dm⁻³,

[Na₂CrO₄] = 1.0 × 10⁻⁴ mol dm⁻³, [Ascorbic acid] = 2.5 × 10⁻⁵ mol dm⁻³ Temp = 298 K

Table 2 : Effect of pH on rate of oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid in aqueous solutions.

S.No	pH	10 ⁸ × (Initial rate) (mol dm ⁻³ s ⁻¹)
1	8.0	9.032
2	6.0	5.786
3	4.5	3.488

[H₂O₂] = 5.0 × 10⁻³ mol dm⁻³, [thymidine] = 5.00 × 10⁻⁵ mol dm⁻³,

[Na₂CrO₄] = 1.0 × 10⁻⁴ mol dm⁻³, [Ascorbic acid] = 2.50 × 10⁻⁵ mol dm⁻³ Temp =

Table 3 : Effect of [Riboflavin] on the rate of oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid

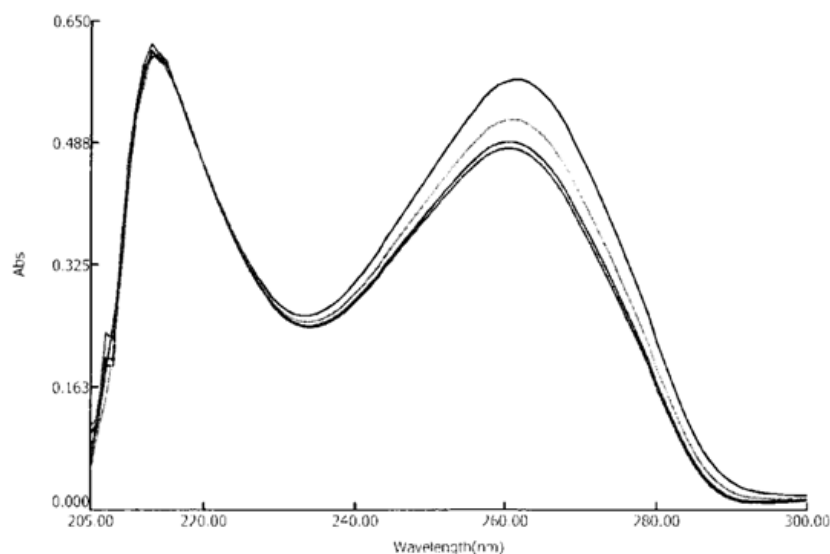
S.No	10 ⁶ × [Riboflavin] (mol dm ⁻³)	10 ⁸ × rate (mol dm ⁻³ s ⁻¹)	p	% Scavenging (1-p)×100
1	0.00	9.032	-	-
2	4.00	7.577	0.810	18.98
3	8.00	6.330	0.681	31.9
4	16.0	4.835	0.516	48.37
5	32.0	3.120	0.348	65.20
6	64.0	2.040	0.210	78.90





Sudha Swaraga

 $[\text{H}_2\text{O}_2] = 5.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{thymidine}] = 5.00 \times 10^{-5} \text{ mol dm}^{-3}$,

 $[\text{Na}_2\text{CrO}_4] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$, $[\text{Ascorbic acid}] = 2.50 \times 10^{-5} \text{ mol dm}^{-3}$ pH= 8, Temp = 298 K


Spectra 1 Absorption spectra of Thymidine oxidation

 $[\text{H}_2\text{O}_2] = 5.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{Thymidine}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$,

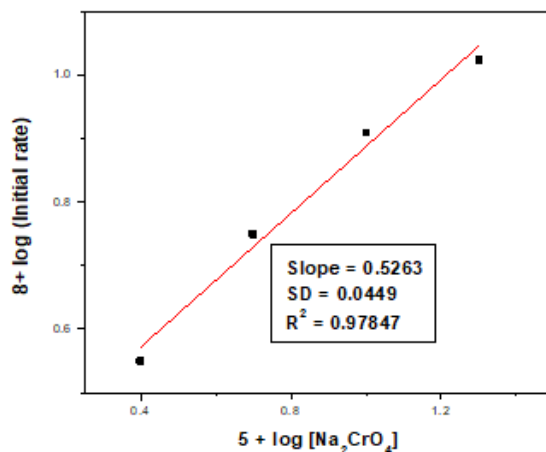
 $[\text{Na}_2\text{CrO}_4] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$, $[\text{Ascorbic acid}] = 2.5 \times 10^{-5} \text{ mol dm}^{-3}$. Temperature = 298K, pH = 8


Figure 1 Order in [Chromate] in the oxidation
of thymidine with Cr(VI)- H_2O_2 system in presence of ascorbic acid





Sudha Swaraga

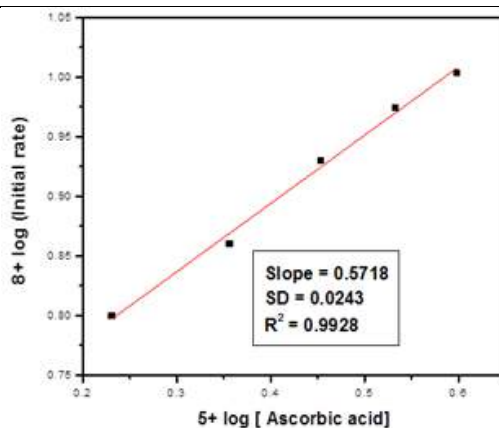


Figure 2 Order in [ascorbic acid] in the oxidation of thymidine with Cr(VI)- H_2O_2 system in presence of ascorbic acid

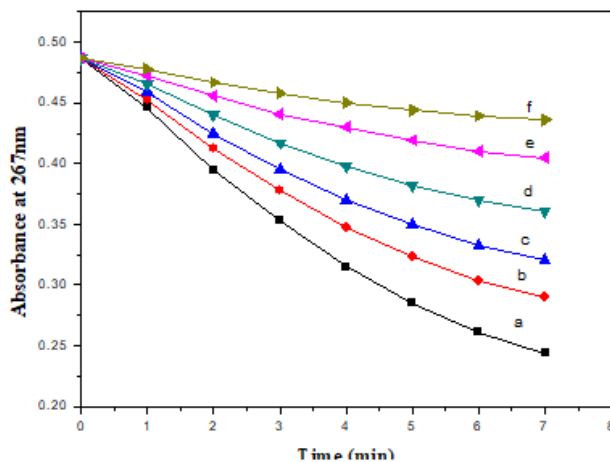


Figure 3 Effect of Riboflavin on the oxidation of thymidine with Cr(VI)- H_2O_2 system in presence of ascorbic acid

$[\text{H}_2\text{O}_2] = 5.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{Thymidine}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$,
 $[\text{Na}_2\text{CrO}_4] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$, $[\text{Ascorbic acid}] = 2.5 \times 10^{-5} \text{ mol dm}^{-3}$
 $[\text{Riboflavin}] = \text{a) } 0.00 \text{ b) } 2.0 \times 10^{-6} \text{ mol dm}^{-3} \text{ c) } 4.0 \times 10^{-6} \text{ mol dm}^{-3}$
 $\text{d) } 8.0 \times 10^{-6} \text{ mol dm}^{-3} \text{ e) } 16.0 \times 10^{-6} \text{ mol dm}^{-3} \text{ f) } 32.0 \times 10^{-6} \text{ mol dm}^{-3}$
 $\text{g) } 64.0 \times 10^{-6} \text{ mol dm}^{-3}$

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Lane - Wise Modelling of Time Headway Distribution Under Mixed Traffic Conditions on Urban Divided Highways

Amit A Amin¹ and L.B.Zala²

¹Ph.D Research Scholar and Assistant Professor, Department of Civil Engineering, Birla Vishvakarma Mahavidyalaya Engineering College, (Affiliated to Gujarat Technological University), Anand, Gujarat, India.

²Professor and HOD (Retired), Department of Civil Engineering Birla Vishvakarma Mahavidyalaya Engineering College, (Affiliated to Gujarat Technological University), Anand, Gujarat, India.

Received: 19 Mar 2026

Revised: 24 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

Amit A Amin

Ph.D Research Scholar and Assistant Professor,
Department of Civil Engineering,
Birla Vishvakarma Mahavidyalaya Engineering College,
(Affiliated to Gujarat Technological University),
Anand, Gujarat, India
E.Mail: amitamin544@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The knowledge of traffic flow characteristics in heterogeneous traffic situation is vital in order to enhance the efficiency in capacity estimation and analysis of such multilane highways. This research focuses on studying the traffic characteristics and time headway distribution by vehicle type on selected urban divided highways that are operating in heterogeneous traffic situation. The traffic data was gathered using video recording techniques. The analysis focused on traffic composition, speed characteristic, DPCU, LOS and lane wise time headway behavior. The traffic stream comprised 33.6% two-wheelers, 39.2% small and big cars, and 12.1% trucks, indicating highly heterogeneous traffic conditions, while the dynamic PCU values estimated using Chandra's method showed noticeable variations from IRC:106–1990 standards, particularly for larger vehicles due to their greater space occupancy and influence on traffic operations; additionally, LOS assessment based on flow, density, and volume-to-capacity ratio indicated that most study sections operated under LOS-C conditions. Distributions of time headway were done using Easy Fit 5.6 and were tested using K–S goodness of fit test at 5% significance level. The Log-Pearson Type III distribution manifested effective fitting performance among the considered statistical distributions for most leader–follower vehicle combinations in all study lanes.. It was also established that two-wheeler following combinations had comparatively smaller headways owing to increased maneuverability while truck following combinations had higher headways owing to cautious behavior



**Amit A Amin and L.B.Zala**

and longer braking times. These findings clearly indicate that there is a significant impact of traffic composition and leader follower combinations on driver behavior and headway.

INTRODUCTION

Time Headway is the most crucial parameter that describes the interaction of successive vehicles along the road. Time headway is defined as the transient spacing between two successive vehicles passing a fixed reference point on a roadway section. Time headway plays a critical part when analyzing traffic flows, estimating capacities, assessing safety performance, and evaluating levels of service. Proper modeling of the distribution of time headways will aid in analyzing vehicle and driver behavior. In the context of designing traffic situations like those found in India, traffic along the roadways is noted for its heterogeneity, given the simultaneous existence of various types of vehicles with different static and dynamic parameters. With the occurrence of irregular lane changes and wide-ranging speed differences, the resultant patterns of traffic behavior deviate considerably from those seen in homogenous traffic systems. It therefore follows that conventional headway models may not be very relevant in such heterogeneous traffic systems.

Thus, there is an urgent need for developing a suitable time headway model which takes care of the traffic dynamics prevailing in urban and peri-urban highways. Sardar Patel Ring Road is one of the busiest high-speed corridors in the state of Gujarat that faces huge and mixed traffic during daytime. The road has both local and through traffic, hence making their composition and interactions dynamic. With the consideration of heterogeneity traffic as well as drivers' behaviors, it makes it necessary to study time headways on this particular route. The current study attempts to develop models for time headway distributions for the Sardar Patel Ring Road based on the field traffic data obtained under various traffic conditions. Different probability distributions are considered and assessed for their appropriateness in capturing the characteristics of observed time headways. Also, the presence of platoon and determination of acceptable gap and margin gaps followed by drivers while following vehicles is considered. Margin gap can be defined as the smallest temporal distance maintained between the vehicles, which gives a valuable insight into driver behavior and perception under mixed traffic condition.

MATERIALS AND METHODS

Time headway is a key microscopic traffic flow measure describing the interval between consecutive vehicles passing a predefined location on the roadway. The distribution analysis of time headways is an important part of the microscopic traffic flow modeling process, capacity analysis on roadways, and the assessment of traffic safety. Differences in the distribution of time headways reveal differences in driver behavior and vehicle following behavior, and intricate interactions between different vehicle classes on the highway. A research study carried out in Denpasar, Bali Province, on time headway distributions in heterogeneous traffic flow classified the traffic flow into three categories, namely; low, medium and high. From this study, it was noted that Negative Exponential, Pearson Type III and Normal were some of the appropriate distributions that could be used for different traffic flows, with Normal being the most appropriate locally (Wiryawan). The analysis was performed on a suburban arterial road in the city of Chennai through an rigorous investigation of microscopic time headway characteristics in a mixed traffic environment based on data collected by the TIRTL traffic sensor. Several leader-follower combinations including two-wheelers, auto-rickshaws, passenger cars, and heavy vehicles were considered by applying statistical distribution fitting methodologies.

Out of all the distributions considered in the study, it was found that the Weibull distribution provides better goodness-of-fit characteristics for most of the vehicle pairs. It was also found that the average headway values vary between 2.2 seconds and 3.0 seconds, with greater headways for those combinations including heavy vehicles.



**Amit A Amin and L.B.Zala**

(Badhrudeen, December 2014). The impact of lane location on time headway distributions in heavy traffic situations was examined through an experiment conducted on an urban multilane highway by using videographic techniques of data acquisition on a six-lane highway. It was found that each lane had a unique statistical distribution, where Lognormal distribution best described the passing lane headway distribution, and Gamma distribution fitted best for middle lane headway distribution (Abtahi, 2011). This study involved analysis of distribution of time headways on an individual vehicle basis for different mid-block sites in Ahmedabad, Gujarat based on videographic surveys during peak hours. Various probability distributions like Dagum (4P), Burr, Pearson 5, Pearson 6, and Generalized Extreme Value distributions were tried out on the basis of Kolmogorov-Smirnov test and it was observed that different leader-follower vehicle combinations exhibited different best fit probability distributions including Burr and Dagum (4P) distributions (Malvi, 2022). A study on vehicle type-specific car following behavior has been conducted to identify the distribution of distance headway (DHW) and time headway (THW) for different leader follower pairs such as car-car, car-truck, truck-car, and truck-truck situations. The various distributions considered include Gamma, Weibull, Lognormal, Inverse Gaussian, and Log-logistic distributions. It has been found that Log-logistic distribution is better suited for car following situations, whereas Gamma distribution suits truck following situations better (Dong S. W., 2015).

Research that was done in a suburban arterial road in Korea formulated theoretical headway distribution models based on the use of large traffic data obtained using the sensors based on laser detectors. This analysis was carried out based on various traffic flow states from 5 to 29 vehicles per minute and the results showed that the best fit was achieved by the Johnson SB and Johnson SU distributions (Jang, 2011). Empirical research was carried out on a traffic link in Amman-Jordan to investigate speed and time headway behavior by analyzing video-recorded traffic data on a 25m long road link under mixed traffic conditions. Various probability distribution functions such as Normal, Lognormal, Weibull, Gamma, Logistic, and Log-logistic distributions were considered for different levels of traffic flows (0-1200 PCU/h) by means of Chi-square goodness-of-fit test. The results were found useful in estimating the capacity of the link, assessing LOS, safety, and microscopic traffic simulations (Alghazawi, 2021). The statistical investigation carried out for two lane and four lane highways in Assam examined time headways for various levels of traffic flow (0 to 2400 PCU/hr) using videographic traffic data obtained at eight sites. Several statistical distribution functions such as Log-Pearson Type III, Burr, Weibull, Lognormal, and Log-logistic distribution functions were considered for various vehicle-to-vehicle interactions and it was found that there are different best fit distribution functions for different traffic and road characteristics which have application in capacity and safety analysis and traffic simulation modeling (Das S. &, (2017)). An empirical analysis of headway distribution for specific types of vehicles performed in a freeway work zone at Greenfield, Massachusetts was done through the study of traffic data obtained from pneumatic tubes in a five-hour morning period. Various leader-follower vehicles were analyzed through the use of Gaussian Kernel and Lognormal distributions such as Car-Car, Car-Van, and Truck-Truck, using Kolmogorov-Smirnov and Chi-square statistical tests (Dong S. W., (2015)).

A case study on a two-lane National Highway stretch in eastern India analyzed the effect of traffic heterogeneity on microscopic time headways in terms of statistical distribution using observed time headway data for traffic flow varying from 310 to 1310 veh/h. Results from fitting observed headways with Log-logistic, Lognormal, Pearson Type V, and Pearson Type VI distributions showed that the Log-logistic distribution model fitted better at moderate traffic densities compared to the Pearson Type V distribution for highly skew headway data according to the Kolmogorov-Smirnov test. (Roy, 2018). In this paper, a statistical analysis was done to analyze the headway distribution characteristics of vehicles using Erlang and Pearson Type III distribution models using continuous traffic data gathered over an eight-week period for each traffic direction. It was found that Erlang distribution is suitable for describing headway distribution as it is a simple form of Pearson Type III distribution (Ben-Edigbe, 2014). The study done on six-lane divided roads in Baghdad, Iraq was based on modeling the time headway for each lane using videographic analysis that was processed using image analysis and Python software.

The statistical analysis involving the use of distributions such as Pearson Type VI, Inverse Gaussian, Dagum, Generalized Pareto, and Generalized Gamma revealed that different lanes had their own best-fit distributions with



**Amit A Amin and L.B.Zala**

time headways of 0.2 seconds to 41.48 seconds (Alhamdany, 2022). Research was carried out in Chennai City on urban four-lane roads on traffic headway characteristics. It examined the Log Normal 2, Inverse Gaussian and Exponential distribution models and gave recommendations of the most appropriate distribution models for various vehicles' categories by fitting them to traffic headways (uresh, (2014)). An investigation carried out at two-lane two-way roads in Kanpur studied the vehicle headway distributions in mixed urban traffic flow situations by means of video observations during peak hours. Different distributions such as Inverse Weibull, Gamma, Erlang, Burr, Log-logistic and Lognormal were tested and compared on the basis of the K-S goodness-of-fit test. Log-logistic proved to be the best fit (Maurya A. K., December 2011). In a study carried out on a two-lane two-way highway in Guwahati, the analysis of speed and headway distributions were done under heterogeneous traffic conditions for various densities. Statistical distributions were applied in analysing the data from the research and it was found that the beta distribution model gave the best results in most instances while higher headways were kept by heavy vehicles like trucks and LCVs (Maurya A. K., 2016). A study carried out in cities of Kolkata, Mumbai, Pune, and Guwahati examined the determinants behind drivers' selection of time headways during staggered car following based on trajectories. It was noted that the mean value of time headways decreased as a result of an increase in the road widths. Also, most of the drivers had headways less than 2 seconds (Das S. M., 2019).

Study Site and Data Collection

The Sardar Patel Ring Road is an important urban arterial road corridor constructed by Ahmedabad Urban Development Authority for enhancing connectivity and alleviating congestion in the region of Ahmedabad. The total length of the corridor is about 76 km long and has a divided six-lane expressway facility. The ring road facilitates connectivity to various highways including NE-1 highway connecting Ahmedabad-Vadodara, National Highway No. 8, National Highway No. 64, and National Highway No. 147. Thus, it acts as an important bypass route for diversion of through traffic from urban road network. The field data used in this research were obtained from three selected sections along the road known as Sardar Patel Ring Road, which include Vastral Road sections (1 & 2), Hanspura Road sections (3 & 4) and Odhav Road sections (5 & 6) within the city of Ahmedabad. Selected sites were chosen without any disturbance such as an intersection, entry point, roadside encroachment, and horizontal curvature in order to maintain uninterrupted heterogeneous traffic flow. A longitudinal trap of 60 meters length was used for each study section.

It is noteworthy that each section of roads was characterized by the same width of road surface, equaling 7.5 m with paved shoulders of 1.1 m on both sides. Also, all sections were placed no closer than 500 meters from traffic signals and intersections in order to eliminate effects of interrupted traffic flows. Traffic data were obtained during the daytime when weather conditions were appropriate to conduct research in the winter season. Traffic was videotaped during four hours per day, including peak morning hours (09:00-11:00 h) and peak evening hours (04:00-06:00 h). Digital cameras were installed on the elevated platform to record traffic stream in two directions with sufficient space coverage for carriageway width. The video data obtained were used to extract microscopic traffic characteristics, including vehicle speeds, time headway, and margin gaps in heterogeneous traffic streams [Figure1].

Data Extraction and Manipulation

The captured video data was manually analyzed in laboratory conditions by viewing them on the projector screen for extracting traffic-related attributes. Traffic volumes were counted based on classification at one-minute intervals to get more detailed information on traffic volumes and traffic composition. The vehicles detected were classified into nine groups: two wheelers (2W), three wheelers (3W), standard cars (SC), big cars (BC), light commercial vehicles (LCV), trucks, buses, tractors, and non-motorized vehicles (NMV). The speed of each vehicle was calculated based on the time of entry and exit of the vehicle through the defined 60m trap length. From the gathered data, parameters related to traffic flow like traffic volume, traffic composition, speed distribution (85th percentile speed), and time headway distribution could be derived for each type of vehicle. This collected data set was further analyzed and used in modeling traffic flow using probability theory. Traffic volume and composition observed from the chosen test sections.





RESULTS AND DISCUSSION

Classified Volume survey

As The two-wheelers (2W) make up the largest proportion of the traffic stream on the entire study sections with an average composition of 33.6%, followed by standard cars (SC) with an average proportion of 27.9% of the total traffic stream. The trucks make up an average of 12.1% of the total traffic stream. This implies the significant amount of freight traffic on the study corridor. On the other hand, the big cars (BC) and the light commercial vehicle (LCV) make up an average of 11.3% and 6.6% of the traffic stream, respectively. Three wheelers (3W) make up 7.71% of the total traffic stream. The buses and tractors have been found to make up an average of less than 1% of the traffic stream, respectively. On the other hand, the non-motorized vehicles (NMV) have been found to be negligible in the traffic stream [Table1].

Category-Wise Speed Characteristics of Various Vehicles

Speed characteristics of various types of vehicles identified on the Sardar Patel Ring Road in both directions of travel. SC and BC types of vehicles were recorded to have relatively higher speed rates among all the types of vehicles identified on the road. For instance, while standard cars had a mean speed of 59.0 km/h in the up direction, big cars had a speed rate of 60.5 km/h. On the other hand, the average speeds of big cars in the down direction were 55.5 km/h and 57.5 km/h for SC and BC classes of vehicles, respectively. The two-wheeled (2W) vehicles had a comparatively moderate speed rate with mean speeds of 53.5 km/h in the up direction and 50.5 km/h in the down direction. Heavy vehicles including trucks and buses were observed to be operated at relatively low speeds compared to passengers' vehicles. For instance, the mean speeds of trucks and buses on the road were 44.5 km/h and 47.5 km/h, respectively. Such differences in speeds by type of vehicles could be attributed to traffic flow and interaction characteristics prevalent along the studied route [Table2].

Speed Distribution Characteristics

In heterogeneous traffic, there will be considerable speed disparities between various vehicle types. To understand the speed-flow relationship, the traffic data were analyzed in five minutes' intervals to obtain the changes in traffic flow rate and speed. Spread Ratio (SR), representing the nature of speed distribution, is calculated by Equation (1):

$$SR = (V_{85} - V_{50}) / (V_{50} - V_{15}) \quad (1)$$

where V_{85} , V_{50} , and V_{15} represent the 85th percentile, median, and 15th percentile speeds, respectively [Table 3].

Estimation of Dynamic Passenger Car Unit (PCU)

Dynamic estimation of PCU is one of the key factors in estimating roadway capacity and LOS. Heterogeneity in traffic can create significant differences among vehicles concerning their physical dimensions, maneuverability, acceleration-deceleration properties, and speeds. Thus, a considerable difference in traffic flow characteristics occurs because of these variations. In India, for instance, where such heterogeneity in traffic is quite common, the use of a constant PCU value can be insufficient in representing the actual traffic scenario. The Indian Road Congress suggested static PCU values for various vehicles in IRC:106-1990 based on limited empirical observations carried out under certain roadway circumstances. But due to the dynamism of the heterogeneous traffic flow, the PCU values were found to vary contingent upon the composition of traffic, geometry of road, traffic volume, and traffic speed. In order to rectify this problem, Chandra S. and Kumar U. (2003) suggested a dynamic PCU value estimation method that is represented by Eq. (2).

$$DPCU_i = V_c / V_i A_c / A_i \quad (2)$$

Where, $DPCU_i$ represents the dynamic Passenger Car Unit value for vehicle class i ; V_c/V_i corresponds to the speed ratio between the standard passenger car and the subject vehicle type; and A_c/A_i indicates the ratio of the effective projected rectangular area of the passenger car to that of vehicle type i . The projected rectangular area characterizes





Amit A Amin and L.B.Zala

the roadway space occupancy requirement of a vehicle within the traffic stream and is estimated as the product of the effective vehicle length and width under prevailing traffic operating conditions. [Table 4].

Fundamental Relationship among Speed, Flow, and Density

The relationship between speed, flow, and density forms the core idea of the traffic stream behaviour in traffic flow theories on macro scale and is the key element in analyzing traffic flow under various traffic conditions. The linear relationship between speed and density first described by Bruce Greenshields contributed to the development of or the development of several theoretical and empirical models for traffic flow analysis. These relations have been widely used to analyze the capacity of the roadways and traffic performance analysis under varied traffic conditions. In the current study, the relationships between speed, flow, and density have been examined using the real traffic data available from the selected sections of Sardar Patel Ring Road. A total of 79 traffic data sets comprising stream speed, flow, and density parameters have been obtained at the selected sections of Sardar Patel Ring Road during peak hour as well as non-peak hour traffic to analyze the effect of congestion on traffic operational characteristics. The findings reveal that the vehicle speed reduces as density increases, whereas traffic flow rises with increasing density until it reaches a critical value followed by decline in flow [Figure2].

Capacity and Level of Service

The capacity of a highway can be described as the number of vehicles that can be reasonably expected to pass through a point on the road in unit time, considering the prevailing road traffic and control conditions. Capacity plays an integral role in a traffic engineer when designing the road sections. The criteria for estimating the capacity of the roads as outlined by different organizations, such as TRB(HCM), Induce (2017), Indian road congress, is indirect empirical approaches. The Level of Service (LOS) is the qualitative criterion used to analyze the quality of service perceived at the different levels of flow. Table 5 illustrates the LOS of lanes and locations using the indoHCM2017 standard that falls within the LOSC category [Table 5].

Statistical Characteristics of Time Headway Distribution

Statistical analysis was conducted for the combined sections of roads consisting of Sections 1 & 2, Sections 3 & 4, and Sections 5 & 6. Microscopic headways distributional changes with regard to their mean, median, minimum, maximum, and standard deviation were analyzed to study the time-dependent characteristics of heterogeneous traffic streams. Several theoretical probability distributions were used to statistically analyze the vehicle headway patterns, which include the following: Lognormal, Weibull, Burr, Log-Pearson Type III, Pearson Type VI, and Generalized Gamma distributions. To check for the suitability of a particular probability model, Kolmogorov-Smirnov (K-S) test of goodness of fit was used to obtain a particular probability distribution that best characterizes the empirical headway pattern. The mathematical expressions related to probability distributions selected are shown below, which form the basis of probabilistic models to be used for modeling the vehicular headway phenomenon. Finally, comparative assessment of lane-wise vehicular headway distributions was undertaken for all combined road sections. [Table 6].

$$f(x) = \frac{\exp\left(-0.5\left(\frac{\ln(x-\tau)-\mu}{\sigma}\right)^2\right)}{(x-\tau)\sigma\sqrt{2\pi}} \quad (3)$$

$$f(x) = \frac{\lambda}{\alpha} \left(\frac{x-\mu}{\alpha}\right)^{\lambda-1} \exp\left(-\left(\frac{x-\mu}{\alpha}\right)^\lambda\right) \quad (4)$$

$$f(x) = \frac{\alpha k \left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta \left(1 + \left(\frac{x-\gamma}{\beta}\right)^\alpha\right)^{k+1}} \quad (5)$$

$$f(x) = \frac{1}{x|\beta|\Gamma(\alpha)} \left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{\ln(x)-\gamma}{\beta}\right)\right) \quad (6)$$

$$f(x) = \frac{\left(\frac{\alpha}{\beta}\right)^{\alpha_1-1}}{\beta B(\alpha_1, \alpha_2) \left(1 + \frac{\gamma}{\beta}\right)^{\alpha_1+\alpha_2}} \quad (7)$$





$$f(x) = \frac{k(x-y)^{k\alpha-1}}{\beta K \alpha \Gamma(\alpha)} \exp\left(-\left(\frac{x-y}{\beta}\right)^k\right) \quad (8)$$

Where $f(x)$ is the probability density function that defines the behavior of the vehicles' time headway statistically; k and α represent the shape parameters of the distribution, which determine the skewness of the distribution; β is the scale parameter that affects the spread of the distribution; while τ represents the shift parameter in seconds. Γ symbolizes the Gamma function used for the probability formula, while λ represents the location parameter, which determines the position of the distribution. Finally, μ represents the mean of the observed headway values of vehicles.

Microscopic Time Headway Distribution for Different Traffic Lanes

A robust statistical framework has been adopted in selecting the most suitable probability distribution model for the vehicular time headway analysis. In this regard, the upper 5% of the extreme headway values were eliminated from consideration in order to minimize any anomalous observations while preserving the underlying traffic characteristic that were captured in the 95% of the total data. Following this step, the Kolmogorov-Smirnov (K-S) test for goodness-of-fit test was carried out using a 5% significance level in testing the suitability of several probability distribution models. In addition to this, all data sets with more than 30 observations have been considered in order to ensure consistency in the statistical analysis process. This is illustrated below by the fitted headway distribution of Lane 1 in Section 1. [Figure3]. The goodness-of-fit test was conducted using six probability models, which included Weibull, Pearson Type VI, Burr, Lognormal, Generalized Gamma, and Log-Pearson Type III distributions for the headway time data of all the four lanes. Each theoretical model's fitness was calculated using the Kolmogorov-Smirnov (K-S) goodness-of-fit test statistics and the p-values. Out of all the theoretical probability distribution models tested, it was found that the Log-Pearson Type III distribution showed the best results with relatively higher p-values and lower K-S test statistics. Regarding Lane 1, the best-fitting theoretical distribution was observed for the Log-Pearson Type III distribution, with the highest p-value of 0.68 and lowest K-S test statistics of 0.02. Likewise, in Lane 2, the best fitting for the distribution was achieved from the Log-Pearson Type III distribution,

where the highest p-value was calculated as 0.89 with the lowest K-S statistics of 0.01. For Lane 3, overall fitting was slightly poor in comparison with other lanes; however, the best results were obtained from the Log-Pearson Type III distribution, with the p-value of 0.35 and K-S statistics of 0.02. As opposed to this, the fitting properties were found to be comparatively weak in the case of the Weibull and Lognormal probability distributions owing to low p-values and high K-S statistics. In contrast, the Pearson Type VI and Burr distributions have shown fairly good agreements with the observed data, while the Generalized Gamma distribution model offered good fitting performance in some cases but was not able to match the fitting efficiency of the Log-Pearson Type III distribution model. Based on the findings of statistical analysis, it can be stated that there are positive skewness characteristics in the observed data and that the Log-Pearson Type III distribution fits best with the observed data in all the lanes. [Table 7]. From the statistical test results illustrated in Table 7, it is apparent that the Log-Pearson

Type III distribution showed superiority in terms of goodness-of-fit due to comparatively high p-values and low K-S statistics. Estimation of the shape (α) and scale (β) parameters showed variations for different sections of the road, which were attributed to varying traffic conditions and vehicle interactions. High shape parameters denoted sharpness of the distribution peak, while high scale parameters suggested wider distributions. Moreover, through further analysis of individual lanes in each section, variations in appropriate probability distributions were noted. While the Burr, Pearson Type VI, Generalized Gamma, and Weibull probability distributions proved to be superior in fitting particular lanes, the Log-Pearson Type III probability distribution was found to be more suitable for most sections under heterogeneous traffic conditions.



**Amit A Amin and L.B.Zala****Statistical Modelling of Headway Distributions for Different Vehicle Pair Categories**

The study of time headway distributions of vehicles according to their types is a crucial aspect that helps understand the nature of interactions between different combinations of leaders and followers in heterogeneous traffic situations. In particular, the study illustrates how the driving behaviors of vehicles vary by type and shows the influence of leader vehicle characteristics on follower vehicle response behaviour. Moreover, the research shows the impact of lane positioning on the distribution of time headways. The headways were categorized according to the different combinations between the leaders and the followers, such as 2W-2W, 2W-SC, 2W-BC, 2W-Truck, SC-2W, SC-SC, SC-BC, SC-Truck, BC-2W, BC-SC, BC-BC, BC-Truck, Truck-2W, Truck-SC, Truck-BC, and Truck-Truck, where 2W, SC, BC, and Truck are two-wheelers, small cars, big cars, and trucks. From the findings obtained, it is evident that small combinations especially those composed of two-wheelers tend to have relatively smaller and more dispersed headways as compared to large combinations due to their manoeuvrability and flexibility in lateral movements. On the other hand, large combinations like Truck-Truck and Truck-BC tend to have relatively larger headways due to cautious driving and long reaction times. Moreover, it was noted that there was variation in the distribution of headways by lane [Table 8].

CONCLUSION

- The traffic flow characteristics and time headways were analyzed in this study in relation to heterogeneous traffic on selected four-lane divided urban highways. The traffic composition analysis revealed that there is great variability in traffic flow, where two wheelers constituted 33.6%, small and big cars made up 39.2%, and trucks made up 12.1%. This reveals the presence of different vehicles in the traffic composition and hence the complexity in traffic flow.
- The speed distribution study conducted for the chosen sections found that the spread ratio ranged between 0.89 and 1.57, suggesting considerable differences in speed behavior across various vehicle types and sections of the roadways. The calculated dynamic PCU values using Chandra's formula showed clear differences compared to the recommended values in IndoHCM (2017) and IRC:106–1990 standards, especially for big cars (1.52), buses (5.15), and trucks (4.10). These increased PCU values for heavy-duty vehicles can be explained by the greater size, reduced maneuverability, and influence on roadway capacity of such vehicles.
- The LOS assessment was conducted based on field observation data at an interval of 5 minutes with regards to flow, volume-to-capacity ratio, and density. The LOS values that were computed were found to be in line with the values recommended by IndoHCM (2017), and the majority of the selected links operated within the LOS-C range.
- The fitting analysis of time headway distributions was carried out by using the EasyFit 5.6 software employing Kolmogorov-Smirnov (K-S) test for a goodness-of-fit at a 5% level of significance. It is observed that among the various distributions that have been studied, the Log-Pearson Type III distribution proved to be the best for most combinations of vehicles for all lanes and sections. Some other distributions, like Pearson Type VI, Weibull, Burr, Log-Normal, and Generalized Gamma distributions, also showed their adequacy for some lane-wise cases. The minimum and maximum values of headways were observed as 0.12 sec and 16.84 sec, respectively.
- It was found through the analysis of traffic composition in the lanes that the middle lanes (Lane 2 and Lane 3) had a higher number of cars and trucks, while the outer lanes (Lane 1 and Lane 4) had more two wheelers and cars but fewer trucks. This difference in vehicle composition has played a crucial role in influencing the headways.
- Analysis of headway by vehicle type revealed that interacting pairs consisting of truck exhibited comparatively larger headways as a result of careful driving behavior and higher safety considerations. On the other hand, 2W-2W interactions had the lowest headways, mainly due to the increased maneuverability and lack of lane discipline associated with two-wheelers. Drivers were also found to keep larger headways behind trucks because of their large sizes and relatively poor braking capacity.





Amit A Amin and L.B.Zala

- The results also show that the traffic flow in the middle lanes depends significantly on the interaction between vehicles coming from adjacent lanes, which shows the significance of lane-changing behavior and interactions between lanes in heterogeneous traffic streams. Thus, future research must concentrate on the study of lane-changing behaviors, drivers' behavior, and variation in speed in different lanes.

ACKNOWLEDGEMENT

The authors express their sincere gratitude to Dr. L. B. Zala for his invaluable technical guidance, continuous motivation, and scholarly support throughout the course of this research work. The authors are also thankful to Dr. Srinivas Arkatkar for his valuable technical suggestions and academic inputs related to traffic flow analysis and simulation studies. The authors gratefully acknowledge Dr. A. M. Jain for his encouragement and institutional support. Special appreciation is extended to Dr. Vinay J. Patel for providing the necessary academic infrastructure, research facilities, and institutional environment required for carrying out this study. The authors also express their sincere thanks to Dr. Rena Shukla and Dr. Pinakin Patel for their constructive technical suggestions and valuable feedback, which significantly contributed to improving the quality of the research work.

The authors further acknowledge the support provided through the TEQIP-II and TEQIP-III initiatives at BVM Engineering College and Gujarat Technological University. Finally, the authors appreciate the assistance and cooperation of the M.Tech and B.Tech students involved in traffic data collection, video extraction, and preliminary traffic data analysis during the execution of this study.

REFERENCES

1. Abtahi, S. M. (2011). Analysis and modeling time headway distributions under heavy traffic flow conditions in the urban highways: Case of Isfahan. *Transport*, 375–382. Retrieved from <https://doi.org/10.3846/16484142.2011.635694>
2. Alghazawi, O. K.-h. (2021). Modelling of Vehicular Speed and Headway on Urban Route in Amman City. 14(3), 289–298.
3. Alhamdany, M. &. (2022). Statistical Modeling of Time Headway on Urban Roads: A Case Study in Baghdad. *Engineering, Technology & Applied Science Research*, 12(3), 8584–8591. Retrieved from <https://doi.org/10.48084/etasr.4878>
4. Badhrudeen, M. R. (December 2014). Headway Analysis Using Automated Sensor Data under Indian Traffic Conditions. *Transportation Research Procedia*, 331–339. Retrieved from <https://doi.org/10.1016/j.trpro.2016.11.103>
5. Ben-Edigbe, J. R. (2014). Headway distributions based on empirical erlang and pearson type III time methods compared. *Research Journal of Applied Sciences, Engineering and Technology*, 7(21), 4410–4414. Retrieved from <https://doi.org/10.19026/r>
6. Das, S. &. (2017). Time Headway Analysis for Four-Lane and Two-Lane Roads. *Transportation in Developing Economies*, 3(1), Retrieved from <https://doi.org/10.1007/s40890-017-0039-8>
7. Das, S. M. (2019). Determinants of time headway in staggered car-following conditions. *Transportation Letters*, 11(8), 447–457. Retrieved from <https://doi.org/10.1080/19427867.2017.1386872>
8. Dong, S. W. (2015). Nonparametric modeling of vehicle-type-specific headway distribution in freeway work zones. *Journal of Transportation Engineering*, 141(11). Retrieved from [https://doi.org/10.1061/\(ASCE\)TE.1943-5436.0000788](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000788)
9. Dong, S. W. (2015). Nonparametric modeling of vehicle-type-specific headway distribution in freeway work zones. *Journal of Transportation Engineering*. Retrieved from [https://doi.org/10.1061/\(ASCE\)TE.1943-5436.0000788](https://doi.org/10.1061/(ASCE)TE.1943-5436.0000788)





Amit A Amin and L.B.Zala

10. Jang, J. P. (2011)). Modeling of time headway distribution on suburban arterial: Case study from South Korea. . *Procedia - Social and Behavioral Sciences*, 16, , 240–247. Retrieved from <https://doi.org/10.1016/j.sbspro.2011.04.446>
11. Malvi, U. C. (2022). . Analysis of Headway Distribution Pattern in Heterogeneous Traffic. *Journal of Emerging Technologies and Innovative Research*, 9(5).
12. Maurya, A. K. (2016). Study on Speed and Time-headway Distributions on Two-lane Bidirectional Road in Heterogeneous Traffic Condition. 17(December), 428–437. Retrieved from <https://doi.org/10.1016/j.trp>
13. Maurya, A. K. (December 2011). Analysis of Vehicular Headway Distribution in Urban Area.139–144.
14. Roy, R. &. (2018). Headway distribution models of two-lane roads under mixed traffic conditions: a case study from India. *European Transport Research Review*, 10(1). Retrieved from <https://doi.org/10.1007/s12544-017-0276-2>
15. uresh, V. S. ((2014)). S. Analysis of Headway of Heterogeneous Traffic on Indian Urban Roads. *Global Journal of Researches in Engineering: Civil And Structural Engineering*, 14(3),, 51–54.
16. Wiryawan, A. G. (n.d.). Time Headway Analysis To Determine The Road Capacity. *Jurnal Spektran*, 4(1), . <https://ojs.unud.ac.id/index.php/jsn/article/view/47468> . 88–96. .

Table 1 Percentage distribution of vehicle classes at study locationn

Sections	Location	2W	3W	SC	BC	LCV	Truck	Others
Section-1 (vastral)	Morning up	45.00	7.00	25.00	9.00	5.00	9.00	0.7
	Morning down	39.00	8.00	27.00	8.00	5.00	12.00	0.9
Section-2 (vastral)	Evening up	30.00	8.00	27.00	11.00	10.00	14.00	0.9
	Evening down	28.00	8.00	27.00	9.00	11.00	16.00	0.7
Secion-3 (Odhav)	Morning up	47.00	10.00	25.00	6.00	3.00	8.00	0.4
	Morning down	35.00	8.00	26.00	17.00	6.00	9.00	0.5
Section-4 (Odhav)	Evening up	27.00	8.00	35.00	11.00	7.00	11.00	0.8
	Evening down	27.00	8.00	35.00	11.00	9.00	11.00	0.6
Section-5 (Hanspura)	Morning up	34.00	8.00	26.00	12.00	5.00	15.00	0.9
	Morning down	40.00	6.00	25.00	11.00	4.00	12.00	1.2
Section-6 (Hanspura)	Evening up	29.00	7.00	26.00	16.00	7.00	14.00	0.7
	Evening down	23.00	8.00	30.00	16.00	8.00	15.00	0.5
Average Composition (%)		33.67	7.83	27.83	11.42	6.67	12.17	0.73

Table 2 Characteristics of Speeds for Different Classes of Vehicles

Vehicle Type	Speed of Up direction of All Sections (kmph)				Speed of Downward direction of All Sections(kmph)			
	Min Speed	Max Speed	Mean Speed	Std.Dev	Min Speed	Max Speed	Mean Speed	Std.Dev
2W	30.00	88.00	54.00	10.40	27.00	83.00	51.00	9.90
3W	27.00	66.00	46.00	7.40	27.00	64.00	52.00	7.10
SC	34.00	93.00	59.00	12.00	28.00	92.00	56.00	11.20
BC	31.00	95.00	61.00	14.00	27.00	96.00	58.00	11.70
LCV	25.00	81.00	50.00	11.00	23.00	73.00	47.00	9.70
Truck	36.00	85.00	50.00	8.00	28.00	73.00	45.00	8.00
Bus	24.00	67.00	51.00	11.00	28.00	66.00	48.00	8.90





Amit A Amin and L.B.Zala

Table 3 Distribution of percentile speeds under heterogeneous traffic conditions

Vehicle Type	Average Up direction all sections (kmph)					Average Down direction all sections (kmph)				
	98th	85th	50th	15th	SR	98th	85th	50th	15th	SR
2W	82.00	66.00	53.00	43.00	1.19	77.00	62.00	50.00	41.00	1.26
3W	63.00	55.00	46.00	37.50	1.00	61.00	52.00	41.00	37.00	0.95
SC	88.00	74.00	59.00	45.00	1.13	85.00	67.00	55.00	47.00	1.70
BC	90.00	76.00	60.00	44.50	1.12	88.00	69.50	58.00	44.00	0.89
LCV	77.00	63.00	50.00	40.00	1.24	69.00	58.00	46.00	37.00	1.27
Truck	77.00	59.00	50.00	42.00	1.28	66.50	53.00	43.50	36.00	1.19
Bus	69.00	64.00	51.00	37.00	0.90	64.50	58.50	46.00	38.00	1.57

Table 4 Assessment of observed PCU characteristics with standard codal values

Vehicle type	Projected Area(m ²)	Acceleration(m/s ²)		Deceleration(m/s ²)		Suggested PCU from IRC 106-1990	Suggested PCU from Indo HCM 2017	Estimated PCU from Chandra's Method
		Maximum	Desired	Maximum	Desired			
2W	1.20	2.20	1.60	1.50	0.50	0.75	0.22	0.23
3W	1.20	1.10	0.90	1.10	0.80	1.20	0.90	0.97
SC	2.40	2.70	1.30	1.80	1.20	1.00	1.00	1.00
BC	2.80	2.70	1.30	1.80	1.20	1.00	1.00	1.52
Buses	7.80	2.50	1.50	1.70	1.20	2.20	4.60	5.15
Trucks	5.00	2.50	1.50	1.70	1.20	3.70	3.90	4.10
LCV	2.70	2.70	1.30	1.80	1.20	1.40	2.38	2.78

Table 5 Evaluation of operational performance using V/C ratio and LOS criteria

Locations	Road Location	Lane (PCUs/hr)	Lanae capacity (s/hr) Indo HCM2017	V/C Ratio	LOS
1	Vastral Morning	984	1350	0.73	Los C
	Vastral Evening	823	1350	0.61	Los C
2	Hanspura Morning	880	1350	0.65	Los C
	Hanspura Evening	848	1350	0.62	Los C
3	Odhav Morning	810	1350	0.6	Los C
	Odhav Evening	842	1350	0.62	Los C

Table 6 Descriptive statistical distribution of time headway at selected study locations

Vastral Location (sections 1 and 2)						
Lane	Sample	Min (sec)	Max (sec)	Mean	Median	Sta Dev
Lane-1	3376	0.20	16.25	3.11	2.36	2.52
Lane-2	3402	0.31	15.85	2.99	2.09	2.55
Lane 3	2398	0.33	16.44	3.24	2.25	2.84
Lane 4	3729	0.20	16.24	2.63	1.89	2.40
Hanspura Location (sections 3 and 4)						
Lane-1	3946	0.12	14.77	3.2	2.36	2.7
Lane-2	3012	0.19	15.79	4.05	2.95	3.3





Amit A Amin and L.B.Zala

Lane 3	3258	0.30	15.75	3.84	2.81	3.17
Lane 4	4905	0.22	15.65	2.89	2.15	2.4
Odhav Location (sections 5 and 6)						
Lane-1	2430	0.2	16.14	2.9	2.13	2.46
Lane-2	2099	0.24	15.55	3.24	2.34	2.68
Lane 3	1625	0.28	16.26	3.06	2.07	2.80
Lane 4	2417	0.17	15.88	2.74	1.90	2.56

Table 7 Goodness-of-fit evaluation and best-fit model identification for headway data

Location	Type of Distribution	Parameters	P - Value	K-S value	Best Fit
Lane 1	Weibull	$\alpha=1.4906 \beta=3.8688$	0.14	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.8528 \alpha_2=2.8179E+8 \beta=5.3699E+8$	0.17	0.03	
	Burr	$k=1007.9 \alpha=1.4579 \beta=448.77$	0.47	0.02	
	Log Normal	$\sigma=0.8508 \mu=0.968$	8.52E-06	0.06	
	Gen. Gamma	$k=0.96597 \alpha=1.9783 \beta=1.7244$	0.13	0.03	
	Log-Pearson 3	$\alpha=7.0802 \beta=-0.31985 \gamma=3.2326$	0.68	0.02	
Lane 2	Weibull	$\alpha=1.3401 \beta=4.0495$	0.15	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.5226 \alpha_2=2.6595E+6 \beta=6.6297E+6$	0.77	0.02	
	Burr	$k=415.26 \alpha=1.286 \beta=445.6$	0.35	0.02	
	Log Normal	$\sigma=0.94439 \mu=0.97045$	5.41E-04	0.05	
	Gen. Gamma	$k=0.98217 \alpha=1.5698 \beta=2.3841$	0.76	0.02	
	Log-Pearson 3	$\alpha=9.1806 \beta=-0.31179 \gamma=3.8329$	0.89	0.01	
Lane 3	Weibull	$\alpha=1.4303 \beta=4.0656$	2.34E-06	0.06	Log-Pearson 3
	Pearson 6	$\alpha_1=2.0244 \alpha_2=6.8441 \beta=11.149$	0.06	0.03	
	Burr	$k=2.9366 \alpha=1.5351 \beta=7.0297$	0.02	0.03	
	Log Normal	$\sigma=0.87461 \mu=1.0012$	0.04	0.03	
	Gen. Gamma	$k=1.0257 \alpha=1.4857 \beta=2.6612$	1.21E-03	0.05	
	Log-Pearson 3	$\alpha=53.745 \beta=-0.11934 \gamma=7.4149$	0.35	0.02	
Lane 4	Weibull	$\alpha=1.3775 \beta=3.2559$	0.01	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.7319 \alpha_2=11.364 \beta=18.457$	0.6	0.02	
	Burr	$k=3.8885 \alpha=1.4573 \beta=7.3384$	0.52	0.02	
	Log Normal	$\sigma=0.9175 \mu=0.76319$	7.11E-05	0.05	
	Gen. Gamma	$k=1.0291 \alpha=1.423 \beta=2.2259$	0.03	0.03	
	Log-Pearson 3	$\alpha=16.667 \beta=-0.22478 \gamma=4.5097$	0.77	0.01	

Table 8 Vehicle-specific time headway distribution by study section

Section 1								
Leading Vehicle	Following Vehicle	Best - fit	P - Value	K-S Value	Mean (Sec)	Median (sec)	Standard deviation (sec)	Sample Size
Lane 1								
2w	2w	Log-Pearson 3	0.433	0.02	2.301	1.6	2.171	1808





Amit A Amin and L.B.Zala

2w	Sc	Log-Pearson 3	0.943	0.051	2.353	1.71	2.164	100
2w	Bc	Log-Pearson 3	0.927	0.054	2.234	1.7	1.951	97
2w	Truck	Burr	0.641	0.091	3.601	2.3	3.032	63
Sc	2w	Log-Pearson 3	0.4	0.014	2.316	1.64	2.157	100
Sc	Sc	Burr	0.988	0.043	1.834	1.20	1.62	100
Sc	Bc	Log-Pearson 3	0.4	0.014	2.358	1.64	2.047	33
Sc	Truc	Log-Pearson 3	0.971	0.178	2.513	1.57	2.264	14
Bc	2w	Pearson 6	0.757	0.068	2.493	1.66	2.493	94
Bc	Sc	Pearson 6	0.77	0.099	1.889	1.54	1.198	42
Bc	Bc	Burr	0.997	0.105	2.298	1.38	2.068	12
Bc	Truck	Log-Pearson 3	0.971	0.178	3.047	2.96	1.055	6
Truck	2w	Log-normal	0.938	0.061	2.887	2.27	2.11	72
Truck	Sc	Log-Pearson 3	0.851	0.153	3.036	2.20	2.175	14
Truck	Bc	Log-Pearson 3	0.914	0.224	1.996	1.64	0.877	15
Truck	Truck	Log-Pearson 3	0.716	0.244	2.574	1.82	1.517	17





Amit A Amin and L.B.Zala

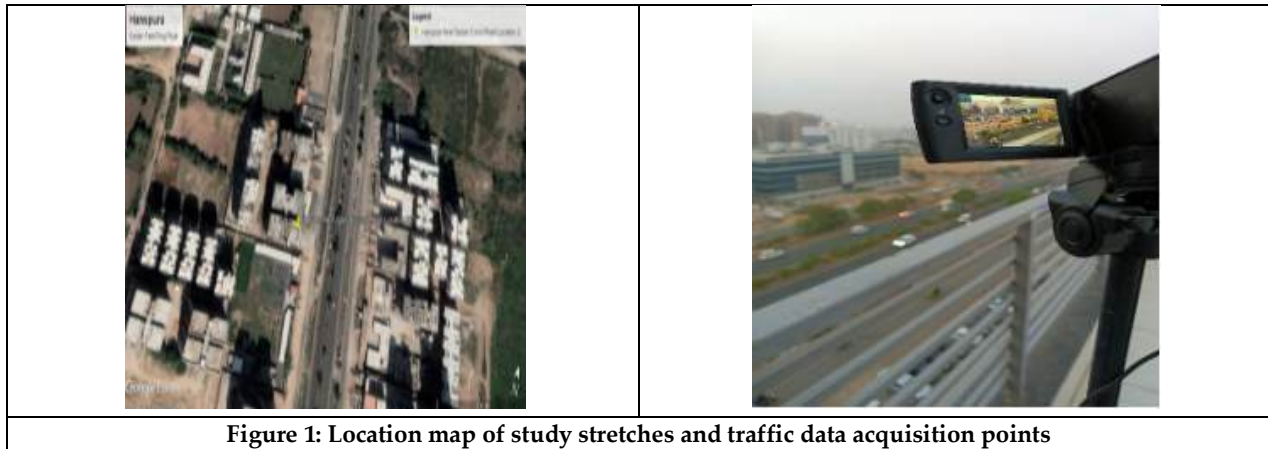


Figure 1: Location map of study stretches and traffic data acquisition points

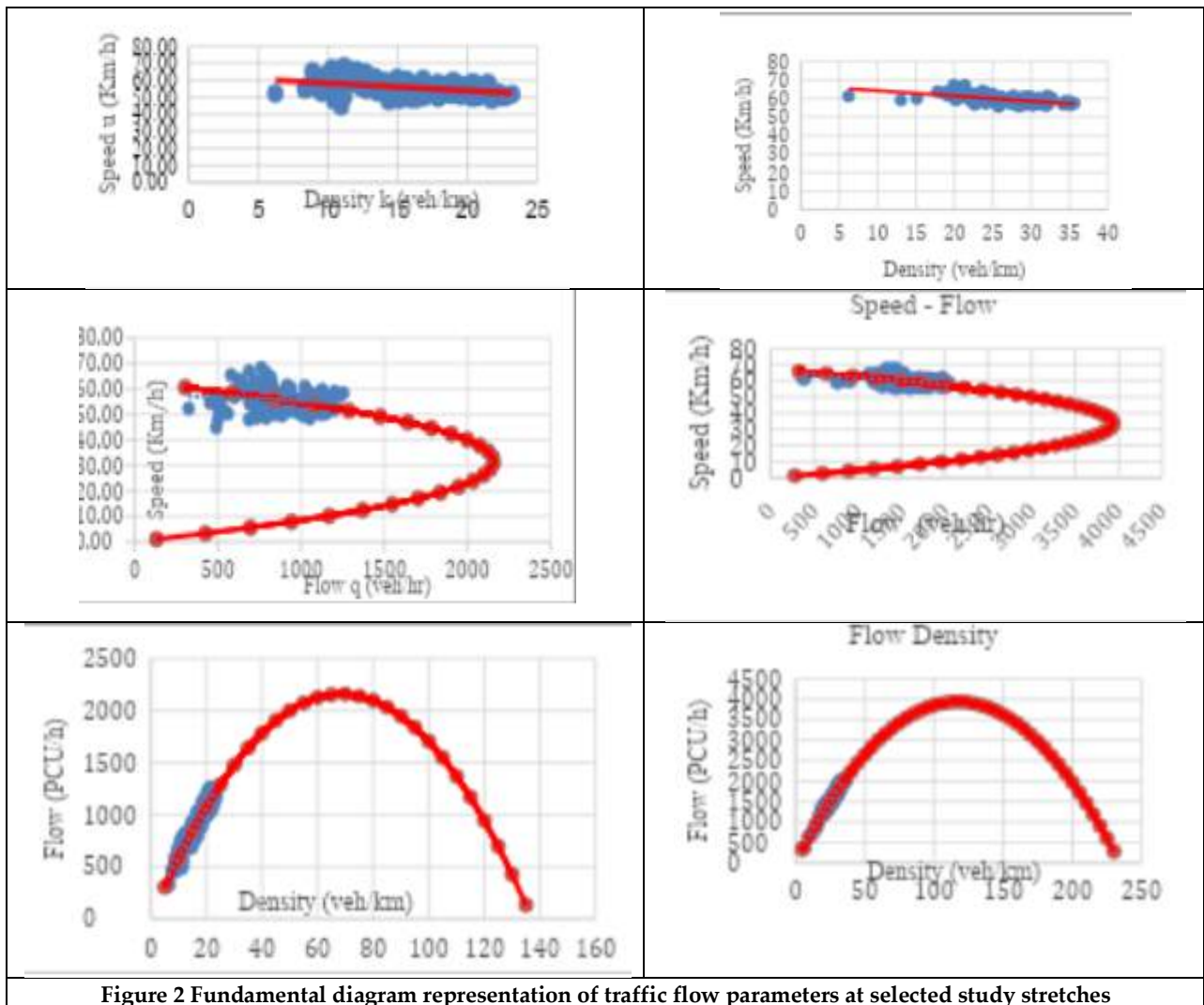
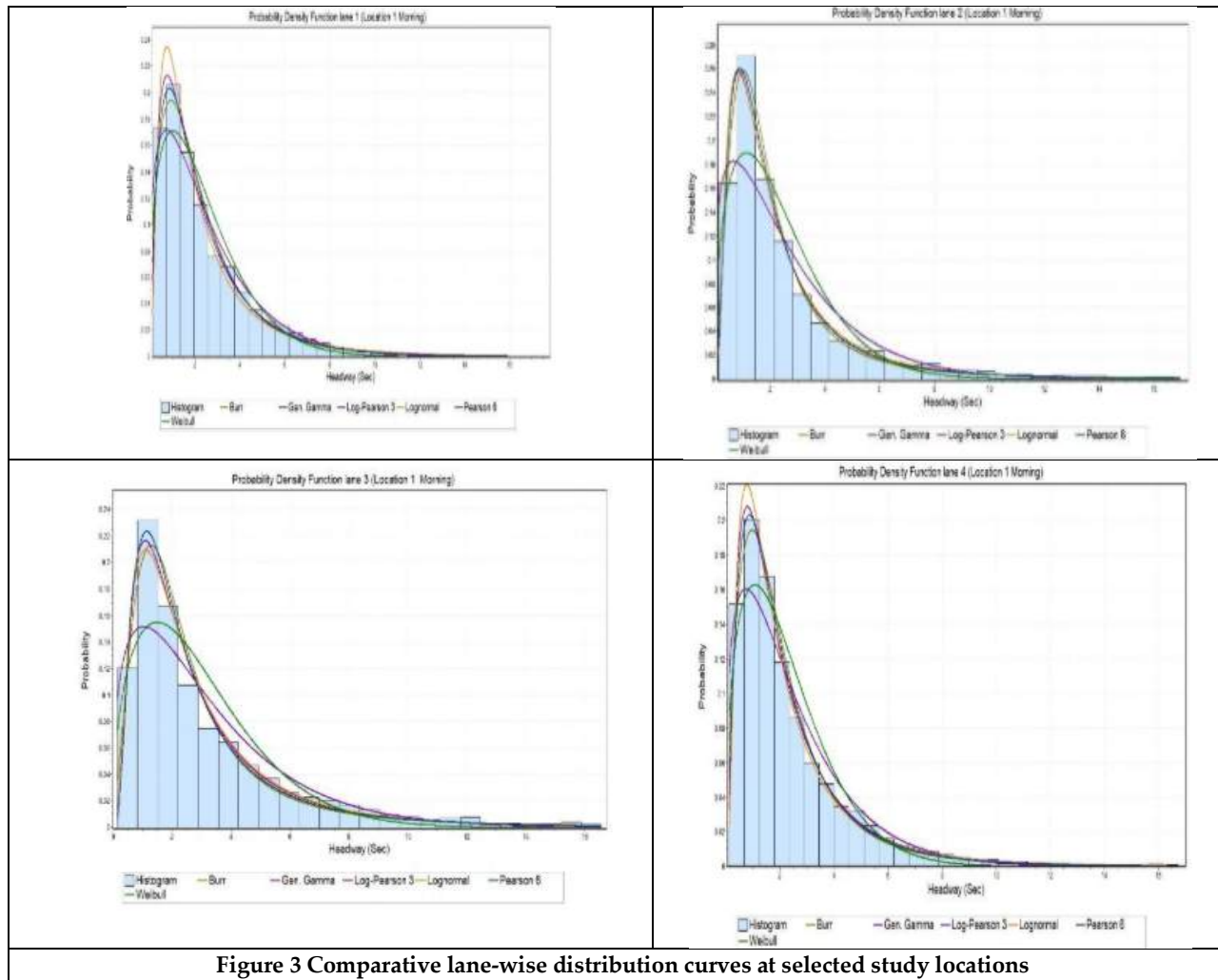


Figure 2 Fundamental diagram representation of traffic flow parameters at selected study stretches





Amit A Amin and L.B.Zala



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Evaluation of Antipyretic Activity of *Annabedhi uppu* using Brewer's Yeast - Induced Pyrexia in Albino Rats

Selvam V.D^{1*}, Rujitha D¹ and Visweswaran S²

¹PG Scholar, Department of Gunapadam, National Institute of Siddha, Sanatorium, (Affiliated to The Tamil Nadu Dr. MGR Medical University), Chennai, Tamil Nadu, India

²Professor, Department of Gunapadam, National Institute of Siddha, Sanatorium, (Affiliated to The Tamil Nadu Dr. MGR Medical University), Chennai, Tamil Nadu, India

Received: 11 Mar 2026

Revised: 10 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

Selvam V.D

PG Scholar, Department of Gunapadam,
National Institute of Siddha, Sanatorium,
(Affiliated to The Tamil Nadu Dr. MGR Medical University),
Chennai, Tamil Nadu, India
E.Mail: duraisamyselvam026@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The Siddha system is one of the traditional Indian systems of medicine that originated in ancient Tamil Nadu, India. Fever is a common physiological response to infections and inflammation, regulated by the hypothalamus through the production of prostaglandins. In the Siddha system of medicine, many herbal and herbomineral preparations are indicated and used for fever. *Annabedhi Uppu* was one of the herbo-mineral preparation mentioned in the Siddha textbook "*Nam Naattu Vaiththiyam*". *Annabedhi Uppu* was indicated for fever, hepatic injury, diarrhoea and anaemia. Ingredients of *Annabedhi Uppu* were *Annabedhi* (Iron sulphate), *Lingam* (Red sulphide of mercury), *Gandhagam* (Sulphur) and Lemon juice. *Annabedhi*, *lingam* and *gandhagam* had antipyretic effects and were widely used for pyrexia. But doesn't have valid scientific evidence. This study aimed to assess the efficacy of *Annabedhi Uppu* against fever in an animal model, focusing on their impact on body temperature. 15 Male and 15 Female Wistar rats were randomly assigned for the study. Animals are divided into 5 groups and each group has 6 animals. Fever was induced in all groups of animals except the control group by Brewer's yeast injection and body temperature was monitored using rectal thermometers at 19 hours after the yeast injection. The control group received only Water, the negative control group received brewer's yeast only, the standard group received paracetamol, and the treatment groups received *Annabedhi Uppu* in 7mg/kg and 14mg/kg. The temperature was measured at 1st, 2nd, and 3rd hr after drug administration. The results showed a significant reduction in body temperature in the standard group and the treatment groups compared to the negative control group. Statistical analysis showed that $P < 0.05$, was statistically significant and the null hypothesis was rejected. This study confirms that *Annabedhi Uppu* is a potent drug for treating fever.

Keywords: Antipyretic, animal model, fever, paracetamol, *Annabedhi Uppu*





INTRODUCTION

Pyrexia, another term for fever, can be treated using various approaches in traditional and complementary medicine systems. Pyrexia is an increase in body temperature above the normal physiological range, which may result from physiological stress such as during ovulation, increased thyroid secretion, excessive exercise, any lesions to the central nervous system, due to leukaemia, and mostly in microbial infections [1]. Pyrexia or fever is caused as a secondary impact of disease, malignancy, or other diseased states. The body's natural defence is to create an environment where infectious agents or damaged tissue cannot survive. Normally the infected or damaged tissue initiates the enhanced formation of pro-inflammatory mediators (Cytokines like interleukin 1β , α , β , and TNF- α), which increase the synthesis of prostaglandin E2 (PG E2) near the peptic hypothalamus area and thereby triggering the hypothalamus to elevate the body temperature. As the temperature regulatory system is governed by a nervous feedback mechanism when body temperature becomes very high, it dilates the blood vessels and increases sweating to reduce the temperature. Still, when the body temperature becomes very low hypothalamus protects the internal temperature by vasoconstriction. High fever often increases disease progression by increasing tissue catabolism, dehydration, and existing complaints, as found in HIV [2].

Suram disease is one of the 4448 diseases mentioned in the Siddha textbook. Siddha medicine, an ancient system of medicine from South India, has its methods for managing fever. According to Siddha philosophy, the main cause of Suram is said to be the formation of *Ama* (indigested metabolic products) in the intestine. Suram is classified into 3 types. There are *Vatha suram*, *Pithasuram*, and *Kabha suram*. 64 types of suram are classified under this classification [4]. *AnnabedhiUppu* (AU) is commonly used in the Siddha system of medicine. It is mentioned in the Siddha textbook "*Nam Naattu Vaiththiyam*" and authored by Judge *Balarammayya*. *Annabedhiuppu* is the combination of *Annabedhi*, *Lingam*, and *Gandhagam*. *Annabedhiuppu* was indicated for *Perunkazhichchal*, *Kalleeralliranam*, *Piththasuram* and *Vaathasuram* [5]. Ingredients of *Annabedhi uppu* are *annabedhi*, *lingam*, *gandhagam*, and lemon juice. *Annabedhi* is classified as one of the *Uparasam* (hydro chemicals), while *lingam* belongs to the *Panchasootham* (mercury and its components), and *Gandhagam* is categorised under the *Paadaanam* (Arsenic compounds) [6]. *Lingam* and *Gandhagam* are highly effective for fever. *Lingam* and *Gandhagam* contained medicines that have been prescribed for a long time against fever. As per the Siddha literature, *Lingam* and *Gandhagam* are indicated for fever [6]. *Lingam* and *Gandhagam* contained medicines that have been used for a long time against fever. *Annabedhiuppu* was indicated for fever and the ingredients of *AnnabedhiUppu* are highly effective for fever.

MATERIALS AND METHODS

Raw drug Collection:

Ingredients of *AnnabedhiUppu* were procured from a local raw drug shop in Chennai, Tamil Nadu. The Citrus limon fruit was bought from a vegetable market. The raw drugs were detoxified as per the methods mentioned in the authentic Siddha textbook [5]. Fresh lemon juice was used for preparation.

Preparation of *AnnabedhiUppu*:

AnnabedhiUppu is mentioned in the Classical Siddha textbook "*Nam Naattu Vaiththiyam*" and authored by Judge *Balarammayya* [5]. The formulation *AnnabedhiUppu* was prepared in the Gunapadam Laboratory of the National Institute of Siddha as per the classical Siddha literature. The purified *annabedhi* is ground with lemon juice to make villai. The villai is dried under sunlight, then placed in a mud pot and closed with a suitable mud pot and the junction of both mud pots is sealed with three layers of clay-smeared cloth, then subjected to the pudam process with 25 varatties and allowed to cool itself. The same procedure is repeated 5 times. The 6th time, the one-eighth weight of the purified *lingam* and one-sixteenth weight of the purified *ganthagam* are added to the weight of the *paspam* and again subjected to the pudam process with 25 varatties and allowed to cool.





Selvam et al.,

Dose:

1-3 Nel edai(65 mg -195 mg)

Vehicle:

Honey

Indication:*kalleeralinranam*(liver cirrhosis), *piththasuram*, *vaathasuram*, *pasimantham*, *seethabedhi*(dysentery).**Reference:***Nam Naattu Vaiththiyam* (pages no 128-129)**Pharmacological study of Annabedhi Uppu in animal model**

The animal study protocol was approved by the Institutional Animal Ethical Committee of the National Institute of Siddha, Chennai, and IAEC Protocol number NIS/IAEC-25/R05/06112023/E08. The studies were conducted in the animal house of the National Institute of Siddha, Chennai, Tamil Nadu, India.

Experiment with animal husbandry:

Male and Female Albino Wistar rats (6 - 8 weeks and weight: 140–160g) were purchased from the Laboratory Animal Medicine – Centre for Animal Health Studies, Tamil Nadu Veterinary and Animal Sciences University, Chennai, and maintained in the animal house of National Institute Siddha, Chennai. Animals were housed individually in polypropylene cages in a ventilated room (air cycles: 12-15/min; 70:30 exchange ratio) under an ambient room temperature of 22±3°C and 40–70% relative humidity, with a 12-h light/dark artificial photoperiod. The animals received RO water ad libitum and fed with Rodent pellet ad libitum

Grouping

Thirty Animals were procured from Tamil Nadu Veterinary and Animal Sciences University, Chennai. The body weights of the animals were recorded and they were randomly divided into 5 groups of 6 animals each group. Group I-It is called the control group. This group was given with 1ml of saline. Group II- It is called a negative control group. This group was treated with 10 ml/kg brewer's yeast alone. Group III –It is called a standard reference group. This group was treated with brewer's yeast and with 150mg/kg of Paracetamol. Group 4- It is called a test group. This group was treated with brewer's yeast and AU (7mg/kg). Group 5- It is also a test group. This group was treated with brewer's yeast and AU (14mg/kg).

Induction of Pyrexia

Before the study Animal weight and rectal temperature were recorded. Fever was induced in all groups of animals except the normal control group by injecting 10ml/Kg (subcutaneous) of 20% suspension of brewer's yeast in normal saline below the nape of the neck. The temperature was measured after 19 hours using a rectal thermometer.

Administration of drugs

After 19 hours of the induction of pyrexia- The paracetamol drug of appropriate dose (150mg/kg) was dissolved in saline solution and was given orally to group III. The test drug of *AnnabedhiUppu* was dissolved in honey and given orally to Group IV and Group V animals.

Temperature Measurements

Basal rectal temperature was measured before the injection of yeast by a digital thermometer. The digital thermometer was inserted at a depth of 2 cm into the rectum and the temperature of the animals was recorded. Standard drugs and trial drugs were given orally, 19h after yeast injection the rectal temperature of animals was noted at regular intervals following the respective treatment. The temperature was measured at 1st, 2nd, and 3rd hr after drug administration.



Selvam *et al.*,

Statistical analysis

Statistical analysis results are expressed as mean $\pm$ SEM. Statistical analysis of data was performed using ANOVA to study differences among the means.

DISCUSSION

Before starting the study, the animals' weights were recorded. Animals were divided into 5 groups and each group had 6 animals. Brewer's yeast was induced in all groups of animals except the normal control group. The rectal temperature of animals was recorded. The rectal temperatures of all groups of animals are presented in Table 3. The analysis of rectal temperatures in animal groups showed that fever was successfully induced. 19 hours after the injection of Brewer's yeast, animals were treated with standard drug and trial drugs. The negative control group received Brewer's yeast only. The standard control group received paracetamol. Group IV and V received AU in different doses. Animals' rectal temperatures were recorded in 1st hr, 2nd hr, 3rd hr, and 4th hr interval.

In the analysis of rectal temperatures, a significant change was seen between the negative control, standard, and trial groups. ($P < 0.05$). Every one-hour interval of rectal temperatures reversed to the normal level. This study described that AU is effective against fever. Furthermore, clinical trials conducted on AU will help evaluate its efficacy in humans in the future. Among the key ingredients, Lingam and Gandhagam are the most popular against fever. Anti-pyretic activity was conducted on Padiga linga chenduram by a yeast-induced method. The drug Padiga linga chenduram showed potent antipyretic activity [8]. Linga chenduram had strong antibacterial activity against *E. coli*, *S. aureus*, and *K. pneumoniae* and moderate anti-bacterial activity against *S. typhi* and *V. cholerae* at 3 and 4 mg concentration. [9] These previous studies proved that Lingam is effective against fever. Gandhagam had anti-microbial activity against *E. coli*, *P. vulgaris*, *K. pneumoniae*, *S. aureus*, *S. mutans*, and *C. albicans*. [10] Medicines that contain gandhagam and annabedhi have been used against fever [6].

CONCLUSION

From all the above observations, it is evident that brewer's yeast induced fever in experimental animals. The trial drug AU reversed the rectal temperatures to normal levels in experimental animals. Hence, this study shows that the test drug was effective against fever. However, further clinical studies are needed to elucidate the Anti-pyretic activity of AU.

REFERENCES

1. Sultana S, Asif HM, Akhtar N, Ahmad K. Medicinal plants with potential antipyretic activity: A review. Asian Pacific Journal of Tropical Disease. 2015 Jan 1;5:S202-8.
2. Begum TN, Ilyas MH, Anand AV. Antipyretic activity of azimatetracantha in experimental animals. Int J Cur Biomed Phar Res. 2011 Apr 30;1(2):41-4.
3. Vengatarajan S. Agathiyarrendayiram, 1st ed. Thanjavore: Thanjavur Saraswathi Mahal; 2005, p. 51-159
4. Kuppasamymuthaliyar K N. Siddha Maruthuvampothu, 6th ed. Chennai: Published by Indiyamaruthuvam Hoemeopathythurai; 2004, p.1-111
5. Nam Nattu Vaiththiyam book authored by Veeraperumal Pillai pg(127-128).
6. Gunapadamthathuseevavaguppu; Dr R.Thiyagarajan.
7. Kannusamiyam Pillai: Pathaarthana Gunasindhaamani
8. Preclinical Evaluation of Siddha Drug Padiga Linga Chenduram for its Anti-Dairrhoeal, Anti-Pyretic and Anti-Spasmodic, Activities. Sophia Anthuvanth, F Masters thesis, Government Siddha Medical College, Palayamkottai. Eprints –TNMGRMU, 2016.





Selvam et al.,

9. J. Savarimuthu Michael, A. J. A. Ranjit Singh, C. Padmalatha. Antibacterial potential of some herbo-mineral Siddha preparation: An alternative medicine for enteric pathogens Journal of Chemical and Pharmaceutical Research., 2011; 3(3): 572-578.
10. Shanmugapriya P, Christian GJ, Vajrai R, Brindha P, Elansekaran S, Murugesan M, Logamanian M, Manickavasakam K. Antimicrobial efficacy of Gandhagam (raw sulphur), purified Gandhagam and Gandhaga Mezhu-gu-a traditional Siddha formulation. J Pure Appl Microbiol. 2013 Jun 1;7:1-4.

Table no 1 Ingredients of AnnabedhiUppu

S.No	Ingredients	Scientific Name	Common Name	Quantity
1	Annabedhi	Ferrous Sulphate	Annabedhi	5 Balam
2	Lingam	Red sulphide of Mercury	Cinnabar	½ Balam
3	Gandhagam	Sulphur	Sulphur	¼ Balam
4	Elumichai charu	Citrus limon	Lemon juice	Required quantity

Table no 2 Pharmacological study of Annabedhi Uppu in animal model

S. No	Groups	Treatment
1	Group I	Normal Control (Normal saline 2ml/kg)
2	Group II	Negative Control (20% w/v of Brewer's yeast)
3	Group III	Standard Group (20% w/v of Brewer's yeast and Paracetamol (150 mg/kg)
4	Group IV	Experimental Group (20% w/v of Brewer's yeast and AU- 7mg/kg)
5	Group V	Experimental Group (20% w/v of Brewer's yeast and AU- 14mg/kg)

Table no 3 Animal weight before starting the study

	Group I	Group II	Group III	Group IV	Group V
Head	174g	182g	142g	158g	196g
Body	187g	189g	166g	190g	175g
Tail	173g	206g	162g	205g	202g
Head and body	140g	130g	138g	134g	162g
Body and tail	157g	132g	116g	161g	154g
No mark	167g	127g	142g	150g	145g

Table no 4 Animal body temperature before yeast induction

	Group I	Group II	Group III	Group IV	Group V
Head	101.8°F	97.4°F	97.9°F	98.9°F	93.6°F
Body	99.3°F	98.9°F	96.9°F	98.5°F	94.9°F
Tail	98.3°F	100.3°F	98.0°F	97.7°F	94.7°F
Head and body	98.6°F	100.1°F	98.8°F	100.8°F	98.5°F
Body and tail	98.2°F	98.5°F	99.8°F	99.3°F	96.2°F
No mark	98.1°F	98.6°F	98.6°F	100.1°F	95.3°F

Table no 5 Animal body temperature after yeast induction

	Group I	Group II	Group III	Group IV	Group V
Head	97.5°F	99.7°F	100.5°F	98.8°F	98.2°F
Body	98.1°F	99.8°F	98.0°F	96.8°F	98.7°F
Tail	100.3°F	100.5°F	99.3°F	98.0°F	99.0°F
Head and body	100.2°F	101.6°F	99.6°F	99.3°F	101.4°F
Body and tail	101.4°F	102.2°F	99.4°F	98.2°F	100.1°F
No mark	102.1°F	102.0°F	98.7°F	102.6°F	100.5°F





Selvam et al.,

Table no 6 Animal body temperature at 1 hr interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.4°F	97.6°F	99.5°F	98.8°F	100.0°F
Body	99.8°F	99.2°F	98.7°F	96.6°F	98.5°F
Tail	97.0°F	99.8°F	98.3°F	96.4°F	98.9°F
Head and body	99.5°F	101.0°F	100.1°F	101.1°F	100.3°F
Body and tail	101.4°F	100.9°F	101.1°F	102.1°F	101.7°F
No mark	101.0°F	100.3°F	100.2°F	102.5°F	101.1°F

Table no 7 Animal body temperature at 2nd hour interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.2°F	98.4°F	99.5°F	100.6°F	99.2°F
Body	99.3°F	99.4°F	99.6°F	98.8°F	97.7°F
Tail	99.6°F	100.2°F	99.6°F	99.5°F	96.3°F
Head and body	99.2°F	100.2°F	100.1°F	101.0°F	100.3°F
Body and tail	101.3°F	100.9°F	101.1°F	100.7°F	101.6°F
No mark	101.4°F	99.7°F	100.3°F	102.7°F	98.6°F

Table no 8 Animal body temperature at 3rd hour interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.2°F	98.5°F	100.5°F	99.8°F	98.3°F
Body	99.4°F	99.1°F	98.6°F	98.8°F	98.9°F
Tail	98.6°F	99.5°F	99.4°F	98.8°F	100.1°F
Head and body	100.0°F	101.7°F	101.1°F	101.8°F	100.8°F
Body and tail	101.9°F	101.4°F	102.2°F	101.3°F	101.2°F
No mark	102.1°F	101.2°F	99.4°F	103.5°F	100.4°F

Table no 9 Animal body temperature at 4th hr interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	97.9°F	98.3°F	100.3°F	98.6°F	97.0°F
Body	97.4°F	96.9°F	99.0°F	99.5°F	100.2°F
Tail	98.0°F	97.8°F	98.5°F	98.9°F	99.6°F
Head and body	100.5°F	101.4°F	100.7°F	101.5°F	99.2°F
Body and tail	102.6°F	101.6°F	101.9°F	101.3°F	101.2°F
No mark	101.5°F	101.3°F	100.7°F	103.4°F	101.3°F





Selvam et al.,

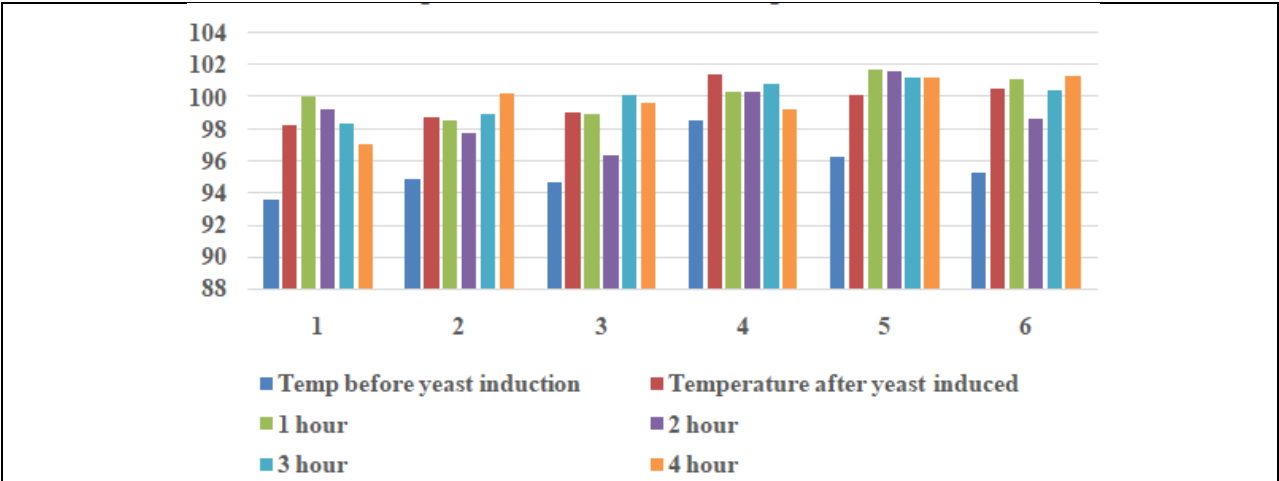


Figure 1: Temperature variation in Group I Animals

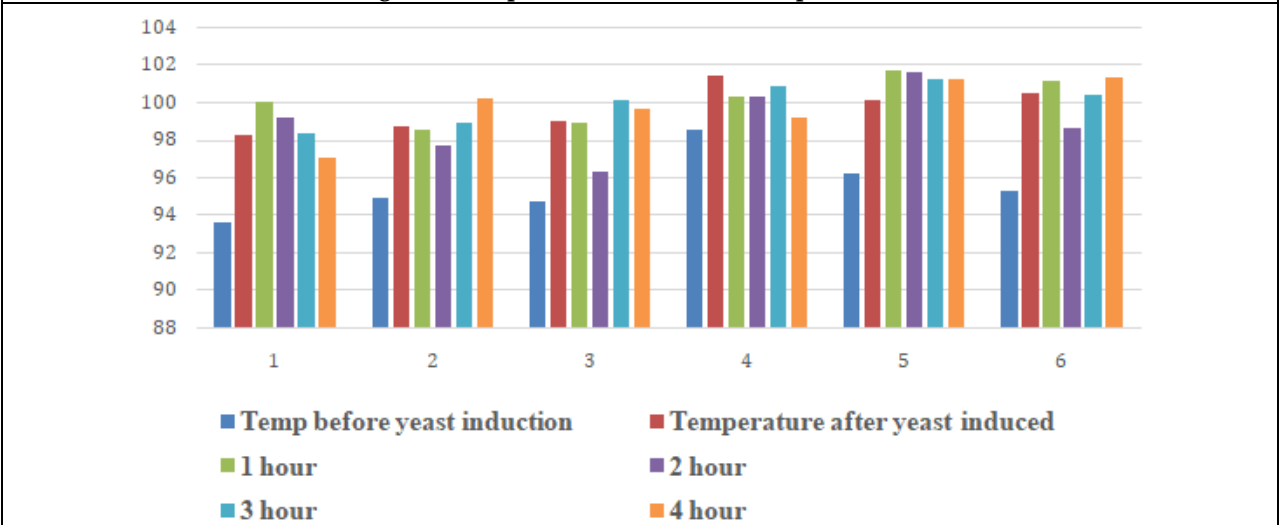


Figure 2: Temperature variation in Group II Animals



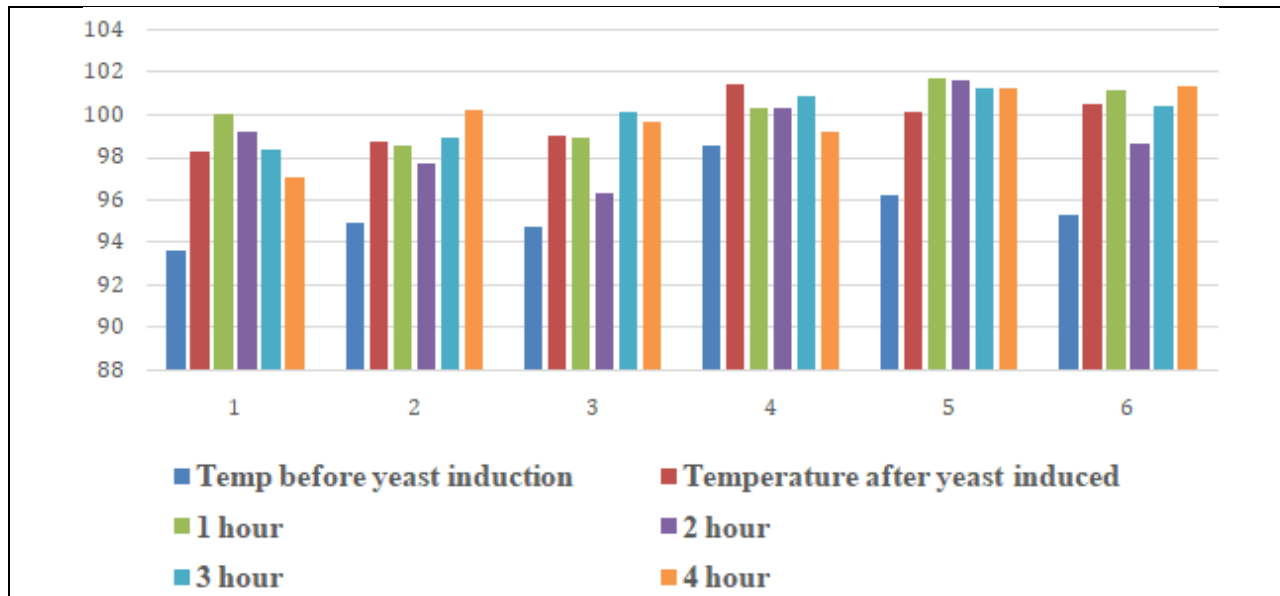
Selvam *et al.*,

Figure 3: Temperature variation in Group III Animals

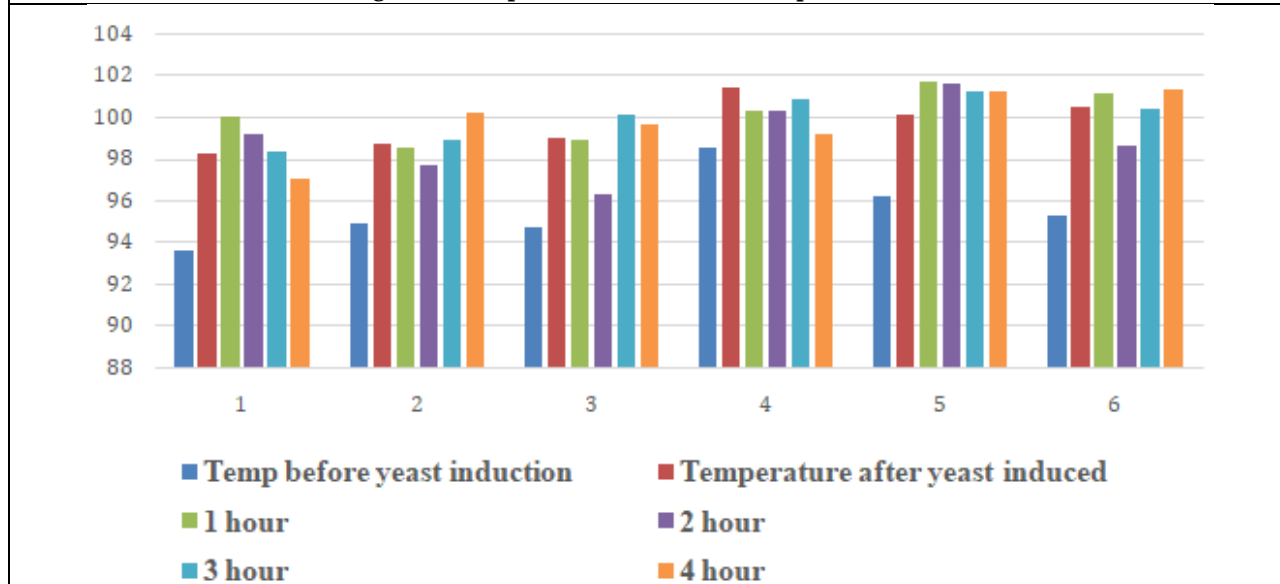


Figure 4: Temperature variation in Group IV Animals

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Environmental Toxicology of Microplastic Particles on Aquatic Animals

Chandrama Basu^{1*}, Rafath Rida² and Shifa Mehreen²

¹Associate Professor, Department of Environmental Science, Mount Carmel College (Autonomous), (Bangaluru City University), Bangaluru, Karnataka, India

²M.Sc Student, Department of Chemistry, Mount Carmel College (Autonomous), (Bangaluru City University), Bangaluru, Karnataka, India

Received: 20 Mar 2026

Revised: 24 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

Chandrama Basu

Associate Professor,
Department of Environmental Science,
Mount Carmel College (Autonomous),
(Bangaluru City University),
Bangaluru, Karnataka, India
E.Mail: chandrama.basu@mccbblr.edu.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Plastics have transformed modern life with their strength, lightness, and affordability but these same qualities have made them one of today's biggest environmental threats. When larger plastics break down, they form tiny fragments called microplastics (less than 5 mm) and nanoplastics (less than 1 μm), which now contaminate nearly every corner of our planet, from rivers and lakes to deep oceans and soils. This study explores where these particles come from, how they spread, and what harm they cause to both the environment and living organisms. Poor waste management, industrial runoff, and synthetic fibers from clothing are among the main sources allowing microplastics to reach water bodies. Once there, they can be swallowed by fish and other aquatic animals, leading to physical injuries, oxidative stress, inflammation, and even changes in behavior and growth. Laboratory studies show that these plastics can also carry toxic chemicals and heavy metals, which then accumulate through the food chain. On land, microplastics affect soil health by disrupting microbial activity and reducing fertility, while humans are exposed through food, water, and air raising concerns about inflammation, hormonal imbalance, and long-term health effects. Addressing this issue requires global cooperation, better waste management, the use of biodegradable materials, stronger environmental laws, and greater public awareness. Overall, microplastic pollution is not just an environmental problem, it's a growing risk to ecosystems and human health that demands urgent and collective action.

Keywords: Microplastics, aquatic ecosystems, bioaccumulation, plastic contamination, biodegradation, oxidative stress, toxicity, waste management





INTRODUCTION

Over the last few decades, plastics have revolutionized industrial development, consumer behavior, and global trade because of their durability, light weight, and cost-[1]. Yet, these very advantages have created one of the most pressing environmental challenges of our time plastic pollution. When inadequately disposed of, plastic waste accumulates in terrestrial and aquatic ecosystems, undergoing fragmentation into progressively smaller particles known as microplastics (MPs, < 5 mm) and nano plastics (< 1 μ m) [2]. Their persistence, coupled with the fact that they are easily transported through water, has made them a pollutant of worldwide concern [3]. Aquatic environments rivers, lakes, estuaries, and oceans serve as the ultimate sink for most plastic debris. Studies have reported the presence of microplastics in surface waters, sediments, and even deep-sea and polar ecosystems, underscoring their global distribution [4]. The small size of MPs allows them to be ingested by a wide range of aquatic organisms, from plankton and mollusks to fish and marine mammals. Consequently, understanding their environmental toxicology, that is, their interactions with biological systems and resulting harmful effects has become a central focus of modern ecotoxicological research [5]. Plastics are widely used for their durability, flexibility, and low cost, but their extensive production and improper disposal have made them a major environmental concern. Among plastic pollutants, microplastics plastic particles smaller than 5 mm have gained global attention due to their persistence, small size, and widespread occurrence in aquatic environments [2, 5].

These particles originate either as primary microplastics, intentionally manufactured for industrial or cosmetic use, or as secondary microplastics, formed by the degradation of larger plastic waste under environmental stress as shown in figure 1. [2,11, 4]. Because of their light weight and resistance to biodegradation, microplastics are now found in oceans, rivers, sediments, and even polar regions [5, 8]. Once introduced into aquatic systems, microplastics interact with both abiotic and biotic components, altering water quality, nutrient cycling, and sediment structure [3, 9]. They are ingested by various aquatic organisms, from plankton and crustaceans to fish and marine mammals, often being mistaken for food [1, 5]. Ingestion can lead to reduced feeding, energy imbalance, growth inhibition, and reproductive failure [1, 6, 10]. Furthermore, the accumulation of microplastics in tissues can cause physical damage, intestinal blockage, and inflammatory responses, threatening the survival of numerous aquatic species [9, 10]. Beyond these physical effects, microplastics act as vectors for environmental contaminants. Their hydrophobic surfaces enable the adsorption of persistent organic pollutants (POPs), heavy metals, and pharmaceuticals from surrounding waters [3, 7]. When ingested, these particles can transfer toxic chemicals to aquatic organisms, increasing their internal pollutant load and leading to bioaccumulation and biomagnification throughout food chains [7, 9]. This dual threat mechanical injury and chemical toxicity makes microplastics particularly hazardous to aquatic ecosystems [3, 7].

Recent studies have highlighted the complex interactions between microplastics and emerging contaminants, showing that they can modify the transport, bioavailability, and toxicity of other pollutants in aquatic environments [3]. Such interactions depend on factors such as polymer type, particle size, and water chemistry, underlining the need for deeper mechanistic understanding of microplastic-contaminant dynamics [7]. Microplastic pollution also has potential implications for human health. Humans are exposed indirectly through the consumption of contaminated seafood, drinking water, and table salt [8]. Although the long-term health consequences are not yet fully known, possible risks include oxidative stress, inflammation, and endocrine disruption [8, 9]. To address this growing issue, integrated strategies such as improving waste management, promoting biodegradable alternatives, enhancing recycling technologies, and enforcing stricter environmental regulations are essential [4]. Public awareness, combined with scientific and legislative efforts, can play a crucial role in minimizing microplastic release and protecting aquatic life [4, 6].

Causes

Ways in which Microplastic Pollution takes place in Rivers, Lakes, and Other Water Bodies



**Chandrama Basu et al.,**

Poor Waste Management, Plastics that are discarded by the people carelessly or not recycled properly often escape into the environment. Rain, wind, flow of water and other factors can carry this debris into lakes, rivers, and oceans. As time passes larger plastics break into much more tiny fragments called secondary microplastics.[32] Intentionally Manufactured Microplastics, some plastic particles are intentionally produced at very small sizes such as include microbeads in cosmetics or tiny industrial pellets and fibres from synthetic clothing. These microplastics can enter water systems directly through sewage, wastewater, or industrial discharge.[32,35] Breakdown of Microplastics, Within Water Bodies Even after reaching water, plastics continue to fragment because of sunlight, temperature fluctuations, water currents, and microbial activity. This creates a variety of micro and nano plastics that can be easily ingested by aquatic animals.[32] Runoff from the industries, Wastewater, and Airborne Deposition Microplastics also reach water indirectly. industrial runoff carries fibres and dust, while wastewater treatment plants often do not filter out exceedingly small particles. Airborne microplastics can settle into rivers, lakes, and reservoirs.[32] Rising Plastic Production and Poor Disposal, the growing use of plastics worldwide due to improper disposal, keeps adding more plastic into aquatic environments, increasing risks for fish and other organisms.[32,35]

How Fishes Take in Microplastics

Direct Consumption, Fish often mistake tiny plastics for food because of their shape, colour, or size. Eating these particles can block digestive tracts, make feeding less efficient, and sometimes cause physical harm [28] Through the Food Chain, Microplastics are first consumed by smaller organisms like plankton. Predatory fish then eat these organisms, leading to accumulation of plastics higher up in the food chain. Toxic Chemicals Attached to Plastics, Microplastics can carry pollutants such as heavy metals or persistent organic compounds. Once ingested, these chemicals may leach into fish tissues, creating additional stress and damage.[28,34] Contamination After Capture, even after fish are caught, they can pick up microplastics from contact with packaging, containers, processing equipment, or even airborne fibres in storage areas.[28]

Effects on Fish at Different Life Stages

Vulnerable Early Stages, Eggs, larvae, and juvenile fish are particularly sensitive to microplastics because their immune systems and detox mechanisms are still developing.[30,31] Growth and Behavioural Effects, Microplastic exposure can reduce growth rates, impair feeding, and alter normal behaviour. Research has shown stunted development and abnormal swimming in species exposed to these particles.[30,31]

Cellular and Biochemical Impacts

Oxidative Stress, Microplastics can trigger excessive production of reactive oxygen species (ROS), which damage cell structures and affect organ function.[29] Liver Inflammation and Injury, ROS can activate immune pathways, causing liver inflammation. Severe exposure can damage liver tissue or even kill liver cells.[33] Metabolic Disruption, Plastics may interfere with the liver's ability to process fats and energy, affecting overall metabolism in fish. Altered Biomarkers, Enzyme activity and protein levels in the liver may change under microplastic exposure, signalling physiological stress.[33,34]

Factors Influencing Toxicity

Particle Size, Dose, and Exposure Duration, Smaller microplastics penetrate tissues more easily. Higher doses or longer exposure periods increase the risk of severe effects.[34] Species Sensitivity, Different fish species react differently depending on metabolism, immune strength, and detoxification abilities.[32] Plastic Additives, Chemicals such as dyes, flame retardants, or plasticizers can intensify toxic effects. Accumulation and Food Chain Transfer, Microplastics can build up in fish tissues over time. Predators that consume contaminated fish may also accumulate plastics and associated toxins, affecting the food chain.[35]

Other Ecological Risks

Mistaken Identity by Marine Animals, few animals confuse microplastics with prey, leading to ingestion, physical injury, and disrupted feeding.[35] Carriers of Pathogens, Microplastics can provide surfaces for bacteria or other



**Chandrama Basu et al.,**

microorganisms, spreading diseases in aquatic ecosystems.[35] Long Term Effects on Growth and Reproduction, Chronic exposure may reduce growth, hinder reproduction, and disturb population stability, ultimately affecting biodiversity and ecosystem balance.[34,35]

Effects

Ecotoxicological Impacts on Aquatic Organisms

Microplastics (MPs) are increasingly recognized as a pervasive environmental contaminant affecting aquatic ecosystems worldwide. Their small size and persistence allow them to be easily ingested by a range of organisms, from plankton to fish and shellfish, leading to significant physiological and biochemical alterations [12]. Studies have demonstrated that exposure to polystyrene microplastics (PS-MPs) reduces the catalytic efficiency of acetylcholinesterase (in zebrafish larvae, impairing cholinergic transmission and neural signaling [12]. This inhibition leads to overstimulation of receptors, resulting in behavioral abnormalities such as sluggish locomotion and feeding difficulties. In addition, long-term ingestion of MPs has been shown to cause gastrointestinal obstruction, enlargement of the colon lumen, and altered feeding behavior in fish, thereby reducing their overall growth and fitness [12]. Microplastics also provoke oxidative stress in aquatic organisms by increasing the production of reactive oxygen species (ROS), which damage cellular structures through lipid peroxidation (LPO) [12]. This oxidative stress disrupts membrane integrity, leading to lesions in critical tissues like gills, liver, and muscles. In fish such as *Dicentrarchus labrax*, LPO has been associated with neuronal damage and increased mercury accumulation in brain tissue when MPs are co-present with heavy metals [12]. Furthermore, co-exposure of MPs with other environmental pollutants like cadmium has been shown to amplify toxicity by suppressing antioxidant enzyme activity and upregulating stress-related genes [12]. These findings emphasize that MPs not only act as independent toxic agents but also serve as vectors that facilitate the bioavailability and accumulation of other hazardous substances within aquatic food webs [12].

Histopathological and Physiological Damage

The ingestion and accumulation of MPs in aquatic fauna induce a range of histopathological changes. Fish and mollusks exposed to low-density polyethylene (LDPE) and PS-MPs exhibit villus fissuring, enterocyte degeneration, and necrosis of intestinal epithelial cells [12]. In zebrafish, MP exposure causes vacuolization and mast cell infiltration in the intestinal lining, indicating inflammatory responses. Moreover, MPs with fibrous morphology tend to remain longer within the gut compared to spherical or fragmented forms, thereby aggravating mechanical injury and inducing higher oxidative stress responses [12]. The physical characteristics of MPs—size, shape, and polymer type—determine the severity of damage; smaller particles penetrate cellular membranes more easily and accumulate within organs, while fibrous MPs cause more extensive abrasion and inflammation [12]. MP-induced inflammation is mediated by the upregulation of immune-related genes such as *il-1b*, *ifngl-2*, and *nfa*, which trigger oxidative damage and apoptotic pathways [12]. Chronic exposure results in impaired intestinal absorption and disrupted metabolic function. Studies on *Oreochromis niloticus* and *Cyprinus carpio* have reported altered liver function, elevated aminotransferase activity, and reduced serum protein levels, indicating hepatic stress and metabolic imbalance [12]. Additionally, MPs cause anemia, disrupt hematological parameters, and elevate plasma glucose and creatinine levels, suggesting impaired kidney and cardiovascular functions in fish [12].

Bioaccumulation and Trophic Transfer

The persistence of microplastics in aquatic environments facilitates their bioaccumulation and trophic transfer through food chains. Planktonic organisms ingest suspended MPs, which are subsequently transferred to higher trophic levels through predation [13]. Filter feeders such as mussels and oysters act as bioindicators, accumulating MPs within their tissues and providing a pathway for human exposure through seafood consumption [13]. The accumulation of MPs in benthic species also influences sediment biogeochemistry by altering nutrient cycling and oxygen exchange at the sediment-water interface. Over time, MPs integrated into benthic communities can release adsorbed contaminants, thereby perpetuating chemical toxicity across trophic levels [13]. The potential for MPs to adsorb hydrophobic organic pollutants and heavy metals such as mercury and cadmium further enhances their



**Chandrama Basu et al.,**

ecotoxicological impact [12], [13]. As a result, organisms ingesting MPs may experience compounded effects from both the physical presence of plastics and the chemical toxicity of co-adsorbed contaminants. This dual mode of toxicity poses a severe risk to aquatic biodiversity, as well as to food safety and human health [13].

Terrestrial and Soil Ecosystem Effects

Although the majority of research focuses on aquatic systems, terrestrial environments are equally susceptible to MP contamination through sewage sludge, agricultural runoff, and atmospheric deposition [14]. MPs introduced into soils affect microbial community structure and reduce soil enzymatic activity essential for nutrient cycling [14]. Their presence alters soil porosity and water retention, indirectly influencing plant growth and productivity. Moreover, earthworms and other soil invertebrates ingest MPs, leading to intestinal blockage, oxidative stress, and changes in reproductive behavior [14]. The persistence of MPs in agricultural lands that use plastic mulch or contaminated fertilizers raises long-term concerns for soil fertility and food crop safety [14].

Impacts on Human Health

Humans are exposed to MPs primarily through ingestion, inhalation, and dermal contact. MPs have been detected in table salt, drinking water, seafood, and even atmospheric dust, indicating their widespread presence [15]. Once ingested, MPs can cross biological barriers and accumulate in organs such as the liver, kidneys, and intestines, potentially leading to inflammatory responses and oxidative stress [15]. Studies suggest that nanoplastics, due to their smaller size, are capable of translocating across cell membranes and the blood-brain barrier, posing neurological risks similar to those observed in aquatic species [12], [15]. Furthermore, MPs can carry endocrine-disrupting chemicals such as phthalates, bisphenols, and flame retardants, which interfere with hormonal regulation and reproductive health [15], [16]. Emerging evidence also links chronic MP exposure to metabolic and immunological disorders. The oxidative damage caused by MPs may contribute to DNA strand breaks and mitochondrial dysfunction, which are precursors to carcinogenic processes [16]. Although human health implications are still under investigation, the continuous accumulation of MPs in food chains underscores the urgency for global monitoring and mitigation measures [16], [17].

Ecosystem-Level Consequences

At the ecosystem scale, MPs interfere with energy transfer, nutrient dynamics, and habitat quality. The presence of MPs in aquatic and terrestrial food webs disrupts predator-prey interactions and alters community structure [17]. In marine environments, MPs contribute to habitat degradation, particularly in coral reefs and seagrass beds, by blocking light penetration and smothering photosynthetic organisms [17]. Moreover, MPs may serve as vectors for pathogenic microorganisms, forming biofilms that facilitate the spread of antibiotic-resistant bacteria [18]. This phenomenon poses a threat to both marine biodiversity and public health, reinforcing the need for comprehensive environmental management.

Measures to Reduce or Prevent Microplastic Pollution

A comprehensive approach is needed to mitigate and prevent microplastics pollution, involving technological, behavioral, and regulatory interventions. Central to this effort is source reduction, which can be achieved by minimizing the production and use of single-use plastics and encouraging manufacturers and consumers to shift to biodegradable alternatives [12]. Replacing conventional plastics with bioplastics derived from renewable resources, such as polylactic acid or polyhydroxyalkanoates, can significantly lower the persistence of microplastics in the environment, especially if these new materials are proven to degrade efficiently under natural conditions [13]. However, care must be taken to ensure that bioplastics do not create secondary pollution challenges, requiring thorough evaluation of their environmental impact and lifecycle performance [14]. Improvement in waste management infrastructure is a crucial measure. Proper collection, recycling, and managed disposal of plastic waste, particularly in coastal regions, cities, and river basins that are major sources of marine microplastics, can drastically reduce the amount entering aquatic environments [15]. Policies that promote a circular economy for plastics, such as extended producer responsibility and incentives for recycling, help create a sustainable system where plastic



**Chandrama Basu et al.,**

materials are reused, further necessitating public and private sector collaboration [16]. Municipalities and regions with robust plastic waste collection and recycling systems show lower levels of mismanaged waste, directly correlating with lower microplastic leakage [17].

Wastewater treatment plant optimization is essential because these plants are important pathways for microplastics to reach rivers, lakes, and seas. Conventional treatment can remove a significant fraction of microplastics, but advanced filtration systems, such as membrane bioreactors and tertiary filtration with very fine meshes, can extract even smaller plastic particles [18]. Implementation of such advanced technology, albeit expensive, prevents the direct release of microplastics into natural waters and should be complemented by regular monitoring and standardization of detection and removal methods [19]. Legislative interventions, including bans or taxes on specific microplastics sources like microbeads in personal care products, have demonstrated effectiveness and should be broadly adopted and enforced [20]. National and international agreements, such as those advocated by the United Nations Environment Programme, provide frameworks for coordinated reduction efforts, while also guiding local policy makers in formulating enforceable and context-appropriate rules [21]. Regulations must also address emissions from synthetic textiles and the loss of fishing gear, two significant contributors to microplastics pollution, by mandating design changes, labeling, and collection requirements [22]. Public education and behavioral change campaigns are vital for long-term success. Raising awareness of the impact of microplastics encourages individuals to reduce their plastic footprint by refusing single-use plastic items, choosing natural fibers over synthetic textiles, and supporting environmentally responsible products [23].

Effective campaigns can change consumption patterns and influence upstream demand, resulting in less plastic entering the market and ultimately the environment [24]. Innovative approaches such as rewarding "plastic fishing" or cleanup efforts, particularly for floating or shoreline plastics, offer community-based solutions to intercept plastics before they degrade into microplastics and reach aquatic systems [25]. While collecting micro- and nanoplastics from open oceans remains technologically and logistically challenging, targeting macroplastics and the most polluted sites can curtail future microplastic formation [26]. Continued research to improve materials and develop new detection, treatment, and removal technologies will further strengthen prevention strategies. Standardizing monitoring protocols and advancing analytical techniques allow for accurate quantification of microplastics in different environments, supporting evidence-based policy decisions and adaptive management [27]. Cross-sector collaboration, including scientists, industry, policymakers, and local communities, is necessary to develop and implement holistic solutions. In summary, addressing microplastics pollution requires a combination of upstream interventions to reduce plastics use, technological advancements in waste and water treatment, strict legislation and enforcement, intensive public education, and ongoing research and development. Overcoming this environmental challenge will depend on global cooperation, integrated policy frameworks, and a sustained commitment to transforming how society produces, consumes, and disposes of plastic materials.

Experimental findings and observations on microplastic toxicity

Effect of Polystyrene Microplastics on Zebrafish Neural Enzyme Activity

In a controlled study, zebrafish larvae (*Danio rerio*) were exposed to 1 mg/L of polystyrene microplastics (PS-MPs) to evaluate the impact on acetylcholinesterase (AChE) enzyme activity [12]. The experiment lasted for 96 hours, during which the catalytic efficiency of AChE was monitored alongside behavioral parameters like swimming activity and feeding response. The researchers observed that inhibition of AChE corresponded with sluggish locomotion, decreased feeding frequency, and disrupted cholinergic transmission, which is crucial for muscle coordination and brain synapse function [12].

Observations

Zebra fish larvae displayed a clear decline in swimming speed and directional control within 72 hours of exposure. The reduction in AChE activity resulted in an accumulation of acetylcholine at synaptic junctions, causing overstimulation of neural receptors [12]. When comparing to larger species like *Dicentrarchus labrax*, no significant



**Chandrama Basu et al.,**

inhibition of AChE was observed at similar concentrations, suggesting that smaller fish are more vulnerable to neurotoxic stress induced by microplastics [12].

Results

As shown in Table 1 Lipid peroxidation (LPO) increased significantly in exposed zebrafish brains, indicating oxidative stress. The study also noted muscle and gill tissue damage correlated with elevated LPO markers. These findings suggest that PS-MPs interfere with antioxidant defense mechanisms, leading to enhanced production of reactive oxygen species (ROS) and potential neurodegeneration [12][13].

Histopathological and Oxidative Stress Response in Adult Zebrafish Exposed to LDPE Microplastics

In another study, adult zebrafish were exposed to low-density polyethylene (LDPE) microplastics for three weeks to determine histopathological and biochemical changes [14]. The concentration of LDPE particles ranged between 5 and 500 µg/L. Despite prolonged exposure, no significant variation in oxidative stress markers was initially recorded [14]. However, when combined with heavy metals like cadmium, there was a notable increase in ROS generation and suppression of antioxidant enzyme activity.

Observations

Zebrafish exposed solely to LDPE particles maintained normal liver and gill histology, but the addition of cadmium resulted in tissue degeneration, liver vacuolization, and nuclear pyknosis [14]. The mRNA expression of oxidative stress-related genes such as SOD1, SOD2, and Nfe212 decreased significantly, indicating suppressed defense mechanisms.

Results

The experiment confirmed that microplastics act as pollutant vectors, enhancing the bioavailability of co-contaminants like cadmium. Table 2 shows the synergistic toxicity resulted in severe oxidative stress, reducing glutathione (GSH) and superoxide dismutase (SOD) levels. The joint exposure led to a 45% decrease in SOD activity compared to the control [14][15].

Reproductive Toxicity of Microplastics in *Sparus aurata*

A laboratory-based experiment on *Sparus aurata* (gilthead seabream) investigated behavioral and physiological effects of polyethylene microplastic ingestion [16]. The fish were divided into two groups—control and exposed (0.1 mg/L PE-MPs)—and monitored for 21 days. The exposure led to significant changes in social behavior, feeding activity, and reproductive indices.

Observations

The exposed group exhibited reduced social interaction and increased lipid peroxidation in gonadal tissues. Alterations were also found in serum biomarkers such as triglycerides, cholesterol, and total protein levels [16]. Behavioral stress indicators, including erratic swimming and reduced mating courtship, were evident after 14 days of exposure.

Results

Biochemical analysis (as shown in Table 3) revealed increased antioxidant enzyme levels as a compensatory response to oxidative stress. However, chronic exposure induced damage to gonadal tissues, reducing sperm motility and egg fertilization rates. The findings suggest endocrine disruption as a secondary effect of microplastic accumulation in reproductive organs [16][17].



Chandrama Basu *et al.*,**Combined Toxicity of Polystyrene Microplastics and 17 α -Methyltestosterone on Zebrafish**

A more recent study evaluated combined exposure of PS-MPs (100 μ g/L) and 17 α -methyltestosterone (10 μ g/L) on the reproductive system of zebrafish (*Danio rerio*) [18]. The experiment ran for 30 days, focusing on gonadal histology, hormone levels, and gene expression related to steroidogenesis.

Observations

Fish exposed to the combined treatment showed severe gonadal atrophy, disrupted spermatogenesis, and reduced oocyte development. There was downregulation of genes like *cyp19a1a* and *lh β* , essential for estrogen synthesis and reproductive hormone regulation [18]. Moreover, testicular tissues exhibited extensive fibrosis and necrosis, while ovarian sections revealed follicular degeneration.

Results

The results confirmed a synergistic interaction between PS-MPs and endocrine disruptors. As we can see in Table 4, Plasma testosterone and estradiol concentrations dropped by 35% and 40%, respectively, compared to the control group. The findings indicate that PS-MPs can enhance hormonal toxicity by acting as carriers for hydrophobic compounds [18][19].

Summary of Experimental Findings on Microplastic Toxicity

The collective analysis of four controlled experiments reveals the multifaceted toxicological effects of microplastics (MPs) on aquatic organisms, emphasizing neural, histopathological, reproductive, and biochemical disruptions across species. In the first experiment, exposure of *Danio rerio* (zebrafish) larvae to 1 mg/L of polystyrene microplastics (PS-MPs) for 96 hours led to significant inhibition of the acetylcholinesterase (AChE) enzyme. This inhibition impaired neurotransmission, resulting in reduced locomotor activity and feeding efficiency. Elevated levels of lipid peroxidation (LPO) and reactive oxygen species (ROS) indicated oxidative stress in neural tissues. The findings demonstrated that smaller fish species are more vulnerable to microplastic-induced neurotoxicity compared to larger ones, highlighting the size-dependent effects of MPs on aquatic neural health [12][13]. The second experiment focused on adult zebrafish exposed to low-density polyethylene (LDPE) microplastics for three weeks, both alone and in combination with cadmium (Cd). While LDPE alone produced minimal oxidative stress, its combination with cadmium amplified reactive oxygen species formation and suppressed key antioxidant enzymes like superoxide dismutase (SOD) and glutathione (GSH). Histological analyses revealed liver vacuolization, cellular necrosis, and nuclear pyknosis, confirming that MPs can act as vectors that increase heavy metal bioavailability and toxicity. The results provided strong evidence for synergistic toxicity between MPs and metal pollutants in aquatic ecosystems [14][15].

The third experiment investigated the reproductive toxicity of polyethylene microplastics (PE-MPs) in *Sparus aurata* (gilthead seabream). Over 21 days, exposed fish exhibited altered social and feeding behaviors, decreased serum protein levels, and elevated cholesterol and triglycerides, reflecting metabolic imbalance. Gonadal tissues showed lipid peroxidation and cellular degeneration, leading to reduced sperm motility and egg fertilization rates. These physiological changes suggested an endocrine-disrupting potential, where chronic exposure to MPs impairs reproductive functions through oxidative and hormonal pathways [16][17]. The fourth experiment explored the combined effect of polystyrene microplastics and 17 α -methyltestosterone (17 α -MT) on zebrafish reproduction. A 30-day exposure caused severe gonadal atrophy, oocyte degeneration, and fibrosis in testicular tissue. Additionally, expression of steroidogenic genes such as *cyp19a1a* and *lh β* was significantly downregulated. Hormonal assays confirmed reductions of approximately 35% in testosterone and 40% in estradiol levels compared to controls. These outcomes demonstrated a synergistic endocrine-disrupting effect, suggesting that microplastics can enhance the bioavailability and toxicity of hydrophobic compounds like synthetic hormones [18][19]. Overall, these experiments collectively underscore the pervasive and complex toxicity of microplastics in aquatic environments. MPs not only exert direct physiological and biochemical damage but also serve as carriers for co-contaminants, amplifying their harmful effects. The recurring trends of oxidative stress, enzyme inhibition, tissue degeneration, and hormonal





imbalance confirm that microplastics act as potent environmental stressors, threatening aquatic biodiversity and, indirectly, human food security. Continued investigation into combined contaminant effects, tissue bioaccumulation, and long-term generational impacts is essential to develop effective mitigation strategies for microplastic pollution.

REFERENCES

1. Guzzetti, E., Sureda, A., Tejada, S., & Faggio, C. (2018). Microplastic in marine organisms: Environmental and toxicological effects. *Environmental Toxicology and Pharmacology*, 64, 164–171.
2. Andrady, A.L. (2011). Microplastics in the marine environment. *Marine Pollution Bulletin*, 62(8), 1596–1605.
3. Menéndez-Pedriza, A., & Jaumot, J. (2020). Interaction of microplastics with emerging contaminants in the aquatic environment: Mechanistic insights. *Environmental Science and Pollution Research*, 27, 41649–41663.
4. Prata, J.C., da Costa, J.P., Lopes, I., Duarte, A.C., & Rocha-Santos, T. (2020). Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *Journal of Cleaner Production*, 273, 122049.
5. Cole, M., Lindeque, P., Halsband, C., & Galloway, T.S. (2011). Microplastics as contaminants in the marine environment: A review. *Marine Pollution Bulletin*, 62(12), 2588–2597.
6. de Sá, L.C., Oliveira, M., Ribeiro, F., Rocha, T.L., & Futter, M.N. (2018). Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? *Science of the Total Environment*, 645, 1029–1039.
7. Koelmans, A.A., Bakir, A., Burton, G.A., & Janssen, C.R. (2016). Microplastic as a vector for chemicals in the aquatic environment: Critical review and model-supported reinterpretation. *Environmental Science & Technology*, 50, 3315–3326.
8. Sharma, S., & Chatterjee, S. (2017). Microplastic pollution, a threat to marine ecosystem and human health: A short review. *Environmental Science and Pollution Research*, 24(27), 21530–21547.
9. Barboza, L.G.A., & Guilhermino, L. (2015). Microplastics in the marine environment: Interaction with aquatic biota and impacts. *Environmental Pollution*, 214, 257–267.
10. Foley, C.J., Feiner, Z.S., Malinich, T.D., & Höök, T.O. (2018). A meta-analysis of the effects of exposure to microplastics on fish and invertebrates. *Science of the Total Environment*, 631–632, 550–563.
11. <https://onlinelibrary.wiley.com/cms/asset/6da81777-2ceb-4e59-a6ea-084e4be5394e/wer11029-toc-0001-m.jpg>
12. Pothiraj, C., et al. (2023). Vulnerability of microplastics on marine environment: A review. *Ecological Indicators*, 155, 111058.
13. Gokul, T. A., et al. (2023). Toxicity and accumulation of microplastics in aquatic food webs. *Marine Pollution Bulletin*, 191, 115113.
14. Ramesh Kumar, K., et al. (2022). Microplastics in soils and terrestrial ecosystems: Sources, impacts, and fate. *Environmental Pollution*, 306, 119486.
15. Pastorino, P., et al. (2023). Microplastics and human health: Pathways, bioaccumulation, and toxicological effects. *Science of the Total Environment*, 879, 162333.
16. Barboza, L. G. A., et al. (2018). Marine microplastic debris: An emerging issue for food security and human health. *Marine Pollution Bulletin*, 133, 336–348.
17. Oliveira, M., et al. (2019). Ecotoxicological implications of microplastic pollution: A review of recent findings. *Environmental Research*, 172, 137–145.
18. Burgos-Aceves, M. A., et al. (2021). Impact of plasticizers and microplastic additives on aquatic invertebrate immunity. *Journal of Hazardous Materials*, 419, 126426.
19. Murphy, F., Ewins, C., Carbonnier, F., Quinn, B., "Wastewater Treatment Works as a Source of Microplastics in the Aquatic Environment," *Environ. Sci. Technol.* 2016.
20. UNEP, "End plastic pollution: Towards an international legally binding instrument," Draft resolution, 2022.
21. Rellan, A.G., et al., "Sources, Sinks and Transformations of Plastics in Our Oceans: Review, Management Strategies, and Modelling," *Sci. Total Environ.* 2023.
22. Prata, J.C., et al., "Environmental Exposure to Microplastics: An Overview on Possible Human Health Effects," *Sci. Total Environ.* 2020.



Chandrama Basu *et al.*,

23. Jones, J.B., et al., "Methanogenesis in Arizona, USA dryland streams," Biogeochemistry 31, 155-173
24. Oliveira, M., Almeida, M., Miguel, I., "A micro(nano)plastic boomerang tale: A never-ending story?" TrAC, Trends Anal. Chem. 112, 196-200.
25. Burton, G.A., "White Paper: Microplastics in Aquatic Systems, An Assessment of Risk," Water Environment Reuse Foundation, Alexandria.
26. Yang, H., Chen, G., Wang, J., "Microplastics in the Marine Environment: Sources, Fates, Impacts and Microbial Degradation," Toxics 2021, 9, 41.
27. Praveena, S.M., Laohaprapanon, S., "Quality Assessment for Methodological Aspects of Microplastics Analysis in Bottled Water: A Critical Review," Food Control 2021, 130, 108285.
28. Microplastics in Fish and Fishery Products and Risks for Human Health: A Review by Leonardo Alberghini ¹, Alessandro Truant¹, Serena Santoni cola Giampaolo Colavita and Valerio Giaccone
29. <https://www.mdpi.com/1660-4601/20/1/789>
30. Chemicals sorbed to environmental microplastics are toxic to early life stages of aquatic organisms panelBettie Cormier ^{a b}, Chiara Gambardella ^c, Tania Tato ^d, Quentin Perdriat ^a, Elisa Costa ^c, Cloé Veclin ^e, Florian e Le Bihanic ^a, Bruno Grassl ^e, Florian Dubocq ^b, Anna Kärrman ^b, Kim Van Arkel ^f, Soazig Lemoine ^g, Fabienne Lagarde ^h, Bénédicte Morin ^a, Francesca Garaventa ^c, Marco Faimali ^c, Xavier Cousin ^{i j}, Marie-Laure Bégout ⁱ, Ricardo Beiras ^d, Jérôme Cachot
31. Mourya, Reenu and Gawande, Snehal and Kharat, Sanjay and Das, Nivedita, Microplastics: An Alarming Signal to Aquatic Ecosystem Increasing Oxidative Stress in Fishes.: <https://ssrn.com/abstract=4685688> or <http://dx.doi.org/10.2139/ssrn.4685688>
32. Asif raza, Mohd Fahad Zaki khan, "microplastics in freshwater systems: a review on its accumulation and effects on fishes", ijar - international journal of research and analytical reviews (ijar), e-issn 2348-1269, p- issn 2349-5138, volume.5, issue 4, page no pp.128-140, October 2018, available at : <http://www.ijar.org/ijar1904519.pdf>
33. Hazards of microplastics exposure to liver function in fishes Yu Sun ^{a b}, Qingfang Deng ^{a b}, Qiurong Zhang ^{a b}, Xin Zhou ^{a b}, Ruhai Chen ^{a b}, Siyu Li ^{a b}, Qing Wu ^{a c}, Huaguo Chen
34. Microplastics bioaccumulation in fish: Its potential toxic effects on hematology, immune response, neurotoxicity, oxidative stress, growth, and reproductive dysfunction Author links open overlay panelTapas Ghosh ^a
35. Chapter 8 - Microplastics contamination in marine system

Table 1. Biochemical parameters of zebrafish exposed to PS-MPs (1 mg/L) for 96 h.

Parameter	Control Group	Exposed Group	% Change
AChE activity (U/mg protein)	5.4	3.1	-42.5%
LPO (nmol MDA/mg protein)	2.3	4.9	+113%
ROS level (a.u.)	1.0	2.4	+140%

Table 2. Enzymatic response in zebrafish after 3-week exposure to LDPE and cadmium .

Biomarker	Control	LDPE + Cd	% Change
SOD activity (U/mg)	18.2	10.1	-44.5%
GSH content (μmol/g)	8.3	5.2	-37.3%
ROS generation (a.u.)	1.2	3.6	+200%

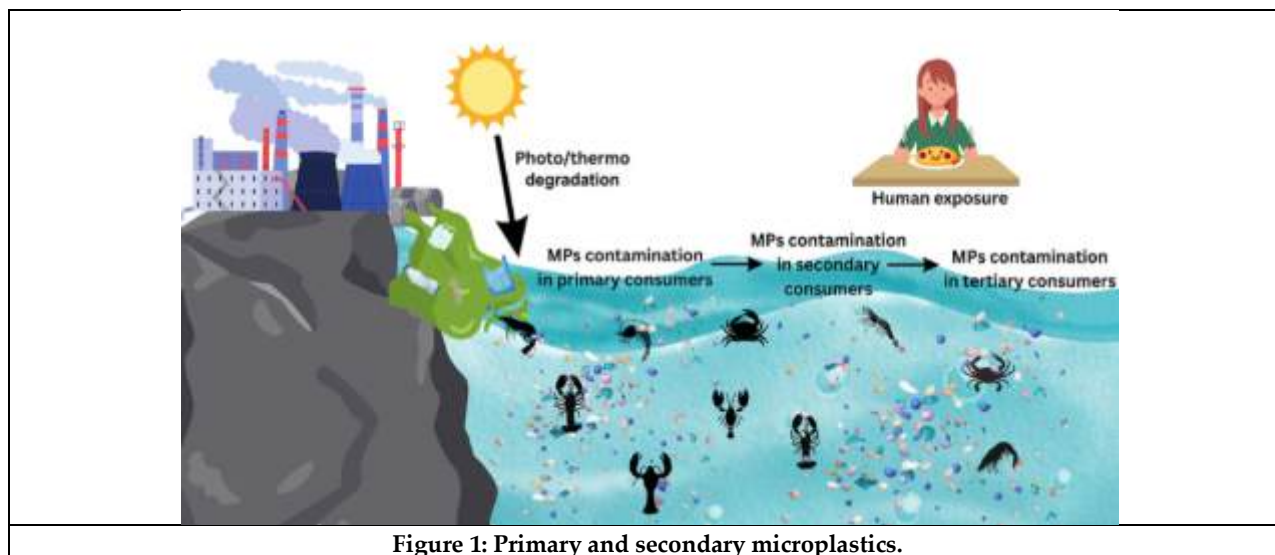
Table 3. Blood biochemical profile of *Sparus aurata* after exposure to PE-MPs (0.1 mg/L)

Parameter	Control	Exposed	% Change
Triglycerides (mg/dL)	120	155	+29%
Cholesterol (mg/dL)	190	250	+31%
Total protein (g/dL)	6.2	5.1	-17%
SOD activity (U/mg)	20.5	29.8	+45%



Chandrama Basu *et al.*,**Table 4. Hormonal and gene expression changes in zebrafish after combined exposure**

Parameter	Control	PS-MP + 17 α -MT	% Change
Testosterone (ng/mL)	5.2	3.4	-35%
Estradiol (pg/mL)	380	228	-40%
cyp19a1a (fold change)	1.00	0.41	-59%

**Figure 1: Primary and secondary microplastics.**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

An Experimental Study on the use of Waste Glass Powder in Bitumen for Flexible Pavements

Mohd Saud¹, Arvind Kumar^{2*}, Rizwan Khan², Zeenat Bee² and Awdhesh Kumar²

¹M.Tech. (CE) Student, Department of Civil Engineering, Invertis University, Bareilly, Uttar Pradesh, India

²Assistant Professor, Department of Civil Engineering, Invertis University, Bareilly, Uttar Pradesh, India

Received: 11 Mar 2026

Revised: 25 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

Arvind Kumar

Assistant Professor,
Department of Civil Engineering,
Invertis University, Bareilly,
Uttar Pradesh, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Due to rapid industrialization and urbanization, there has been a significant growth of the waste glass production resulting in great environmental and disposal problems because of its non-biodegradable properties. At the same time, flexible pavements demand better materials to increase the strength, durability, and resistance to the load of traffic and temperature changes. In this research, the researcher examines the possibility of using waste glass powder (WGP) as a partial substitute of traditional mineral filler in flexible pavement construction bituminous mixes. The waste glass that was acquired as a result of discarded glass materials underwent washing, crushing, and grinding into fine powder under 75-micron sieve. VG-40 grade bitumen was used to add the glass powder by the replacement levels of 5, 10, 15, and 20. The laboratory tests such as penetration, softening point, ductility, flash and fire point tests and stripping value tests were conducted to assess binder characteristics and the aggregate impact tests, crushing tests and abrasion tests were conducted to check the suitability of the aggregate. Marshall Stability and flow tests had been conducted to estimate the strength characteristics of the mixes. The experiments have shown that waste glass powder enhances stability, stiffness, and moisture resistance and does not reduce the flexibility significantly. The optimum replacement level was observed at 15%. The research supports the hypothesis that waste glass powder could be used as a reliable and environmentally friendly and sustainable material in the construction of flexible pavements.

Keywords: Waste glass powder, VG-40 bitumen, flexible pavement, Marshall stability, sustainable construction



**Mohd Saud et al.,**

INTRODUCTION

The rapid industrialization and urbanization has contributed to the rapid increase in the production of solid waste materials in the globe with waste glass being one of the major environmental issues. Glass products like bottles, window panels, containers, and electronic components have a wide usage because they are durable, as well as, chemical stable. Nevertheless, the same properties render glass non-biodegradable thus posing great disposal challenges when they are deposited in landfills. The amount of waste glass is also very high and it is a waste product that takes up a lot of space in the landfills and this adds to the degradation of the environment. Glass recycling consumes a lot of energy and complex facilities that are not necessarily economically viable. As a result, there have been other ways of utilizing waste glass effectively, and this has emerged as a research field of interest. Simultaneously, flexible pavements experience ever-growing traffic loads, intense pressure of axles, and changes in temperature that further accelerate the weakening of pavements. Traditional bituminous mixes usually suffer problems of rutting, fatigue cracking, bleeding and moisture damage that lead to loss of service life and high maintenance. The use of waste products in the construction of pavements has thus been seen as a sustainable strategy with the intention of enhancing the performance of pavements as well as dealing with the issue of the environment.

Bituminous mixtures rely on aggregates, binder and mineral fillers in realizing stability and durability. Mineral fillers are important in enhancing bonding of aggregates and bitumen, decreasing air vacuity, and augmenting asphalt mix stiffness. The glass wastes collected by means of crushing and grinding of the discarded glass glasses contain high silica content and angular particles structure that qualifies them to be used as filler materials in the mix of bituminous products. Waste glass powder can be utilized to offer a good potential in substituting the traditional filler materials like limestone dust and save on natural resources. Fine particles of glass may be added to enhance the density and deformation resistance of the mixtures through enhanced interlocking of the particles, as well as, enhanced interaction between the particles and the binder. The utilization of these environmental friendly materials aids in the development of infrastructure that is eco-friendly and helps in the practice of the circular economy through the conversion of the waste into quality construction materials.

Past research has conducted studies into the possibility of using waste glass either as an aggregate or as filler in the asphalt mixtures. Preliminary researchers showed that the particles of crushed glass can be successfully incorporated into asphalt concrete without substantial impact on workability and compaction properties. Abu Salem et al. (2017) claimed that angular form and hardness of the glass particles provided the asphalt mixtures with waste glass with better skid resistance and durability. In the work, it was also noted that a moderate content of glass positively interacted with the stability of the Marshall without compromising the acceptable flow values. The same observations have been made by Su and Chen (2002) who established that the strength of a mixture and the resistance to permanent deformation was enhanced by replacement of fine aggregates partially by waste glass provided good gradation is ensured. A study by Jony et al. (2011) has identified the possibility of using glass powder as mineral filler in asphalt mixtures with evidence of a significant increase in stability and load-bearing capacity. The fillers activity was noted to be increased due to fine particle size of glass powder that was used which was known to promote bonding of aggregates and the binder. Phan et al. (2024) researched the mixtures of asphalt with different proportions of waste glass and stated that the mixtures with about 15 percent of glasses in them performed best in terms of stability and volumetric characteristics. Similar outcomes were achieved by Khater et al. (2021), who noted an increase in fatigue resistance and a decrease in deformation under repeated loading conditions because of the rigidity of glass particles.

The additional research gave a stress on the ecological advantages of using glasses in pavements. In another study, Bilgen and Altuntas (2022) showed that waste glass reuse greatly decreases the landfill disposal and reduces the extraction of the natural aggregates to a minimum. According to Ming et al. (2022), glass powder filler increases resistance to rutting and stiffness properties of asphalt mixtures in the high-temperature condition. Research works



**Mohd Saud et al.,**

on waste glass controlled incorporation also by Moreno-Navarro et al. (2015) proved that using waste glass to enhance the mechanical strength and long-term durability of flexible pavements and lowering construction costs. Although positive results concerning the benefits are cited, scientists have found some flaws in the form of the high level of glass. Anochie-Boateng and George (2016) have also provided similar results and stated that an overabundance of glass powder might adversely affect the cohesion and stability of mixtures. These observations indicate the significance in establishing an optimum level of replacement in order to have a balanced mechanical performance.

Recent research has been oriented towards enhancement of moisture resistance and serviceability properties of glass modified asphalt mixtures. Grinys et al. (2021) indicated that appropriately graded glass powder filler can be used to increase stripping resistance and durability at specific controlled limits. Simone et al. (2017) affirmed that the asphalt mixtures with waste glass powder had satisfactory volumetric and mechanical requirements that could be applied in pavements. The review studies by Nandal et al. (2023) and Lee et al. (2023) concluded that recycled glass materials have a high potential of sustainable construction of pavements with regard to their mechanical strength, chemical inertness, and broad availability.

The overall summaries of the past studies point out that the waste glass powder could be utilized in the form of an alternative filler material in the flexible pavements which would help enhance the strength, stiffness and environmental sustainability. There is however a great dependence on the characteristics of performance based on the distribution of particle sizes, replacement percent, and reaction with the bitumen binder. There is also a dearth of experimental research on the behavior of VG-40 grade bitumen that is modified with waste glass powder under different degrees of replacement, especially when subjected to conditions that emulate heavy traffic conditions and in the conditions of high temperature. Consequently, there is a need to conduct systematic investigation of waste glass powder by laboratory experts to determine its effect on the physical and mechanical characteristics of bituminous mixtures and the best content which can be used in the construction of flexible pavement. The primary goal of the paper is to assess the appropriateness of waste glass powder as a sustainable substance in bituminous mixtures in pavements construction of flexible pavements. The following are the particular objectives of the study:

- To investigate the impact on physical and performance properties of VG-40 grade bitumen of waste glass powder.
- To examine how the various percentages of waste glass powder (5, 10, 15 and 20) affect the properties of the bituminous mixtures in terms of strength.
- To establish the variation in the penetration, softening point, ductility, flash and fire point, and stripping resistance of modified bitumen.
- To determine the most ideal content of the waste glass powder that gives the best stability, longevity and waterproofing.
- To enhance the use of waste glass materials in the construction of sustainable pavement and that which is environmentally friendly.

Materials Used

The materials applicable in this experimental study are VG-40 grade bitumen, waste glass powder and coarse aggregate, fine aggregates and mineral filler. The choice of all materials was made according to the standard specifications to make sure that the materials are appropriate to be used in the construction of flexible pavement.

Bitumen

The binding material used in this research was VG-40 grade bitumen because it is more viscous and works well with heavy traffic and high temperature. Bitumen is used as a binding substance that holds aggregates in place and gives the pavement construction the flexibility and strength. Penetration, softening point, ductility, flash point, and fire point tests were used in determining the physical characteristics of bitumen.



**Waste Glass Powder**

Glass waste was glass powder that had been discarded and glass bottles and window glass collected in the area. The glass waste, which was collected was rinsed to eliminate contaminants after which it was crushed and ground to fine powder. The sieved glass powder was passed through a sieve consisting of 75-micron diameter to get homogenous particle size that could be used as filler material. Glass powder waste was used on a partial basis of substitute of the conventional mineral filler at a percentage of 5, 10, 15 and 20 percent of the weight of the filler material. The angular shape of the glass particles and the high silica make the particles of the bituminous mix more rigid and stronger.

Coarse Aggregates

The coarse aggregates in the form of bituminous mixtures were prepared with crushed stone aggregates. The following aggregates offer strength, stability and load bearing capacity to pavements that are flexible. Aggregates that were properly graded were used to ensure that there was good interlocking and withstand to traffic loads. The Aggregate Impact Value, Aggregate Crushing Value, and Los Angeles Abrasion tests were done to ascertain the viability of the tests in pavement.

Fine Aggregates

The mix was filled with fine aggregates of natural sand that created the coarse aggregates density within the mix and also enhanced the overall mix density. The fine aggregates were dry and not organic in nature. Gradation of fine aggregates in a proper manner increases the workability, stability and bonding properties of the bituminous mixture.

Mineral Filler

The bituminous mix had conventional mineral filler, stone dust, and the wastage of glass powder. Filler materials are favourable in the enhancement of cohesion, reduction of air cavities, and the increase of the adhesion between the bitumen and the aggregates. It was conducted at a partial replacement of the mineral filler with waste glass powder to determine its effect on the pavement performance.

METHODOLOGY

The research methodology that will be used in this research experimental study aims at assessing the functionality of flexible pavements that use waste glass powder as a partial replacement of the traditional mineral filler. The experimental program was to prepare the material, prepare modified bituminous mixes, conduct laboratory tests and discuss results as per the specifications under Indian Standards. All the materials needed to complete the study including VG-40 grade bitumen, an aggregate, mineral filler, and waste glass powder were first collected and ready to be tested. Waste glass was collected on the discarded glass materials and it was cleaned to get rid of dust and impurities. The cleaned glass was broken and pulverized into minute powder and filtered through a 75-micron sieve to get evenly sized particles that can be used to replace fillers. Bituminous mixes were made by substituting the traditional filler mineral in different proportions of 5 percent, 10 percent, 15 percent and 20 percent by weight of filler material by waste glass powder. VG-40 bitumen was warmed at a temperature of about 160-170 °C in order to obtain the right fluidity to be mixed. To remove the moisture contents, the aggregates were heated individually to ensure homogenous mixing temperature. The filler material, waste glass powder and the heated aggregates were mixed in details and then hot bitumen was added and mixed thoroughly to get a homogeneous mixture of bituminous mixture.

Aggregates were also tested before the preparation of mixes to determine that they are suitable in the construction of pavements. Aggregate Impact Value Test, Aggregate Crushing Value Test, and Los Angeles Abrasion Test are some of the standard laboratory tests that were carried out to determine toughness, strength and wear resistance. Conventional and modified bitumen samples were then subjected to laboratory tests to ascertain the change of binder properties after waste glass powder was added. IS 1203:1978 was used to carry out the penetration test to ascertain the consistency of bitumen. Temperature susceptibility was determined by the softening point test by



**Mohd Saud et al.,**

the use of the ring and ball apparatus in accordance with the IS 1205:1978. The ductility test was conducted according to the requirements of the IS 1208:1978 to determine the flexibility qualities of the binder. To establish the thermal safety limit during heating processes, flash and fire point tests were done in accordance with IS 1209:1978. The stripping value test was used to test the moisture susceptibility of the mix as per IS 6241:1971. In order to test the strength properties of the bituminous mix, the Marshall Stability Test was performed. The standard specification compaction procedures were done to the cylindrical specimens, which were tested to ascertain the Marshall stability and flow values. These were the parameters that were applied to evaluate the load-bearing capacity, deformation resistance, and performance of the modified mixtures. Experimental results of both conventional and waste glass powder modified mixes obtained were made and compared systematically. The effect of different proportions of waste glass powder on strength, durability, flexible and moisture resistance was examined to find out the best replacement percentage proportions that can be applied to construct flexible pavement.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental study was made on the basis of the investigation of the performance of bituminous mixtures with waste glass powder (WGP) as the partial replacement of traditional mineral filler. Replacement was done with waste glass powder at 0%, 5%, 10%, 15%, and 20%. The findings of the aggregate analysis, bitumen tests, and Marshall Stability test are indicated below and discussed.

Aggregate Test Results

The overall effect figure of 17.8 percent means it is good against sudden impact loads availed by moving cars. Redder values of impact denote robust aggregates with the ability to support the dynamic stress of traffic. The aggregate crushing value of 22.1% elucidates adequate compressive power and carrying capacity needed by flexible pavements. Equally, the value of the abrasion of 24.5% shows that it has sufficient resistivity to wear and surface aggression due to movements in the road. As all the acquired values are within the acceptable limits of the Indian Standards, the aggregates that are acquired can be utilized in construction of pavements making the subsequent observations of the experiment reliable.

Penetration Test Results

With increasing contents of waste glass powder, there was a gradual reduction in the value of penetration. The 68-56 (0.1 mm) decrease implies that the bituminous binder on the increase of the stiffness. Waste glass powder is a fine filler which decreases the mobility of binder and increases internal resistance. The higher the stiffness, the better the resistance attributed to heavy traffic conditions in rutting and permanent deformation. Nevertheless, over-stiffness of higher replacement will lead to a loss of flexibility and susceptibility to cracking.

Softening Point Test Results

The softening temperature increased gradually with the increase in waste glass powder content, indicating improved resistance of the modified bitumen to softening at elevated temperatures. Higher softening point values suggest enhanced thermal stability of the binder, which may help reduce the susceptibility of pavements to bleeding and rutting under high-temperature conditions. This improvement indicates better performance of the binder in resisting deformation at elevated service temperatures.

Ductility Test Results

The values of ductility reduced as the content of glass powder increased because of higher rigidity of the modified mix. The decrease implies a constrained ability to elongate due to hard glass particles in the binder system. However, even with 15 percent replacement the ductility is acceptable and therefore offers enough flexibility to withstand stresses caused by the traffic without cracking.



**Flash and Fire Point Results**

There was an increase in the temperatures of flash and fire points with the addition of waste glass powder. A good thermal stability and safe handling properties of mixtures and building processes are shown by the increased ignition temperatures. Glass powder is inert, which reduces the volatilization of the lighter components of bitumen, and thus increases resistance to accidental ignition.

Stripping Value Test Results

The value of stripping and the content of glass powder waste declined substantially with the content of the waste powder, which implied that there was better adhesion among aggregates and between aggregates and the binder. Glass powder occupies the micro-voids in the mixture and improves the effectiveness of coating, thus minimizing moisture penetration. Better moisture resistance helps to bring increased durability of pavement and minimal maintenance.

Marshall Stability and Flow Results

The Marshall Stability values increased steadily up to 15% waste glass powder replacement, indicating an improvement in the load-carrying capacity of the asphalt mix. The presence of angular and rigid glass powder particles may contribute to better aggregate interlocking and increased internal resistance within the mix, resulting in higher stability values. Beyond 15% replacement, a slight reduction in Marshall Stability values was observed, which may be attributed to excessive filler content affecting proper binder coating and workability of the mix. The flow values remained within the specified limits of 2–4 mm, indicating acceptable deformation characteristics and adequate flexibility of the modified asphalt mixture.

The findings of the experiment demonstrate that addition of waste glass powder enhances greatly the stiffness, temperature resisting, adhesion as well as strength of bituminous mixtures. The maximum stability was obtained at 15 percent of replacement which gave balanced stability and flexibility application in flexible pavement.

Findings and Conclusion**Major Findings**

The experimental study was carried out to assess the performance of flexible pavement mixes with the usage of waste glass powder as a partial substitute of traditional mineral filler with the help of VG-40 grade bitumen. According to the laboratory test findings and other analytic observations, the following key findings were established:

- The aggregate test data met Indian Standard standards, as far as sufficient toughness, strength, and abrasion resistance are required to build flexible pavement.
- The penetration values declined with an increase in the content of waste glass powder and this situation implied that the binder was becoming stiffer and was becoming more resistant to the permanent deformation during loading under traffic.
- It was observed that the softening point of the bitumen increased as the quantity of waste glass powder was added and this showed greater resistance to high temperature conditions and lesser affinity to rutting.
- Ductility values were gradually decreasing with the increase of the content of the glass powder in the mixture because of higher rigidity of the modified binder; however, acceptable flexibility was ensured until 15 factor of replacement.
- Flash and fire point temperatures rose as waste glass powder was added, which implies that the waste glass powder is more stable in terms of thermal properties and can be safely handled during mixing and construction processes.
- The percentage of stripping was reduced with the addition of the glass powder, which confirmed the improvement of the adhesion between the aggregates and binder and resistance to the moisture damage.



**Mohd Saud et al.,**

- Increase in Marshall Stability: Adding powder of waste glass enhanced the Marshall Stability values significantly and the values were found to be maximum at 15 percent replacement and thus the load carrying capacity of the bituminous mix was improved.
- Flow values were kept within acceptable values, which proved that the modified mix was not overly deformed.

CONCLUSION

The current research shows that waste glass powder can be successfully used as an alternative filler material that should be applied to the flexible pavements as a sustainable one. Waste glass powder incorporation enhances the mechanical strength, thermal resistance and moisture durability of bituminous mixes compared to the traditional mixes. The stability and stiffness are also improved due to angularity of particles and high silica content of the waste glass powder, which makes the aggregate interlock with each other and the binder filler to interact. Higher values of softening point and lower values of penetration are signs of higher resistance to rutting and deformation of heavy traffic and high-temperature conditions. The enhanced adhesion properties also add to the increased service life, which is delivered by pavements, since stripping and failures caused by moisture are reduced.

Out of the various replacement levels that were evaluated, 15% waste glass powder replacement was determined as the most appropriate content, and it offered the right balance of power, elasticity and longevity. The replacement over and above this level led to a marginal decrease in stability through too much filler content in terms of workability and coating of binders. Besides the benefits to performance, the use of waste glass powder is also characterized by important environmental benefits in terms of decreased landfill disposal, less use of natural filler materials, and the development of sustainable infrastructure. Thus, it can be stated that the use of waste glass powder modified bituminous mixes is recommendable in the use of flexible pavement especially in areas that are exposed to heavy traffic and high temperatures.

REFERENCES

1. Abendeh, R. (2017). Effect of waste glass on properties of asphalt concrete mixtures. *ResearchGate*. https://www.researchgate.net/publication/325430398_Effect_of_Waste_Glass_on_Properties_of_Asphalt_Concrete_Mixtures
2. Su, N., & Chen, J. (2002). Engineering properties of asphalt concrete made with recycled glass. *Resources Conservation and Recycling*, 35(4), 259–274. [https://doi.org/10.1016/s0921-3449\(02\)00007-1](https://doi.org/10.1016/s0921-3449(02)00007-1)
3. Jony, H., Jahad, I. Y., & Al-Rubaie, M. F. (2011). *The effect of using glass powder filler on hot asphalt concrete mixtures properties*. <https://www.semanticscholar.org/paper/The-Effect-of-Using-Glass-Powder-Filler-on-Hot-Jony-Jahad/b44c42c1d7b9761a815740e1fd278a04ba3c70c4>
4. Phan, T. M., Kang, S., Vo, H. V., & Park, D. (2024). Evaluation on performances of cold asphalt mixture containing recycled waste glass and red mud. *Case Studies in Construction Materials*, 20, e03194. <https://doi.org/10.1016/j.cscm.2024.e03194>
5. Khater, A., Luo, D., Abdelsalam, M., Yue, Y., Hou, Y., & Ghazy, M. (2021). Laboratory evaluation of asphalt mixture performance using composite admixtures of lignin and glass fibers. *Applied Sciences*, 11(1), 364. <https://doi.org/10.3390/app11010364>
6. Bilgen, G., & Altuntas, O. F. (2022). Sustainable re-use of waste glass, cement and lime treated dredged material as pavement material. *Case Studies in Construction Materials*, 18, e01815. <https://doi.org/10.1016/j.cscm.2022.e01815>
7. Ming, N. C., Jaya, R. P., Awang, H., Ing, N. L. S., Hasan, M. R. M., & Al-Saffar, Z. H. (2022). Performance of glass powder as bitumen modifier in hot mix asphalt. *Physics and Chemistry of the Earth Parts a/B/C*, 128, 103263. <https://doi.org/10.1016/j.pce.2022.103263>





Mohd Saud et al.,

8. Moreno-Navarro, F., Pérez-Martínez, M., Martín-Marín, J., Sol-Sánchez, M., & Del Carmen Rubio-Gámez, M. (2015). Mechanical performance of asphalt mixes incorporating waste glass. *The Baltic Journal of Road and Bridge Engineering*, 10(3), 255–261. <https://doi.org/10.3846/bjrbe.2015.32>
9. Anochie-Boateng, J., & George, T. (2016). Use of waste crushed glass for the production of Hot-Mix asphalt. *Sustainable Construction Materials and Technologies*, 1, 573–582. <https://doi.org/10.18552/2016/scmt4s198>
10. Grinys, A., Balamurugan, M., Augonis, A., & Ivanauskas, E. (2021). Mechanical properties and durability of rubberized and glass powder modified rubberized concrete for whitetopping structures. *Materials*, 14(9), 2321. <https://doi.org/10.3390/ma14092321>
11. Simone, A., Mazzotta, F., Eskandarsefat, S., Sangiorgi, C., Vignali, V., Lantieri, C., & Dondi, G. (2017). Experimental application of waste glass powder filler in recycled dense-graded asphalt mixtures. *Road Materials and Pavement Design*, 20(3), 592–607. <https://doi.org/10.1080/14680629.2017.1407818>
12. Nandal, M., Sood, H., & Gupta, P. K. (2023). A review study on sustainable utilisation of waste in bituminous layers of flexible pavement. *Case Studies in Construction Materials*, 19, e02525. <https://doi.org/10.1016/j.cscm.2023.e02525>
13. Lee, S., Kim, K., Yun, Y., & Le, T. H. M. (2023). Evaluation of eco-friendly asphalt mixtures incorporating waste plastic aggregates and additives: Magnesium, fly ash, and steel slag. *Case Studies in Construction Materials*, 20, e02756. <https://doi.org/10.1016/j.cscm.2023.e02756>

Table 1 - Aggregate Properties

Test	Test Result (%)	IS Permissible Limit
Aggregate Impact Value	17.8	< 24
Aggregate Crushing Value	22.1	< 30
Los Angeles Abrasion Value	24.5	< 30

Table.2 - Penetration Values

WGP Content (%)	Penetration (0.1 mm)
0	68
5	65
10	62
15	59
20	56

Table.3 - Softening Point Values

WGP Content (%)	Softening Point (°C)
0	49
5	51
10	53
15	56
20	58

Table 4 - Ductility Values

WGP Content (%)	Ductility (cm)
0	78
5	72
10	66
15	60
20	52



Mohd Saud *et al.*,**Table 5 - Flash and Fire Point Values**

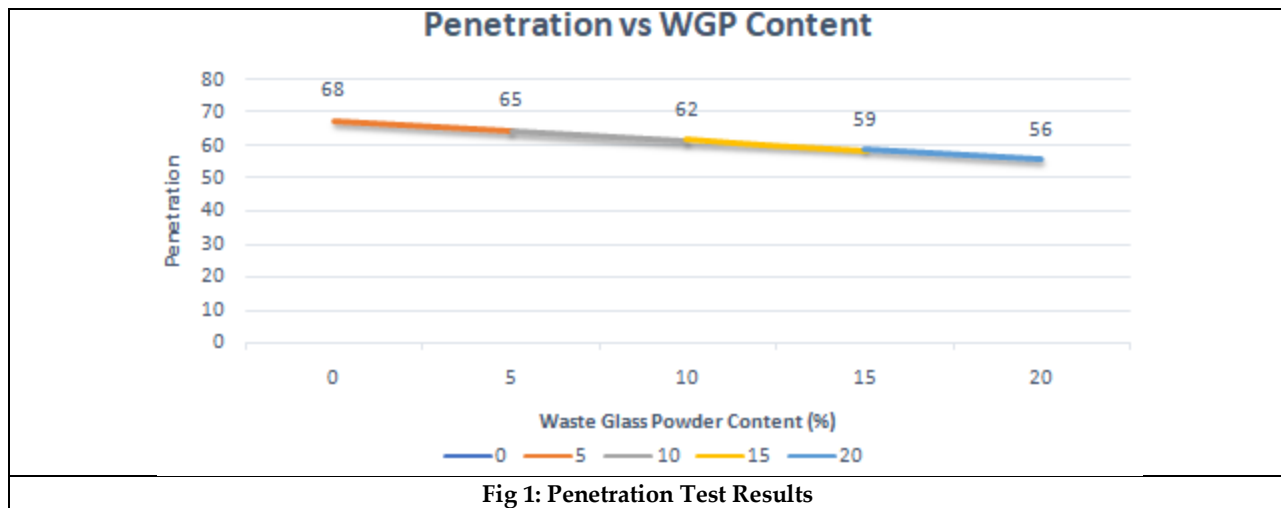
WGP Content (%)	Flash Point (°C)	Fire Point (°C)
0	232	245
5	236	250
10	241	256
15	247	262
20	252	268

Table 6 - Stripping Value

WGP Content (%)	Stripping Value (%)
0	8
5	6
10	4
15	3
20	3

Table 7 - Marshall Stability and Flow Values

WGP (%)	Stability (kN)	Flow (mm)
0	9.8	3.6
5	11.2	3.4
10	12.6	3.2
15	13.9	3.1
20	12.8	3.5





Mohd Saud et al.,

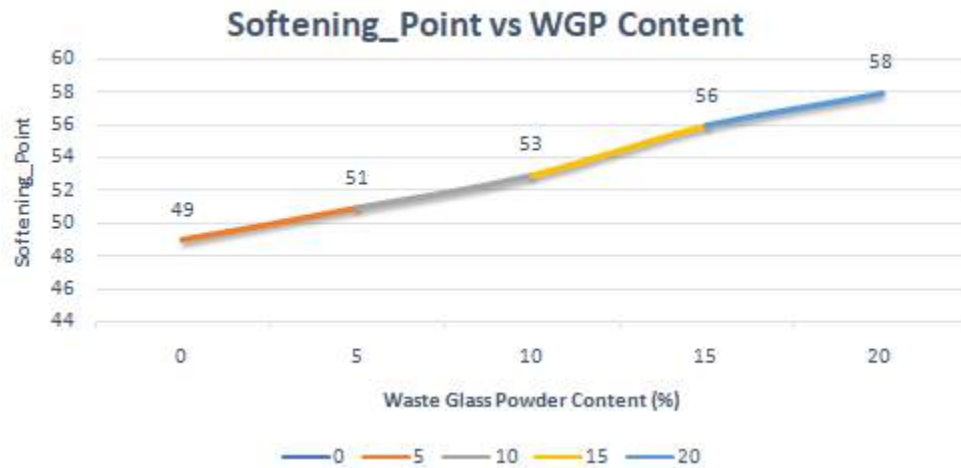


Fig 2: Softening Point Test Results

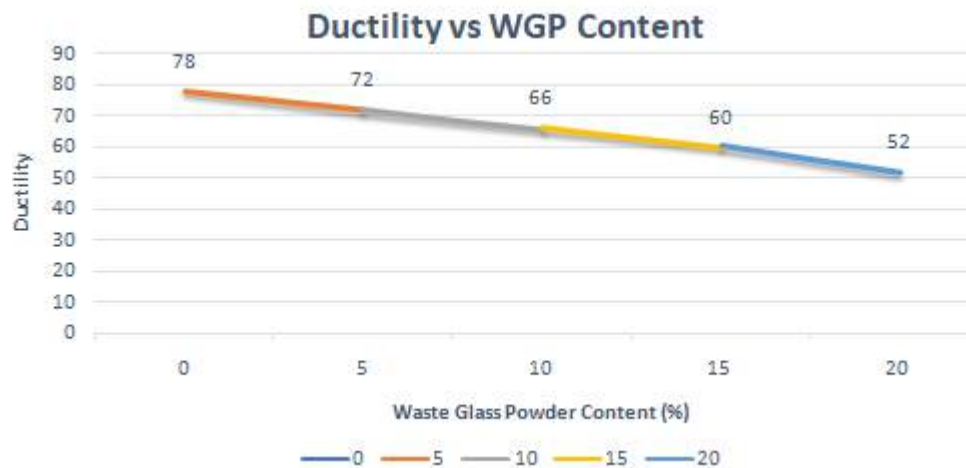
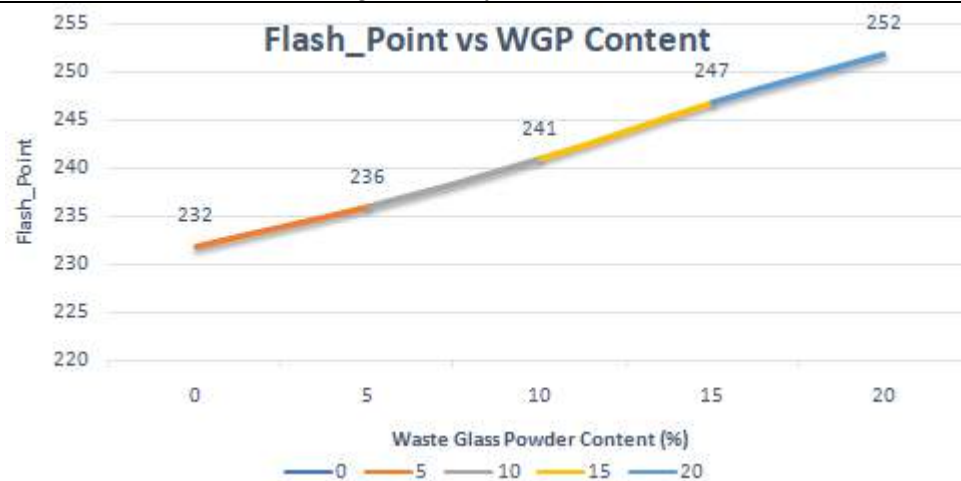


Fig 3: Ductility Test Results





Mohd Saud et al.,

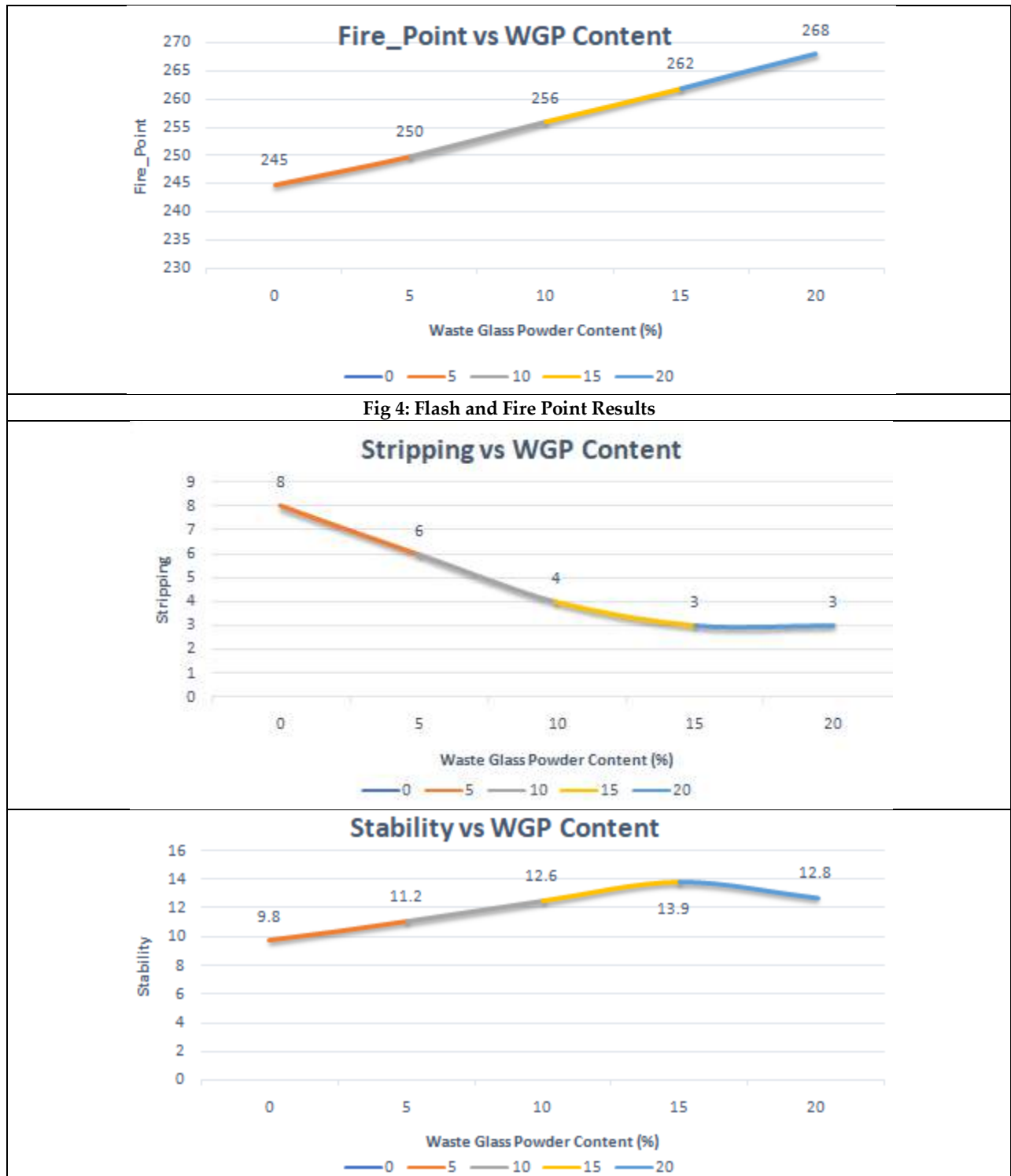
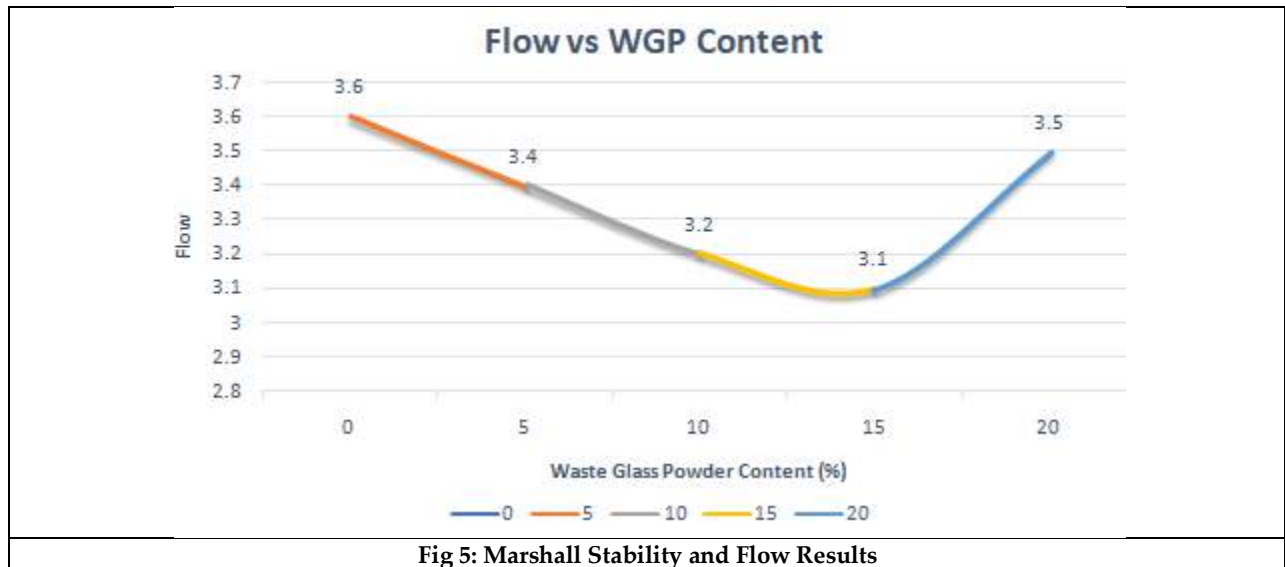


Fig 4: Flash and Fire Point Results



**Mohd Saud et al.,**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Effectiveness of Median Nerve Mobilization on Hand Grip Strength, Pinch Strength and Median Nerve Conduction Velocity among College Students with Smartphone Overuse : A Two Group Pre-Test Post-Test Randomised Controlled Trial Study Protocol

Shahrukh Ansari^{1*} and Kanika²

¹MPT Student, Department of Physiotherapy, Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana- Ambala, Haryana, India.

²Assistant Professor, Department of Physiotherapy, Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana - Ambala, Haryana, India

Received: 12 Mar 2026

Revised: 20 Apr 2026

Accepted: 26 May 2026

*Address for Correspondence

Shahrukh Ansari

MPT Student,

Department of Physiotherapy,

Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation,

Maharishi Markandeshwar (Deemed to be University),

Mullana- Ambala, Haryana, India

E.Mail: srkmmmdumulana@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Background: Excessive smart phone use has been associated with altered upper-limb function, including decreased hand grip strength, pinch strength and motor nerve conduction velocity of median nerve due to repetitive stress on the median nerve. Median nerve mobilization is a therapeutic technique that may improve nerve function. To evaluate the effectiveness of median nerve mobilization in improving hand grip strength, pinch strength, and median nerve conduction velocity among college students with smart phone use. Two-group pre-test- post-test randomised controlled trial. College students aged 18 to 30 years who use smart phones for more than 3.5 hours per day will be recruited and randomized into experimental and control groups. The experimental group will receive median nerve mobilization using ULTT1-based sliding and tensioning techniques, while the control group will receive stretching and strengthening exercises. The intervention will be delivered three times per week for four weeks. Outcomes will be assessed at baseline and after four weeks. Data will be analysed using SPSS. Normality will be checked using the Shapiro-Wilk test. Depending on the distribution, paired t-test or Wilcoxon signed-rank test will be used for within-group comparison, and independent t-test or Mann-Whitney U



**Shahrukh Ansari and Kanika**

test will be used for between-group comparison. A p-value of less than 0.05 will be considered statistically significant.

Keywords: Median nerve mobilization, hand grip strength, pinch strength, median nerve conduction velocity, smart phone usage, randomized controlled trial.

INTRODUCTION

The median nerve is one of the major mixed peripheral nerves of the upper limb and a key player in hand function, during the control of fine object manipulation, both at the sensory and motor levels. In fact, during effective manipulation, the motor mechanisms to regulate the hand's muscles and the sensory mechanisms related to the fingers' investigations work closely¹⁻². Kinetic chain principles say to the upper limb is composed of up of related segments which coordinate to carry out daily tasks. Put differently, a broad muscle weakness and resulting decrease grip strength would result from muscle weakness generated in one area of the afflicted upper arm³. The hand's capability to grip and move objects are essential for daily life, and specific professions require sustained handgrip strength, that is linked to several illnesses. A valid and reliable handgrip strength assessment is used to specify treatment measures, examine the performance of various techniques, and assess patient functionality⁴⁻⁵. The use of mobile devices particularly smartphones for internet browsing and communication has greatly raised through the past 10 years.

The price of these devices continues to drop, which suggests that more people will use smartphones. Overuse of cell phones has been linked to physical health issues like neck and wrist pain⁶⁻⁷. Over the past few years, the number of individuals using cell phones has steadily increased. It was predicted that there would be 3.5 billion smartphone users worldwide in 2020, a 9.3% increase over 2019⁸. It has also been reported by numerous surveys that the bulk of smartphone users worldwide are younger adults. As indicated by study findings, 50% of teenagers become addicted to their smartphones because of the rise in smartphone usage. Even though cell phones are made to be used with both hands, young people prefer to use them one-handed. A clear influence is observed the usage of smartphones has increased and report in the general clinical literature suggest a connection between using handheld device and upper extremity, which is consistent with the rise in smartphone use⁹. the excessive use of smartphone has been linked to trauma illnesses affecting the wrist ,shoulder ,hand ,neck. It was shown that university students used their smartphones for an average of more than 3.5 hours per day, and that this was associated by thumb base pain.¹⁰Clinical guidelines suggest median nerve mobilization and ncv however, high-quality trials evaluating median nerve mobilization are limited.⁶This study aims to assess median nerve mobilization is improving hand grip strength, pinch strength, and motor nerve conduction velocity of the median nerve among college students with excessive smartphone use.

MATERIALS AND METHODS

Study design

Study Design Parallel design, two – group, pre-test post-test randomized controlled trial

Recruitment and allocation

Recommendations for Interventional Trials (SPIRIT) guidelines will be followed to conduct the trial¹¹. The results obtained from the trial will be written using the CONSolidated Standards of Reporting Trials for non-pharmacological trials (Modified CONSORT) checklist and the template for intervention, description, and replication (TIDieR). Outcome measurements will be taken at baseline and after completion of intervention at 4 week. The schematic Consolidated Standards of Reporting Trials flow chart for the study protocol is shown in Figure.1.



**Study setting**

The study will be conducted at Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Mullana, Ambala, Haryana, India.

Study Population

College students with smartphone overuse will be screened for eligibility.

Ethical considerations

The study has been registered with the Clinical Trials Registry of India (CTRI/2025/07/091673) and this study has been approved by the Institutional Ethics Committee (IEC-3448). All procedures will be conducted in strict accordance with the National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (Indian Council of Medical Research), the principles of the Declaration of Helsinki (World Medical Association), and the International Ethical Guidelines for Health-Related Research Involving Humans (2017 revision, Council for International Organizations of Medical Sciences). Written informed consent will be obtained from all participants prior to enrolment, and confidentiality of their data will be ensured throughout the study.¹²

Sample Selection**Inclusion criteria**

- Individuals with high smartphone usage (e.g., using smartphones for > 3.5 hours per day).
- Both male and female college students aged 18 to 30 years
- Individuals with hand grip strength < 27 kg (both males and females)
- Individuals with hand pinch strength < 21.1 lbs for men and < 13.4 lbs for female
- Individuals with motor nerve conduction velocity of median nerve < 49 m/s for males and < 53 m/s for females.

Exclusion criteria

- Individuals with a history of wrist, hand, or forearm injury or surgery in the past 6 months.
- Participants diagnosed with any neurological disorders affecting hand or wrist function (e.g., peripheral neuropathy, carpal tunnel syndrome).
- Presence of any systemic musculoskeletal conditions (e.g., rheumatoid arthritis) that may influence hand function.
- Participants who have undergone recent physical therapy or nerve mobilization for hand or wrist issues within the past 3 months.

Hypothesis**Null Hypothesis (H0)**

The Median Nerve Mobilization will not have a significant effect on Hand Grip Strength, pinch strength and median nerve conduction velocity among college going students with smartphone overuse.

Alternate Hypothesis (H1)

The Median Nerve Mobilization will have a significant effect on Hand Grip Strength, pinch strength and motor median nerve conduction velocity among college going students with smartphone overuse.

Variables**Independent variables**

- Median nerve mobilization

Dependent variables

- Hand-grip strength
- Pinch strength
- Nerve conduction velocity
- Smartphone addiction scale



**Randomization and blinding**

Participants will be randomly divided into two groups: EG (N = 20) and CG (N = 20) using the manual block randomization method. The randomization scheme will be based on a block randomization procedure, and participants will be allocated to either an experimental group or a control group. Figure. 1 As the sample size of this study is 40, therefore, Participants will be randomized using block randomization with a block size of 4 and 1:1 allocation ratio in Figure. 2. Allocation concealment will be maintained using sequentially numbered opaque sealed envelopes (SNOSE)

Intervention

Participants will be divided into two groups: EG and CG. EG will be treated with nerve sliding and tensioning techniques and CG will be treated with Stretching and Strengthening Exercises. The treatment will be given over four weeks by a trained physiotherapist. Sessions are conducted three times per week, each lasting 15 minutes, for a total of 12 sessions.

Intervention for the experimental group (EG)

Patients lay supine with the shoulder abducted to 90° and externally rotated, elbow extended, forearm supinated, wrist, fingers, and thumb extended, and the head positioned for cervical lateral flexion away from the treated arm.¹³ Weeks 1–2, nerve sliding involves alternating wrist/finger extension with cervical side flexion to promote median nerve excursion, performed rhythmically for 2 sets of 10–15 pain-free repetitions.¹⁴ In weeks 3–4, nerve tensioning aims to improve nerve compliance, with cervical lateral flexion maintained and end-range stretch applied at the wrist and fingers for 2 sets of 8–10 repetitions, holding 3–5 seconds per repetition, and discontinued if symptoms worsen.¹⁴

Intervention for the control group (CG)**Stretching Exercises**

(Perform 1–2 times daily; hold each stretch 15–20 seconds, repeat 2–3 times.)

Wrist flexor stretch: Arm straight, palm up, gently pull fingers down/back with other hand.

Wrist extensor stretch: Arm straight, palm down, and gently pull fingers inward/down.

Thumb stretch: Pull thumb gently back away from palm.

Forearm pronation/supination stretch: Slowly rotate palm up and down while elbow flexed 90°. ¹⁵⁻¹⁶

Strengthening Exercises

(Do 3–4 times per week, 8–12 repetitions each, and 2–3 sets.)

Grip strengthening: Use a soft ball or therapy putty, squeeze and hold 3–5 seconds.

Pinch strengthening: Pinch a soft ball/putty between thumb and fingers.

Wrist curls (flexion & extension): Use light weight (0.5–1 kg) or water bottle. ¹⁵⁻¹⁶

Outcome Measures**Hand-grip strength**

A handheld dynamometer is a portable device used for measuring muscle strength, especially grip strength in the hand and forearm, and is widely applied in clinical, sport, and rehabilitation settings. It typically includes adjustable grip handles, a force display, a reset button, and sometimes a digital interface. Standard use involves seating the patient upright with the elbow at 90° and forearm neutral, adjusting the handle for comfort, and instructing the patient to squeeze for 3–5 seconds. Usually, three trials per hand are performed, with brief rests, and the best or average reading is recorded.¹⁵

Pinch strength

A pinch dynamometer is a handheld device that measures pinch strength between the thumb and fingers. The patient sits with the arm at the side, elbow at 90°, and wrist neutral using tip, lateral, or three-jaw chuck grip, they squeeze as hard as possible for three trials, with the best or average value is recorded.¹⁵



**Nerve conduction velocity**

Nerve Conduction Velocity (NCV) measures the speed of electrical signals along peripheral nerves to assess their function. Electrodes are used to stimulate and record the nerve of two different points, and NCV is calculated as the distance between two stimulation points divided by the time taken for the impulse to travel. Normal motor nerve values are about 50-60 m/s.¹⁷

Smartphone addiction scale

The Smartphone Addiction Scale (SAS) is a standardized self-reported questionnaire used to assess the level of smartphone addiction in individuals. Originally developed by Min Kwon et al. (2013), the SAS has been widely employed in clinical and research settings. The scale consists of 33 items; each rated on a 6-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree). The total score ranges from 33 to 198, with higher scores indicate greater level of smartphone addiction.⁸

Statistical Analysis Plan

Data will be analyzed using Statistical Package for the Social Sciences (SPSS) version 20.0. The normality of the data will be assessed using the Shapiro–Wilk test, as the sample size is less than 50. Descriptive statistics will be used to summarize demographic variables and outcome measures (mean $\pm$ standard deviation for continuous variables and frequency/percentage for categorical variables). For baseline comparison between groups, an independent t-test (for normally distributed data) or Mann–Whitney U test (for non-normally distributed data) will be applied. For within-group comparison (pre- and post-intervention), a paired t-test (for normally distributed data) or Wilcoxon signed-rank test (for non-normally distributed data) will be used. For between-group comparison of treatment effects, the mean change scores (post-intervention minus pre-intervention values) will be calculated and compared using an independent t-test or Mann–Whitney U test, depending on data normality. A p-value of less than 0.05 will be considered statistically significant.

Risk and Safety

The intervention used in this study is considered low risk, as it involves non-invasive physiotherapy techniques commonly used in clinical practice. However, participants may experience mild discomfort, stretching sensation, or temporary soreness during or after the intervention. All procedures will be performed under the supervision of a qualified physiotherapist to ensure safety. Participants will be closely monitored throughout the study for any adverse events. In case of any unusual symptoms or discomfort, participants will be advised to report immediately to the researcher, and appropriate action will be taken. Participants will also have the right to withdraw from the study at any point without any consequences. All necessary precautions will be taken to minimize risk and ensure participant safety throughout the study duration.

DISCUSSION

Excessive smartphone use has been associated with repetitive strain injuries, including pain and dysfunction in the wrist and hand. These issues are often attributed to prolonged gripping, repetitive thumb movements, and sustained awkward postures during smartphone use, which may lead to increased mechanical stress on the median nerve and restrict its normal mobility.^{9,10} Median nerve mobilization is a neurodynamic intervention aimed at restoring nerve mobility and improving physiological function. It is hypothesized that this technique may enhance axoplasmic flow and intraneural blood circulation, thereby reducing adhesions and improving overall nerve function.¹⁸⁻¹⁹ It is expected that improvements in hand grip strength and pinch strength may reflect enhanced neuromuscular efficiency, possibly due to improved motor unit recruitment and reduced neural inhibition.² Similarly, improvements in median nerve conduction velocity may indicate restoration of normal nerve physiology, which may occur due to reduced intraneural edema, improved vascular supply, and enhanced nerve conduction properties.²⁰ The findings of this study may be consistent with previous literature supporting the effectiveness of neural mobilization techniques in improving both neurological and musculoskeletal function.¹⁹ Clinically, this study may provide evidence



**Shahrukh Ansari and Kanika**

supporting the inclusion of median nerve mobilization as part of a comprehensive rehabilitation program for individuals with excessive smartphone use and related upper extremity dysfunction.

CONCLUSION

This study aims to evaluate the effectiveness of median nerve mobilization on hand grip strength, pinch strength, and median nerve conduction velocity among college students with excessive smartphone use. It is anticipated that median nerve mobilization may lead to significant improvements in these outcome measures by enhancing neural mobility and physiological function. The findings of this study may contribute to the existing body of evidence supporting neurodynamic techniques and provide a basis for incorporating median nerve mobilization into rehabilitation programs for individuals experiencing upper extremity dysfunction associated with smartphone overuse. Furthermore, this study may help in developing targeted physiotherapy interventions to improve hand function and prevent long-term musculoskeletal complications in young adults.

Disclosure of Interest

There are no interests to declare.

Declaration of Funding

No funding was received.

Caption

Figures

Figure 1: Procedure Flow Chart according to MODIFIED CONSORT guideline

Figure 2: Block randomization with a block size of 4 and 1:1

Author contribution

Conceptualization: SA, K

Draft formation: SA

Supervision: K

Writing- original draft: SA, K

Writing- review & editing: K

REFERENCES

1. Dierick F, Brismée JM, White O, Bouché AF, Périchon C, Filoni N, Barvaux V, Buisseret F. Fine adaptive control of precision grip without maximum pinch strength changes after median nerve mobilization. medRxiv. 2020 :2020-04.
2. Shacklock M. Clinical neurodynamics: a new system of neuromusculoskeletal treatment. Elsevier Health Sciences; 2005 .
3. Butler DS. *The sensitive nervous system*. Adelaide: Noigroup Publications; 2000.
4. Araujo BF, Nascimento CM, Busarello FD, Moreira NB, Baroni MP, Carvalho AR, Bertolini GR. Assessment of hand grip strength after neural mobilization. Revista Brasileira de Medicina Do Esporte. 2012;18:242-5.
5. Kim HJ, Kim JS. The relationship between smartphone use and subjective musculoskeletal symptoms and university students. Journal of physical therapy science. 2015;27(3):575-9.
6. Alshahrani A, Samy Abd rabo M, Aly SM, Alshahrani MS, Alqhtani RS, Asiri F, Ahmad I. Effect of smartphone usage on neck muscle endurance, hand grip and pinch strength among healthy college students: A cross-sectional study. International journal of environmental research and public health. 2021 ;18(12):6290
7. Osailan A. The relationship between smartphone usage duration (using smartphone's ability to monitor screen time) with hand-grip and pinch-grip strength among young people: an observational study. BMC musculoskeletal disorders. 2021 ;22:1-8.
8. Kwon M, Kim DJ, Cho H, Yang S. The smartphone addiction scale: development and validation of a short version for adolescents. PloS one. 2013 ;8(12):e83558.





Shahrukh Ansari and Kanika

9. Gustafsson E, Johnson PW, Hagberg M. Thumb postures and physical loads during mobile phone use—A comparison of young adults with and without musculoskeletal symptoms. *Journal of Electromyography and Kinesiology*. 2010 ;20(1):127-35.
10. İnal EE, Demirci K, Çetİntürk A, Akgönül M, Savaş S. Effects of smartphone overuse on hand function, pinch strength, and the median nerve. *Muscle & nerve*. 2015 ;52(2):183-8.
11. Chan AW, Tetzlaff JM, Altman DG, Laupacis A, Gøtzsche PC, Krleža-Jeric K, Hrobjartsson A, Mann H, Dickersin K, Berlin JA, Dore CJ. Declaración SPIRIT 2013: definición de los elementos estándares del protocolo de un ensayo clínico. *Rev Panam salud pública*. 2015 ;38(6):507.
12. Mathur R, Swaminathan S. National ethical guidelines for biomedical & health research involving human participants, 2017: A commentary. *Indian J Med Res*. 2018;148(3):279–83.
13. Alharmoodi BY, Arumugam A, Ahbouch A, Moustafa IM. Comparative effects of tensioning and sliding neural mobilization on peripheral and autonomic nervous system function: A randomized controlled trial. *Hong Kong Physiotherapy Journal*. 2022 ;42(01):41-53.
14. Beddaa H, Kably B, Marzouk B, Mouhi I, Marfak A, Azemmour Y, Bouzekraoui Alaoui I, Birouk N. The effectiveness of the median nerve neurodynamic mobilisation techniques in women with mild or moderate bilateral carpal tunnel syndrome: A single-blind clinical randomised trial. *South African Journal of Physiotherapy*. 2022 ;78(1):1823.
15. Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: normative data for adults. *Arch Phys Med Rehabil*. 1985 ;66(2):69-74.
16. Hong SJ, Lee MY, Lee BH. Effects of wrist stability training combined with grip strength exercise on pain and function in patients with nonspecific chronic wrist pain. *Medicina*. 2024 ;60(7):1144.
17. Singh M, Gupta S, Singh KD, Kumar A. Normative data for median nerve conduction in healthy young adults from Punjab, India. *Journal of Neurosciences in Rural Practice*. 2017 ;8(Suppl 1):S83.
18. Coppieters MW, Butler DS. Do 'sliders' slide and 'tensioners' tension? An analysis of neurodynamic techniques and considerations regarding their application. *Manual therapy*. 2008 ;13(3):213-21.
19. Basson A, Olivier B, Ellis R, Coppieters M, Stewart A, Mudzi W. The effectiveness of neural mobilization for neuromusculoskeletal conditions: a systematic review and meta-analysis. *journal of orthopaedic & sports physical therapy*. 2017 ;47(9):593-615.
20. de Souza Bezerra E, Diefenthaler F, Sakugawa RL, Cadore EL, Izquierdo M, Moro AR. Effects of different strength training volumes and subsequent detraining on strength performance in aging adults. *Journal of Bodywork and Movement Therapies*. 2019 ;23(3):466-72

Table 1: SPIRIT schedule of enrolment, interventions, and assessments for participation

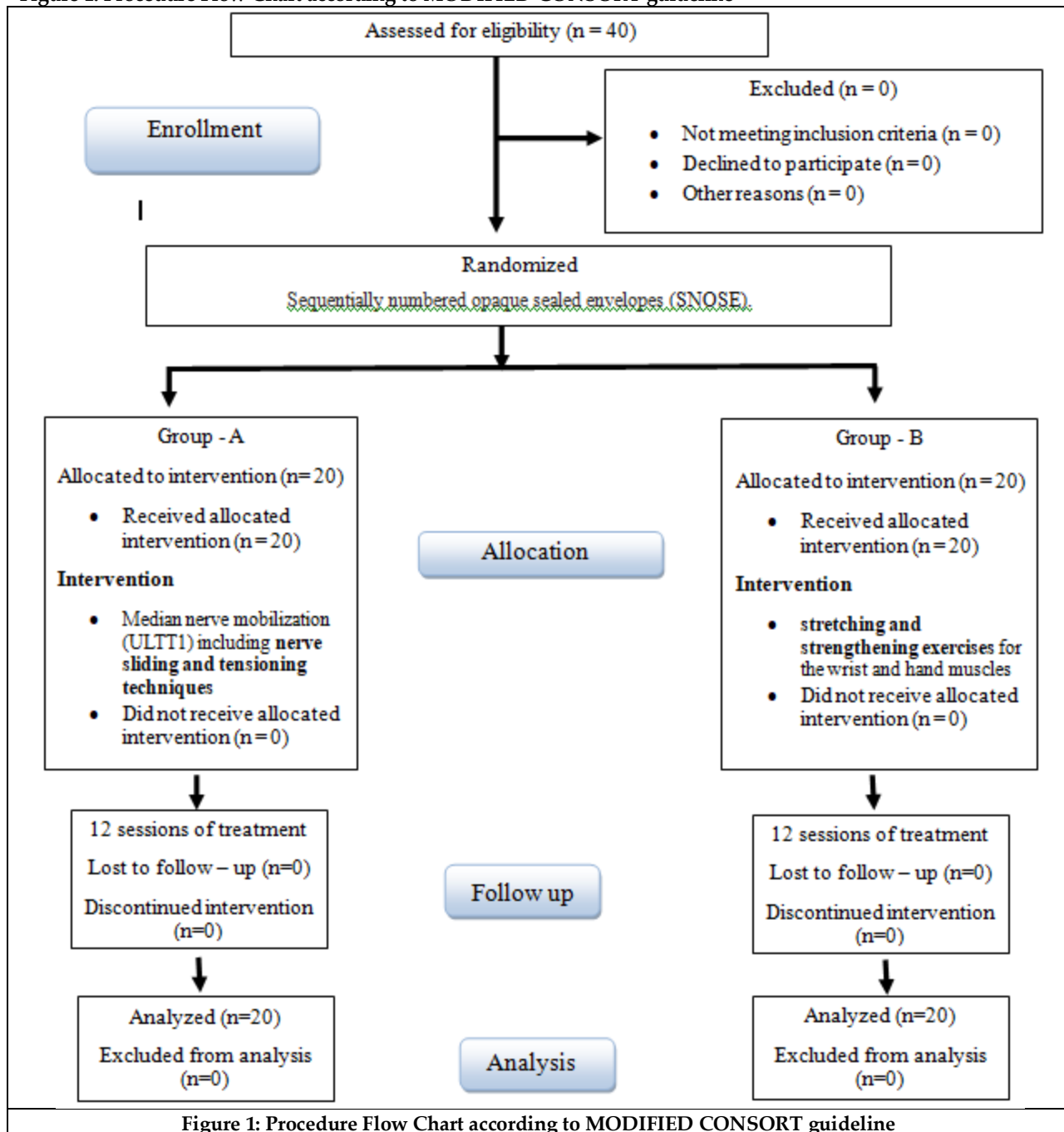
Time point	Enrolment	Allocation	Post-allocation (Treatment)	
	0-week	0-week	1-week	4 th week
Eligibility screening	×			
Informed consent	×			
Allocation		×		
Interventions				
Experimental group (median nerve mobilization)			×	×
Control group (Conventional treatment)			×	×
Assessments				
Demographic data		×		
Hand-held dynamometer (grip strength)		×		×
Pinch meter (pinch strength)		×		×
Median nerve conduction velocity (MNCV)		×		×





Shahrukh Ansari and Kanika

Figure 1: Procedure Flow Chart according to MODIFIED CONSORT guideline





Shahrukh Ansari and Kanika

Rows	EG	CG	EG	CG
1	•	•	•	•
2	•	•	•	•
3	•	•	•	•
4	•	•	•	•
5	•	•	•	•
6	•	•	•	•
7	•	•	•	•
8	•	•	•	•
9	•	•	•	•
10	•	•	•	•

Figure. 2: block randomization with a block size of 4 and 1:1

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Gullying Induced Land Degradation as an Indicator of Ecological Stress and Shift in Livelihood Opportunities of Santals in South Western Birbhum District, India

Sucheta Mukherjee¹, Druheen Chakraborty² and Abhisek Saha^{3*}

¹Assistant Professor, Department of Geography, Sripat Singh College (Affiliated to Kalyani University), West Bengal, India

²Assistant Professor, Department of Geography, Bankura Christian College (Affiliated to Bankura University), Bankura, West Bengal, India

³Assistant Professor, Department of Geography, Chatra Ramai Pandit Mahavidyalaya (Affiliated to Bankura University), Bankura, West Bengal, India

Received: 22 Mar 2026

Revised: 26 Apr 2026

Accepted: 27 May 2026

*Address for Correspondence

Abhisek Saha

Assistant Professor,

Department of Geography,

Chatra Ramai Pandit Mahavidyalaya

(Affiliated to Bankura University),

Bankura, West Bengal, India

E.Mail: abhiseksaha2014@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Land degradation has significant impact on food security, rural livelihoods, creates environmental and ecological perturbations in developing countries with growing population and resulting in reduction of arable land area. Gullying induced land degradation is a significant indicator of future ecological stress in a land unit due to soil erosion. Rill and gully erosion degrades a parcel of land to badland. The study area is observed to be characterized by incidences of mass movement, weathering and denudation. The spatio temporal estimation of soil erosion in the study area was carried out by using RUSLE method with GIS platform (Arc GIS 10.5) The five parameters used are runoff–rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness (LS), cropping management factor (C), and support practice factor (P). ResourceSAT 2 with 24 m resolution and LISS III image has been used for estimation LULC change detection. The daily rainfall data (2012–2019) from 4 rain gauge stations located in the South Western Birbhum district have been used to estimate the R factor. The increases in continuous and interrupted gullies with their areal coverage have been estimated and the annual average soil loss of the study area has been classified into five categories for soil loss. The highest rate of gullying was estimated in Rajnagar CD block (>34 t ha⁻¹ year⁻¹) of soil erosion was found along the whereas very low rate of gully formation was observed at Illambazar CD block where the amount of soil loss (<8 t ha⁻¹ year⁻¹) was estimated

115848



**Sucheta Mukherjee et al.,**

within densely forested areas. The reduction in size of landholdings due to gullying, impacts crop yields. Field observation and analysis reveals that the study area experiences land degradation in the form of sheet, rill, gullying and also through human initiated land degradation processes. There is very sparse or almost no undergrowth on the forest floors resulting in washing away of the loosened top soil. Integrated eco- management for sustainable use of land resources in the study area is required to restore natural spaces to the Santhals to maintain their traditional livelihoods.

Keywords: laterite, pluvial, gully erosion, ecological stress, sustainable

INTRODUCTION

Soil plays an important role in determining the nature of vegetation growth. Soil erosion when uncontrolled leads to ecological stress by restricting natural vegetation growth. In a man nature interface loss of soil cover by natural processes affects crop yields and food security. *Soil loss is a serious environmental threat in humid sub-tropical* (Bera, 2017) regions like the South Western Birbhum district. Soil erosion is a serious problem arising from agricultural intensification, land degradation and other anthropogenic activities. (Ganashri & Ramesh2016) Severe cases of top soil loss and decreased crop yields leads to change in landuse i.e. occupational resources and livelihood opportunities, where the stake holders gradually adapt to other sources to supplement their incomes. Climate, soil, slope, land use/ land cover (LULC), and soil management are all factors that influence erosive (Khadse et al. 2015, Brahim2022) The study has been attempted using climate ,soil constitution ,slope and LULC parameters to determine the extent of land degradation and suggest soil management methods to manage soil erosion. Tropical regions are characterized by pluvial erosion in the form of rain splash, sheet erosion, overland flow in the form of rill and inter rill erosion which later coalesces to gully erosion. Gully erosion is among the major causes for land degradation in tropical regions which are composed of laterite soil. It destructs major portion of the top soil and causes loss of areal parcels of land as a result of slumping, slope retreat and cave ins. This leads to rapid destabilization of land surface, water tables are exposed, draining them out. There is gradual loss of soil moisture leading to depletion of natural vegetation cover, loosening of top soil and washing out of regolith induced by rainfall or wind action .This results in severe land degradation and desertification and crop yields are lowered significantly. Degraded lands account for about 2 billion ha. (15%) in the world, 39.0% in Asia, and about 9.4% in India. Degraded lands in India cover about 187.7 million ha. or 57.1% of its total area.

Objectives

This study is an attempt to -

- analyze the characteristics of soil on the basis of genesis, location and geoclimatic factors of the study area.
- The nature and extent of gullying in the study area, the extent of ecological stress induced by gullying and identify land degradation prone areas in the study area.
- observe and record the change in livelihoods for Santhals due to gullying induced land degradation living in the study area.
- Suggest some remedial measures to maintain the geo-ecological balance in the South Western part of Birbhum District.

Study area

The South Western part of Birbhum district (1128.97sq.km) is between longitude: 86°89'50"E to 87°13'50"E and latitudes 23°23'50"N to 23°52'00"N. The study involves four C.D Blocks of Birbhum District: Rajnagar (225.67 sq.km), Khoyrasole (282.71 sq. km), Dubrajpur (357.98 sq.km), Illambazar -262.61sq.km (Fig.1). The average annual rainfall is recorded at 149.40mm.and temperature in cold months: 5°-10°c (December to February) temperature in warm month: 37° -40°c (April to May). The climate is tropical monsoon type with very hot summers and cold winters and heavy





Sucheta Mukherjee et al.,

monsoonal rains between July to September thus scope for leaching is enhanced. The average Relief is 80 mts and average. The rivers Hingloi, Kopai and Bakreshwar flow from West to South East and are rainfed (Fig.2) The lithological layers, slope, height and drainage density are analyzed to understand the susceptibility of gully erosion of the region. Slope: 1° - 3° -Terrain condition is undulating with no sudden changes in profile. Slopes generally prevent infiltration of rain water with regard to their steepness. The general slope of the land is from West to South East with drainage lines flowing SE. The most densely covered natural vegetation is noted to be on the south eastern part of the study area. The western part is elevated and rocky with bare soil in patches.(Fig.3)The eroded detrital finer soil is brought down by pluvial action (surface flow) and drainage lines and deposited in South eastern region providing base for plant growth. The runoff generated from slope will find a path nearby and this would lead to erosion of soil as the velocity of the runoff increases (Gansari&Ramesh2016)

Soil

The soil type is predominantly detritus late rites .Agricultural productivity is very low and most of the arable land remains fallow (Ghosh & Guchchait 2020) after winter harvest in the study area.

Livelihoods practiced by Santhals in the South Western Birbhum district –

- Collection of dry twigs for firewood.
- Collection of Sal (*shorea robusta*) for making plates and bowls.
- Collection of wild mushrooms that grow on forest floors – considered a delicacy in local cuisine.
- Collection of honey during winters.
- Acting as local guides for growing geo tourism of local geomorphosites.
- Farming on flat expanse of land during winters (maize, rice, paddy, potatoes and winter vegetables).
- Bidi (a locally made) from Kendu (*Diospyros melanoxylon*) leaves rolled with tobacco.
- Daily laboring in paddy fields for transplanting seedlings just after monsoon when rain water collects.
- Morrum (loose pebbles from nodules of laterites) collection from top soil layer, used extensively for garden pathways .This alters the slope and topography of the region due to removal from slope pediments.
- Pasturing of domestic cattle on grassland areas

METHODOLOGY

The present work consists of investigation of South Western Part of Birbhum District using satellite data (ResourceSat2, LISS III) 24 metres resolution on 2012 and 2019, (DOP Feb.2012 & May 2019) topographical map interpretation, lithology (SoI) map of the region together with field observation. The procedures included preparation of base map on 1: 50,000 scale by visual interpretation of satellite imageries of the study area and topographical sheets on 1:50,000 scales supplemented by the field investigation and ground truth observation. It was followed by landscape ecological analysis and Revised Universal Soil Loss Equation (RUSLE) method and mapping the study area. They have been used in this study to prepare gully erosion susceptibility maps. The prioritizations of each gully regarding their ranks have been computed by using GIS techniques. On the basis of the field survey the problems of land degradation in the study area have been identified, and appropriate measures have been suggested for sustainable land use planning and management to maintain existing livelihoods of the Santhals in the region. Different types of fluvially induced erosion leading to loss of top soil and are identified in the study area. They are

Splash erosion – The impact of falling raindrops creates small depressions. These coalesce and guide rainwater over a slope in finger like patterns.

Rill erosion– The fingerlike flow channels of water further coalesce to form rills which appear as very narrow channels carrying water and negligible debris down slope under the influence of gravity.(Photo plate 2)

Gully erosion – Numerous adjoining rills joins when the inter space between them is obliterated due to erosive action of flowing water. Normally this takes 2-3 years in fragile laterite profiles in tropical monsoon regions like the study area. (Photo plate 3)

Sheet erosion– The top soil is removed in thin layers by rapid overland flow due to pluvial action on gentle slopes.



Sucheta Mukherjee *et al.*,

Stream and bank erosion – The washing down of earth material from banks of rivers and streams into the drainage channel.

RUSLE – The Revised Universal Soil Loss Equation(RUSLE) devised by USDA-Agricultural Research Service (ARS) “is an index method having factors that represent how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff.” in cooperation with the USDA-Natural Resources Conservation RUSLE is derived with the equation:

$$A = R K L S C P$$

Where: A = average annual soil loss,

R = rainfall erosivity factor

K = soil erodibility factor,

L = slope length factor,

S = slope steepness factor,

C = cover-management factor, and

P = supporting practices factor.

The erosion rate of soil loss/ acre per year is derived by substituting values for six RUSLE factors mentioned above for the study area. The study area is characterized by dry summers with thunderstorms and rain at its onset (Nor'westers) which bring in short periods of heavy pounding rain .The months May to mid July are dry with increased low pressure conditions due to bare soil radiating high heat. The onset of monsoons later in July brings heavy rains with the bare soil regions and slope (rolling or steep) aid flowing down of loose soil which accumulate at the base of free fall zones (Photo plate 1). The annual top soil loss amount estimated for four sample villages of Rajnagar, Khoyrasole, Dubrajpur, Illambazar.jungle are assessed to be 38.37%, 27.84%, 35.71% and 11.33% respectively in regard to their total area.

RESULTS

The LULC analysis and field observation reveals that the highest tendency of gully erosion was observed in regions not covered by natural vegetation (Rajnagar, Khoyrasole and Dubrajpur CD blocks). In those areas with natural vegetation or forests, the tendency for gully erosion was negligible. Table 3 displays the spatio-temporal status of gullies and change in affected areas of the four CD blocks of South Western Birbhum district of India between 2012-2019. There are two tendencies of gullies observed in the study area i) continuous gullies and ii) interrupted gullies. The causes for development of continuous gullies are “gentle footslopes in zones of saturation along drainage paths with a large contributing area, erodible duplex soils derived from mudstones and poor vegetation cover due to overgrazing” (LeRoux & Paul, 2012). The interrupted gullies are observed to be situated on the lower pediment zones and usually covered by finer debris brought down by flowing water as sheet erosion (photoplate 4). After the monsoon season these zones have sufficient moisture for sparse natural vegetation to sprout which holds the soil together through its roots. The area wise degradation of land was 457.09 sq.km in 2012 and increased to 458.87 sq.km in 2019. There has been a 1.78 sq km increase (ie 1.71%) in a seven year span in the study area. The LULC analysis (Table 2) reveals that there has been a decrease in dense vegetation regions from 40.76 sq.km to 13.14 sq.km (about 27.62 sq.km) and agricultural/fallow land from 841.12 sq.km to 797.54 sq.km (43.58 sq.km) (Fig.4) with an increase in bare soil from 85.43 sq.km to 139.21 sq.km (53.78sq.km).

DISCUSSIONS

Due to gullying the flat expanse of the soil is interrupted .Soil erosion by pluvial action results in fertile top soil loss.The study area is situated in tropical monsoon climatic region and hence experiences both physical and chemical weathering The nature of laterite soil enhances the scope of rapid disintegration of soil blocks and being friable with little clay or organic content to bind the soil particles together allows free movement of water molecules and initiates leaching. This leads to percolation of essential minerals from regolith to lower parts of the soil profile. The soil of the





Sucheta Mukherjee et al.,

study area is impoverished and gullyng reduces the area allocated for crops. The nature and extent of gullyng in the study area (Table 2) and the extent of ecological stress induced by gullyng is observed to be moderate to severe.

Land degradation as an indicator of ecological stress in the study area

The nature of land degradation process in the study area is observed to be chiefly due to weathering, mass wasting and erosion with reduction in soil organic content. The patches of bare soil are lateritic and have moderate to severe rates of degradation. The 4 sample sites are observed for processes leading to land degradation. The forested region of Illambazar displays slow rate of degradation. Different scale of degradation (Severe to very severe degradation) is found in 3.9 Square km or 32.76% of land, in 0.67 Square km or about 55.51 % in Shyambati area and 10.37 Square km or 59.73% in Illambazar forest area where operation of rill-gully erosion initiated badland in reserve forest or moderate relief deformity in protected forest; it is observed near Rajnagar lateritic or rocky surface that shows with low to moderate local mining area of lateritic wastes. The encroachment of sandy or degraded soil towards agricultural land is also observed in the selected four CD blocks. The nature of land degradation here is a precursor to desertification processes in future which will be irreversible. The conservation methods should involve vegetative and engineering measures to prevent further degradation and restore already degraded areas.

Impact of gullyng in the study area

- Deterioration in nature and quality of land.
- Slumping, sliding, slope retreat, undercutting and cave ins of slopes is observed during monsoons.
- Washing down of top soil rapidly, where flow is aided by gully slopes.
- Numerous breaks in expanse and elevation of land which reduces the availability of flat lands for cultivation. This reduces crop yields.

More use of fertilizers. Reduction in arable land leads to pressure on existing flat lands to increase yields.

The characteristic of soil on the basis of genesis, location and geoclimatic factors of the study area is investigated. It is well understood that the interdependence of land use, soil, and water, as well as the connectivity between uplands and downstream areas (Tiderman 1996) impacts the rate of land degradation.

A notable change in livelihoods for Santhals due to gullyng induced land degradation in the study area is as follows:

Shift in livelihoods practiced by Santhals in the South Western Birbhum district –

- Working in stone quarries/stone crushing sites endangering lung health.
- Migrating to different states around India to work as unskilled labour at construction sites.
- Selling wares like kitchen utensils, clothing items and other knick knacks locally.
- Women folk go out to work as household help in nearby settlements.
- Bidi (a locally made smoking product) from Kend (*Diospyros melanoxylon*) leaves rolled with tobacco.
- Working in paddy farmlands just after monsoon when rain water collects and stagnates in the farm lands.
- Pasturing area is reduced due to loss of regolith leading to loss of grassland cover and reduced area for grazing cattle.

Suggestions

Some steps have been taken by State Agricultural Department and local bodies to check rapid soil erosion and gullyng. They are as follows –

- Afforestation: Planting trees or afforestation especially in badland topography area is very significant methods of soil conservation.
- Keeping bare soil cover after harvesting.
- Building embankments along riverbanks.
- Poly mulching to plant crops and prevent top soil loss.
- Gully head stabilization by earth plug, brush fills and check dams;
- Improvement of irrigation network,



Sucheta Mukherjee *et al.*,

- Suitable opportunities and training for dry land farming (by govt. initiative/NGOs)
- The study area is subject to moderate to severe land degradation. This is due to active geomorphic processes like weathering, mass movement and erosion actively in operation in sub humid tropical regions which have genetically poor physical and chemical of the existing soil profile. The removal of natural vegetative cover has triggered severe desertification.

CONCLUSION

Soil moisture encourages vegetation growth. The presence of natural vegetation cover encourages creation and presence of humus that is good for soil health. A natural vegetation cover prevents sheet erosion i.e. removal of top soil through overland flow of water due to pluvial activity. Presence of soil moisture reduces the chance for termite infestation as termites require dry soil to build their nests. The loss of natural vegetal cover causes depletion in organic nutrients that can enrich soil by decaying of leaves and humification. As a result, the soil structure gets impoverished, available plant food along with mineral material is carried away by rain-wash and the ability of the land to hold moisture for plant growth is reduced with the beneficial activity of micro-organisms lessened. Construction of operational approaches to analyzing on soil organic carbon (SOC) as part of sub-indicator which is a major concern for the SDGs. Soils stores the largest proportion of terrestrial carbon pool (TCP) and play a significant role in the global carbon balance (GCB) by the inter-exchange of greenhouse gases with the atmospheric layers and controlling the dynamic bio-geo chemical processes. Macro and micro climatic factors are the key indicator of greenhouse gas emissions from the soil profile and are dominantly influenced by land use, soil management and vegetation covers. Several FAO's work and planning on soils is organized through the Global Soil Partnership (GSP). <https://www.fao.org/land-water/land/ldn/en/>

REFERENCES

1. Bera, A.(2017) Assessment of soil loss by universal soil loss equation (USLE) model using GIS techniques: a case study of Gumti River Basin, Tripura, India. Model. Earth Syst. Environ. 3, 29 (2017).<https://doi.org/10.1007/s40808-017-0289-9>
2. Brahim, Benzougagh & Gajbiye, Sarita & Dridri, Abdallah & Boudad, Larbi & Brahim, Baamar & Driss, Sadkaoui & Khedher, Khaled. (2022). Identification of critical watershed at risk of soil erosion using morphometric and geographic information system analysis. Applied Water Science. 12. 10.1007/s13201-021-01532-z.
3. Ganasri,B.P., Ramesh H,(2016): Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin,Geoscience Frontiers,Volume 7, Issue 6,2016,Pages 953-961,ISSN 1674-9871<https://doi.org/10.1016/j.gsf.2015.10.007>.(<https://www.sciencedirect.com/science/article/pii/S1674987115001255>)
4. Ghosh Sandipan ,Guchhait ,Sanat Kumar (2020): Laterites of Bengal Basin Characterization,Geochronology and Evolution –Springer Briefs in Geography Pub.Springer ISBN 978-3-030-22937-5 e Book ISSN 2211- 4165 pp44
5. <https://doi.org/10.1007/978-3-030-22937-5>
6. Gully Prioritisation(2016) New Queensland – Dry Tropics The Burdekin Dry Tropics Gully Prioritisation Project is a joint initiative between the Queensland Government Environment and Heritage Protection Reef Water Quality Science Program and NQ DryTropics.<https://www.nqdrytropics.com.au/projects/sustainable-agriculture/gully-prioritisation/>
7. Khadse-Gajanan K, Vijay R, Labhasetwar PK (2015) Prioritization of catchments based on soil erosion using remote sensing and GIS. Environ Monit Assess 187(6):333–343. <https://doi.org/10.1007/s10661-015-4545-z>
8. Le Roux, Jay & Sumner, Paul. (2012). Factors controlling gully development: Comparing continuous and discontinuous gullies. Land Degradation & Development. 23. 10.1002/ldr.1083.
9. Thornbury, D, William, principle Of Geomorphology, revised second edition, New age international publishers



Sucheta Mukherjee *et al.*,

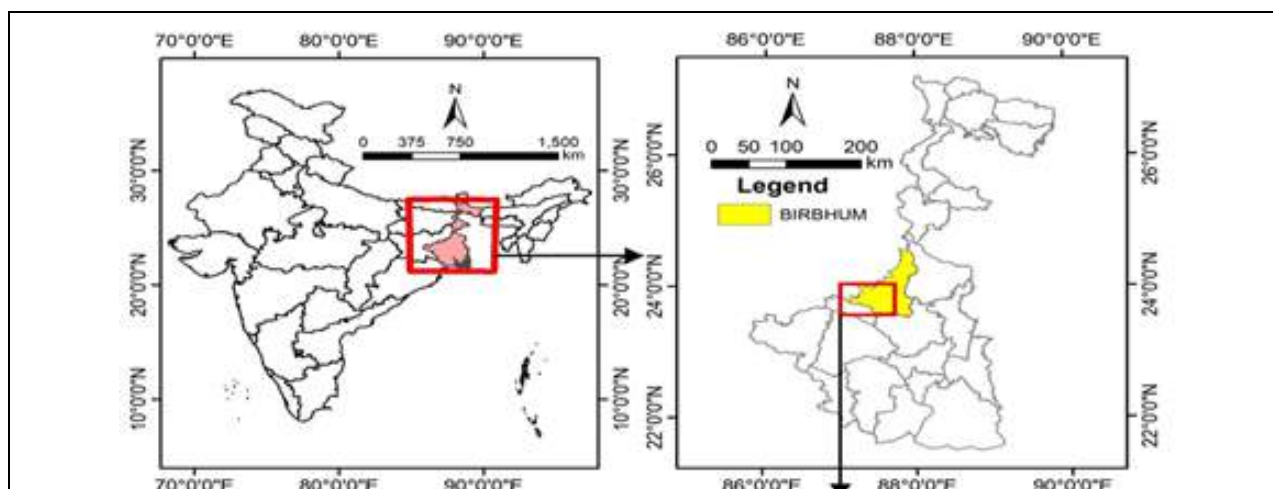
10. Singh, Savindra. and Dubey, Alok.: Gully Erosion and Management Methods and Application, New Academic Publishers, 2002
11. Chakraborty,A,Rathore, V,Kumar, P,Singh

Table 1 : LULC change detection between 2012 – 2019 of South West Birbhum district, India

Classes	2012 (Area in kms)	Percentage	2019 (Area in kms.)	Percentage	Change Detection
					Area in sq .km
Water	08.10	0.07	17.03	01.51	8.93
Dense Vegetation	40.76	03.61	13.14	01.16	-27.62
Agricultural land & fallow	841.12	74.50	797.54	70.64	- 43.58
Degraded Vegetation & shrubs	116.37	10.31	125.49	11.12	9.12
Settlements and Build up	25.53	2.26	30.81	02.73	5.28
Bare Soil	85.43	7.57	139.21	12.33	53.78
Sand or Dry River Bed	11.66	1.03	05.67	00.50	- 5.99
Total	1128.97	100	1128.89	100	

Table 2 : Status of gully erosion and their areal coverage in South Western Birbhum district , India

CD Block	Area (sq.km)	No. of Gullies		No. of continuous gullies		No. of interrupted gullies		Area affected (sq.km)		% area affected (sq.km)	
		2010	2022	2010	2022	2010	2022	2010	2022	2010	2022
Rajnagar	229.69	11	15	05	08	06	07	104.03	109.11	09.46	09.92
Khoyrasole	292.49	13	14	09	04	04	10	113.01	116.29	10.27	10.57
Dubrajpur	334.88	09	11	06	08	03	03	109.05	110.07	09.91	10.00
Illambazar	271.91	10	12	03	05	07	07	121.60	123.40	11.22	11.22
Total	1128.97	43	52	23	25	20	27	447.69	458.87	40.86	41.71



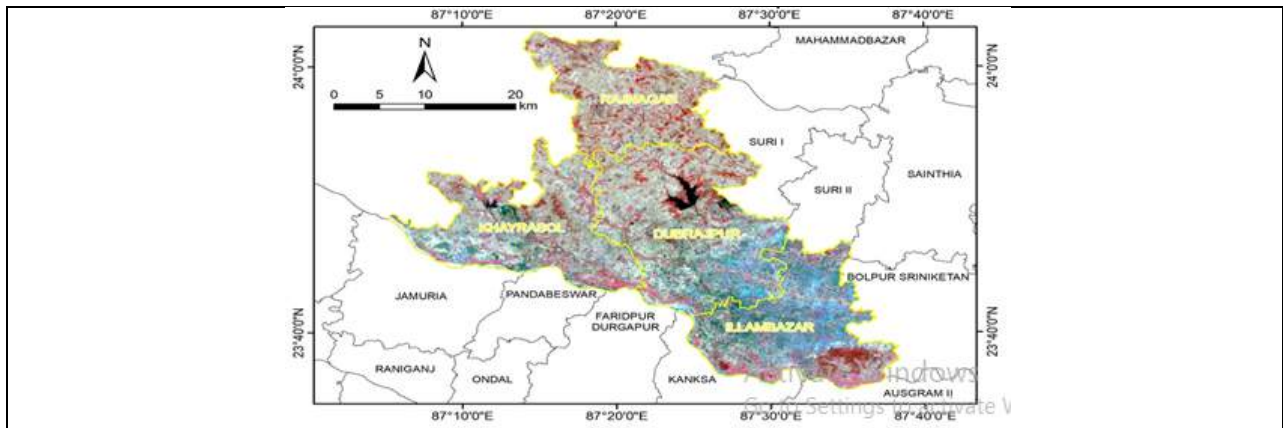


Fig.1 The study involves four C.D Blocks of Birbhum District: Rajnagar, Khoyrasole, Dubrajpur, and Illambazar

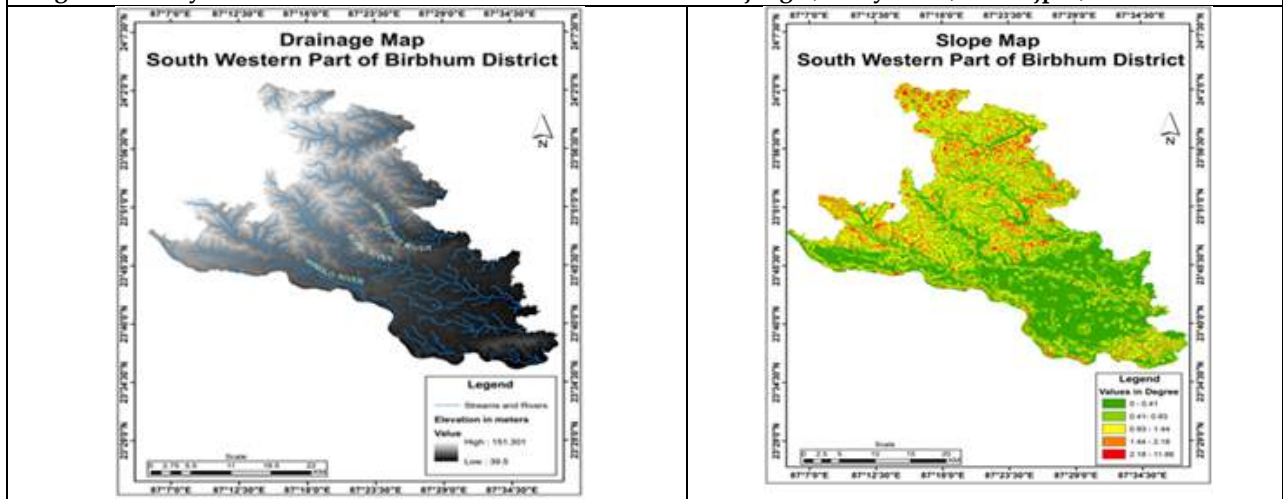


Fig.2 Drainage

Fig.3 Slope

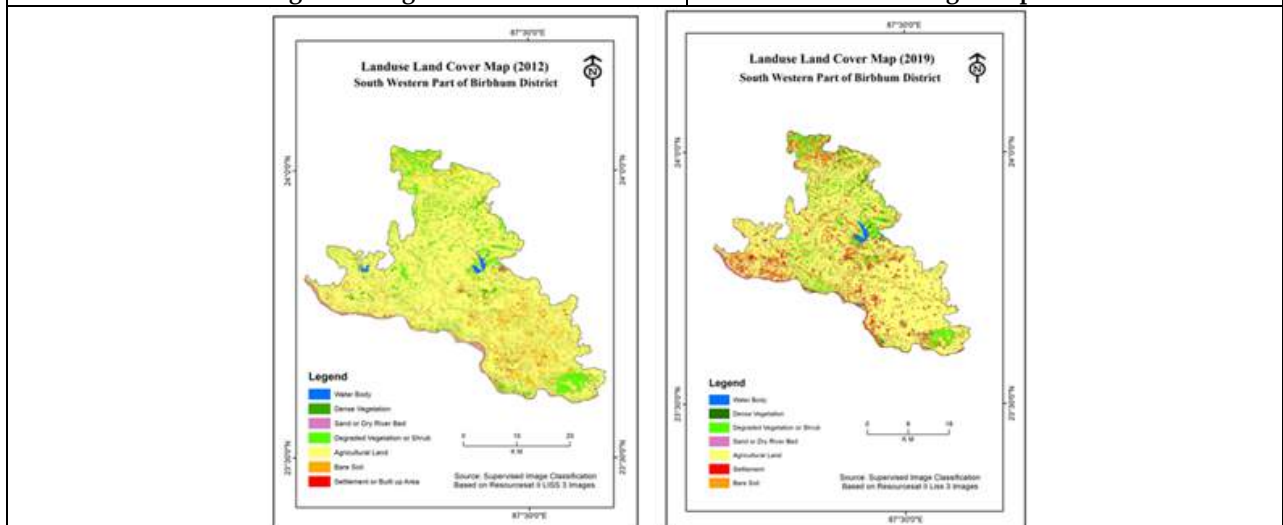


Fig.4(i & ii) LULC change detection (2012 - 2019) for South West Birbhum district, India



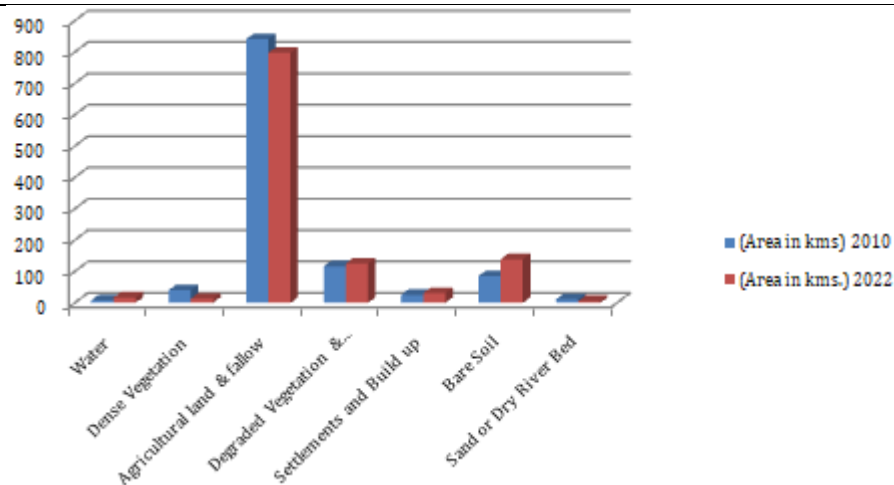
Sucheta Mukherjee *et al.*,

Fig 5 : Showing LULC pattern of 2012 and 2019 South West Birbhum district, India

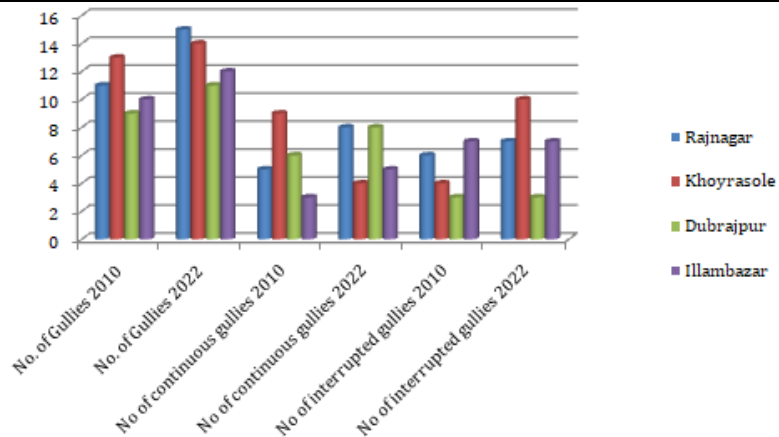


Fig 6 : Showing the distribution of different types of gullies during 2010 and 2022

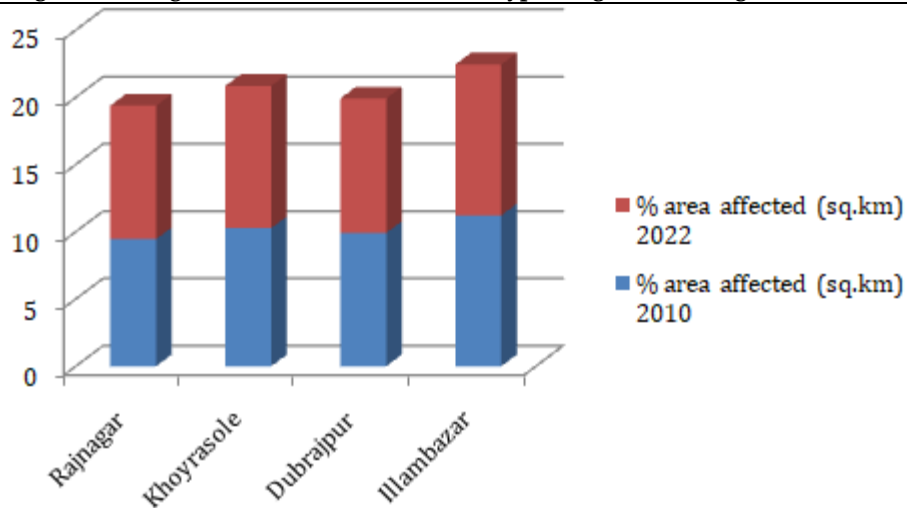


Fig 7 : Showing % of gullies affected area in comparison to 2010 and 2022





Sucheta Mukherjee et al.,

	
Photo plate 1: Initiation of rills	Photo plate 2: Rills coalesce to form gullies
	
Photo plate 3: Matured gully	Photo plate 4: Poly mulching to prevent soil erosion
	
Photo plate 5. Mushrooms on forest floor	Photo plate 6. Degraded landscape



Sucheta Mukherjee *et al.*,

	
Photoplate 7: Slumping with finer debris at pediment	Photoplate 8: Hard topped mesa like feature
	
Photoplate 9: Gullies initiated from slope.	Photoplate 10. Undulating slope in Rajnagar CD block
	
Photo plate 11. Free face slope in Rajnagar CD block.	

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Video Instance Segmentation: A Comprehensive Survey

Jigar A Dalvadi^{1*}, Niteen Vaghela² and Rushikesh Chaudhar¹

¹Assistant Professor, Department of Computer Engineering, Sardar Patel College of Engineering and Technology, (Affiliated to Gujarat Technological University), Bakrol, Anand, Gujarat, India

²Assistant Professor, Department of Computer Science Engineering, Sardar Patel College of Engineering and Technology, (Affiliated to Gujarat Technological University), Bakrol, Anand, Gujarat, India

Received: 16 Mar 2026

Revised: 25 Apr 2026

Accepted: 27 May 2026

*Address for Correspondence

Jigar A Dalvadi

Assistant Professor,

Department of Computer Engineering,

Sardar Patel College of Engineering and Technology,

(Affiliated to Gujarat Technological University),

Bakrol, Anand, Gujarat, India

E.Mail: jigardalvadi.ce@spec.edu.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Video Instance Segmentation (VIS) is a complex computer vision task that requires simultaneously detecting, segmenting, and tracking object instances across video frames. It represents a significant step beyond image-level segmentation by introducing the critical element of temporal consistency. This paper provides a comprehensive survey of the evolving landscape of VIS. We begin by outlining the fundamental challenges that distinguish VIS from its image-based counterpart, including occlusions, motion blur, and the need for robust temporal association. The survey then systematically categorizes and reviews modern VIS methodologies, dividing them into three predominant paradigms: online methods, which process frames sequentially for real-time applications; offline methods, which utilize future frames for higher accuracy; and the emerging query-based methods, which leverage attention mechanisms to unify the task.

Keywords: Video Instance Segmentation, Video Object Tracking, Instance Segmentation, Temporal Modeling, Computer Vision.





Jigar A Dalvadi et al.,

INTRODUCTION

The field of computer vision has made remarkable strides in understanding static images, with tasks like object detection and instance segmentation achieving human-level performance on many benchmarks [1]. However, the visual world is inherently dynamic. Videos, which constitute a vast portion of visual data, present a more complex and richer domain for analysis. Video Instance Segmentation (VIS) has emerged as a pivotal task that sits at the intersection of image instance segmentation and multi-object tracking. The goal of VIS is not only to identify and precisely delineate each object in every frame but also to consistently associate the same object instance across the temporal dimension of the video [2]. This unification offers a more holistic understanding of visual scenes, enabling applications that require a fine-grained and persistent perception of objects. Such applications are diverse and critical, including autonomous driving, where tracking other vehicles and pedestrians is essential for navigation; video editing and content creation, allowing for automated object manipulation; video surveillance for security and monitoring; and advanced human-computer interaction systems [3].

Despite its potential, VIS is fraught with challenges that are absent in image-based tasks. Factors such as significant object motion, partial or complete occlusions, motion blur, changes in appearance and lighting, and the computational burden of processing frame sequences all contribute to the difficulty of the problem [4]. A successful VIS system must be robust to these temporal variations while maintaining high spatial accuracy. The objective of this survey is to provide a structured overview of the current state of Video Instance Segmentation. We will trace the evolution of VIS methodologies from their early prototype stages to the sophisticated deep learning models of today. We will categorize existing approaches, analyze their strengths and weaknesses, and review the standard benchmarks and metrics used for evaluation. By synthesizing the recent advancements and identifying open challenges, this paper aims to offer a clear roadmap for future research in this rapidly advancing field.

Objectives

The primary objectives of this survey paper are as follows:

- **To Define and Formalize the VIS Task:** Provide a clear and concise definition of the Video Instance Segmentation problem, distinguishing it from related tasks like video object segmentation (VOS) and tracking-by-detection.
- **To Categorize Methodological Paradigms:** Systematically organize and present a taxonomy of contemporary VIS methods, with a focus on the key distinction between online, offline, and query-based frameworks.
- **To Review Key Architectures and Techniques:** Delve into the technical details of representative state-of-the-art models, explaining their core components, such as propagation networks, association modules, and the novel use of object queries in transformer-based architectures.
- **To Summarize Benchmarks and Evaluation:** Catalog the standard datasets (e.g., YouTube-VIS [2], OVIS [5]) and evaluation metrics (e.g., average precision and recall) used to measure progress in the field.
- **To Identify Challenges and Future Directions:** Highlight the persistent challenges facing VIS research and propose promising avenues for future work, including the integration of large-scale models, self-supervised learning, and efficiency improvements.

METHODS

The methodologies for Video Instance Segmentation can be broadly classified into three main paradigms based on their inference strategy and architectural design.

Online Methods

Online methods represent the foundational approach to the Video Instance Segmentation (VIS) task. Characterized by their sequential, frame-by-frame processing, these methods are designed for scenarios requiring real-time or low-





Jigar A Dalvadi *et al.*,

latency inference, such as autonomous navigation and live video analysis. The core principle of online methods is to propagate information from past frames to the current frame to maintain temporal consistency of instance identities.

- **Detection-based Propagation:** Early methods like MaskTrack R-CNN [2] extended the popular Mask R-CNN [1] architecture by adding a tracking head. This head takes the previously predicted mask and RoI features to compute similarity scores for association in the current frame.
- **Feature Propagation:** Subsequent works focused on propagating deep features rather than just masks. For instance, STEm-Seg [6] constructs a spatiotemporal volume from a clip of frames and uses 3D convolutions to jointly model spatial and temporal contexts, generating instance masks and associations simultaneously.

Offline Methods

Offline methods, also known as clip-based or batch processing methods, represent a fundamental paradigm in Video Instance Segmentation (VIS) that leverages global temporal context to achieve superior accuracy and robustness. Unlike their online counterparts that process frames sequentially, offline methods operate on complete video clips, enabling them to utilize information from both past and future frames simultaneously.

The core philosophy of offline VIS stems from the observation that human visual perception often requires looking ahead and behind to resolve ambiguities in complex scenes. When humans encounter occlusions or rapid motion in videos, we naturally use contextual information from adjacent frames to maintain consistent object identities and precise boundaries.

- **Proposal Linking:** Methods like CrossVIS [7] generate instance segmentation masks for each frame independently and then link these masks across frames in a post-processing step using learned similarity measures. This can be computationally expensive but achieves strong performance.
- **Dense Feature Correlation:** These approaches build a dense feature representation for the entire video and perform segmentation and tracking in a unified volume. They excel at handling complex motions but can be memory-intensive for long videos.

Query-Based Methods

Video Instance Segmentation has undergone a revolutionary transformation with the advent of query-based methods, marking a significant departure from traditional multi-stage pipelines. This paradigm shift represents the convergence of several key trends in computer vision. Inspired by the success of DETR [8] in object detection, a new paradigm has emerged that frames VIS as a set prediction problem. This family of methods has rapidly become state-of-the-art. Traditional VIS methods inherited a fragmented approach from their image-based predecessors, treating detection, segmentation, and tracking as separate problems requiring complex hand-crafted components. The breakthrough came with the adaptation of transformer architectures from natural language processing to computer vision. The key insight was recognizing that VIS could be reformulated as a set prediction problem, where the goal is to directly predict a set of video-level instance tracks from pixel-level features.

- **VIS with Transformers (VisTR):** VisTR [9] was a pioneering work that directly models VIS as a sequence-to-sequence problem. It leverages a transformer architecture to process a sequence of video frames and output a sequence of instance predictions for the entire video clip in one pass, eliminating the need for many hand-crafted components like non-maximum suppression or tracklet association.
- **Improved Query Design:** Building on VisTR, methods like Mask2Former-VIS [10] and VITA [11] introduced deformable attention and contrastive learning for queries, respectively, to improve efficiency and handle a larger number of instances. These models use a fixed set of object queries that interact with the spatiotemporal feature volume via attention mechanisms to simultaneously decode the spatial extents and temporal identities of all instances.





Jigar A Dalvadi *et al.*,

Application Scenarios

- **Choose Online Methods when:**
 - Real-time processing is critical
 - Hardware resources are limited
 - Application can tolerate occasional tracking failures
 - Examples: Autonomous vehicles, surveillance systems
- **Choose Offline Methods when:**
 - Accuracy is more important than speed
 - Full video context is available
 - Complex occlusions need to be handled
 - Examples: Video editing, scientific analysis
- **Choose Query-Based Methods when:**
 - State-of-the-art performance is required
 - Research and development focus
 - Unified architecture is preferred
 - Examples: Benchmark competitions, advanced applications

DISCUSSION

The field of Video Instance Segmentation has progressed at an accelerated pace, largely driven by the adoption of transformer architectures and the conceptualization of the task as a direct set prediction problem. The query-based paradigm, in particular, has simplified the overall pipeline and set new performance standards. However, several challenges remain. First, the computational cost of processing long video sequences is still prohibitive. While clip-based methods are effective, scaling them to minute-long videos requires efficient memory and attention mechanisms. Second, generalization to unseen object categories and complex real-world scenarios, such as crowded scenes with severe and prolonged occlusions (as in OVIS [5]), is still inadequate. Most models are trained and evaluated on curated datasets and struggle with domain shift.

- **Efficient Long-Range Modeling:** Developing architectures that can efficiently capture long-term temporal dependencies without quadratic memory growth.
- **Self-Supervised and Weakly-Supervised Learning:** Reducing the reliance on expensive per-frame mask annotations by leveraging unlabeled video data for pre-training [13].
- **Unified Video Understanding Models:** Moving beyond a single task, future models may aim to jointly perform VIS, action recognition, and video captioning in a single, holistic framework, perhaps inspired by large language-vision models [14].
- **Robustness and Fairness:** Ensuring that VIS models are robust to adversarial attacks and do not exhibit biases against certain object types or in varying environmental conditions.

In conclusion, while current VIS methods, especially query-based models, have demonstrated impressive capabilities, the path towards human-level video understanding is long. The key to future breakthroughs lies in creating more efficient, generalizable, and holistic models.

REFERENCES

1. He, K., Gkioxari, G., Dollár, P., & Girshick, R. (2017). Mask R-CNN. In Proceedings of the IEEE International Conference on Computer Vision (pp. 2961-2969).
2. Yang, L., Fan, Y., & Xu, N. (2019). Video instance segmentation. In Proceedings of the IEEE/CVF International Conference on Computer Vision (pp. 5188-5197).





Jigar A Dalvadi et al.,

3. Wang, Y., Xu, Z., Wang, X., Shen, C., Cheng, B., Shen, H., & Xia, H. (2021). End-to-end video instance segmentation with transformers. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 8741-8750).
4. Caelles, S., Pont-Tuset, J., Perazzi, F., Montes, A., Maninis, K. K., & Van Gool, L. (2019). The 2019 DAVIS challenge on video object segmentation. arXiv preprint arXiv:1905.00737.
5. Qi, J., Gao, Y., Hu, Y., Wang, X., Liu, X., Bai, X., ... & Liu, W. (2022). OVIS: Open-Vocabulary Instance Segmentation. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. penetrated- penetrated).
6. Athar, A., Mahadevan, S., Osep, A., Leal-Taixe, L., & Leibe, B. (2020). STEm-Seg: Spatiotemporal embeddings for instance segmentation in videos. In European Conference on Computer Vision (pp. 158-177). Springer, Cham.
7. Yang, S., Fang, Y., Wang, X., Li, Y., & Liu, C. (2021). CrossVIS: Cross-view fusion for video instance segmentation. In Proceedings of the IEEE/CVF International Conference on Computer Vision (pp. 4400-4409).
8. Carion, N., Massa, F., Synnaeve, G., Usunier, N., Kirillov, A., & Zagoruyko, S. (2020). End-to-end object detection with transformers. In European Conference on Computer Vision (pp. 213-229). Springer, Cham.
9. Wang, Y., Xu, Z., Wang, X., Shen, C., Cheng, B., Shen, H., & Xia, H. (2021). VisTR: End-to-end video instance segmentation with transformers. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 8741-8750).
10. Cheng, B., Misra, I., Schwing, A. G., Kirillov, A., & Girdhar, R. (2022). Masked-attention mask transformer for universal image segmentation. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 1290-1299).
11. Heo, M., Hwang, S., Oh, S. W., Lee, J. Y., & Kim, S. J. (2022). Video instance segmentation using object queries. In European Conference on Computer Vision (pp. 745-762). Springer, Cham.
12. Hwang, S., Heo, M., Oh, S. W., & Kim, S. J. (2021). Video instance segmentation by inter-frame communication. In Advances in Neural Information Processing Systems, 34.
13. Wang, X., Zhang, R., Shen, C., Kong, T., & Li, L. (2021). Dense contrastive learning for self-supervised visual pre-training. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 3024-3033).
14. Radford, A., Kim, J. W., Hallacy, C., Ramesh, A., Goh, G., Agarwal, S., ... & Sutskever, I. (2021). Learning transferable visual models from natural language supervision. In International Conference on Machine Learning (pp. 8748-8763). PMLR.

Table 1: Comprehensive Comparison of VIS Methodologies

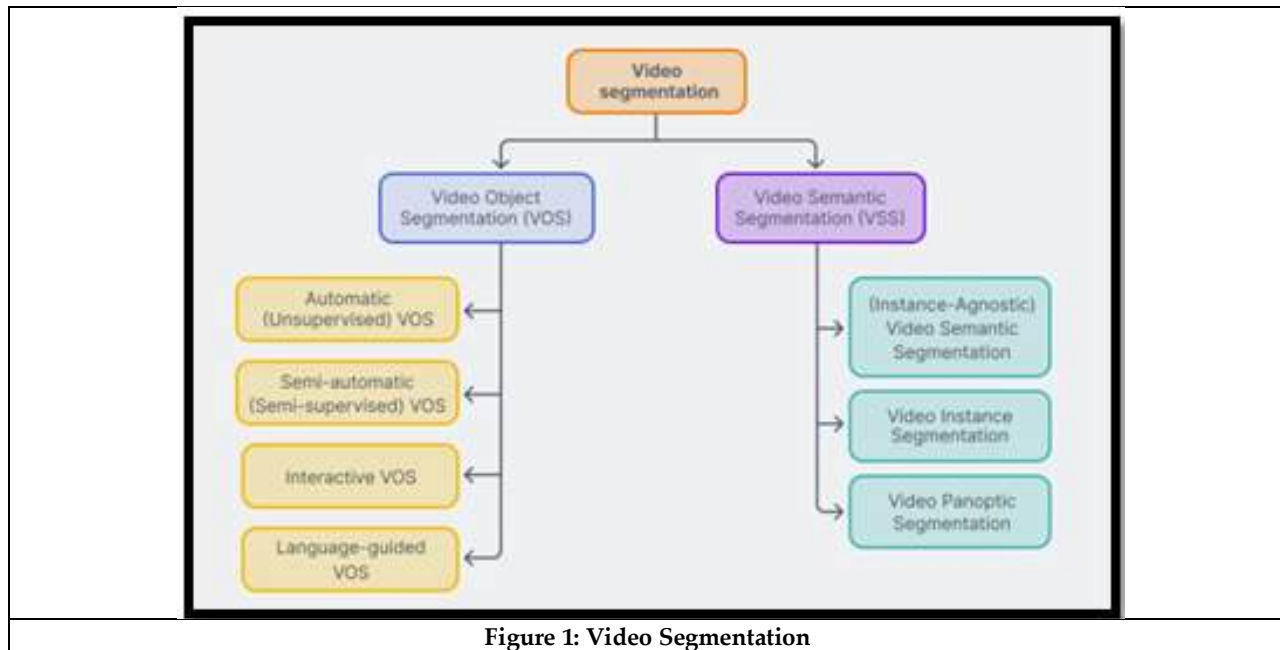
Aspect	Online Methods	Offline Methods	Query-Based Methods
Processing Strategy	Frame-by-frame sequential processing	Entire video clip processing	End-to-end set prediction
Temporal Context	Limited to past frames	Full clip context (past + future)	Variable context length
Inference Type	Real-time capable	Batch processing	Batch processing
Architecture	Multi-stage pipeline	Two-stage: detection + association	Unified transformer-based
Key Components	Detection head + tracking head	Per-frame masks + linking algorithm	Object queries + attention
Temporal Modeling	Propagation-based	Feature matching & optimization	Attention mechanisms
Memory Usage	Low	High	Moderate to High
Inference Speed	Fast	Slow	Moderate
Accuracy	Moderate	High	State-of-the-art
Typical AP on YouTube-VIS	30-35%	34-40%	40-50%+





Jigar A Dalvadi et al.,

Handling Occlusions	Poor to Moderate	Good	Excellent
Implementation Complexity	Moderate	High	Moderate
Representative Models	MaskTrack R-CNN, SipMask	STEm-Seg, CrossVIS	VisTR, IFC, Mask2Former-VIS



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Constructing Sequences of Dio-3 Tuples from 30- Gonal Figurate Numbers of Eclectic Genres of Ranks

S. Shanmuga Priya^{1*} and G. Janaki²

¹Research Scholar, Department of Mathematics, Cauvery College for Women (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

²Associate Professor, Department of Mathematics, Cauvery College for Women (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India

Received: 21 Mar 2026

Revised: 18 Apr 2026

Accepted: 27 May 2026

*Address for Correspondence

S. Shanmuga Priya
Research Scholar,
Department of Mathematics,
Cauvery College for Women (Autonomous),
(Affiliated to Bharathidasan University),
Tiruchirappalli, Tamil Nadu, India
E.Mail: dr.shannu005@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This study looks into the construction and characteristics of Diophantine triples made from centered triacontagonal numbers across different ranks. The paper creates these 3-tuples using generalized half-companion sequences and explores their mathematical properties. It especially focuses on their connection to 30-sided figurate numbers. A key analytical step is testing whether these triples can be extended into quadruples. This is done by determining which ranks allow for the addition of a fourth element through a careful algebraic procedure that often involves solving simultaneous Pellian equations. The research uses MATLAB for computational simulations to support the theoretical findings. These simulations reveal complex numerical patterns and give a visual representation of the relationships between the sequence ranks and their Diophantine features.

Keywords: quadruples, triacontagona, Diophantine features, Diophantine equations

INTRODUCTION

Diophantine equations is an essential part of number theory. It has important uses in modern cryptography and network security. One interesting area in this field is the creation of Diophantine triples and their special variants. This study dates back to Diophantus of Alexandria, who first found sets of rational numbers $\{a_1, a_2, \dots, a_m\}$. In these sets, the product of any two different elements, when increased by one, results in a perfect square, $a_i a_j + 1 = k^2$.





Shanmuga Priya and Janaki

Over time, this exploration has moved from rational numbers to integer sequences, leading to significant research on how to extend these sets. The study of Diophantine m -tuples involves m positive integers where the product of any two distinct elements plus a given integer n is a perfect square. This area has grown a lot in the last decade. Early in that time, Bačić and Filipin (2013)[1] set key limits on how $D(4)$ -pairs can be extended. They showed how specific square values of n affect the size of these sets. Then, Zhang and Grossman (2015)[2] provided a broader description of the structural properties that control Diophantine triples and quadruples. Their work supported the growing agreement on the finite nature of these sets. By 2018, Adzaga et al.[3] broadened the field by looking into rare triples that meet the $D(n)$ property for several values of n at once. As the decade ended, research started to link with specific number sequences. For example, Saranya and Janaki (2019)[4] used half-companion sequences to create special Dio-triples that focus on centered square numbers.

The year 2020 was a productive time for the field. Cipu, Filipin, and Fujita (2020)[5] provided a thorough analysis of pairs that produce specific triples. At the same time, Park (2020)[6] addressed the unique challenges of the $D(-1)$ property. Earp-Lynch et al. (2020)[7] expanded square-value properties by studying the $D(9)$ and $D(64)$ cases. In 2021, research became more specialized. Adzaga, Filipin, and Jurasic (2021)[8] looked into the specific triple $\{2, b, c\}$. Adedji et al. (2021)[9] explored the pair $\{a, 3a\}$ in depth. These studies were important for improving the computational and analytical tools needed to tackle the toughest conjectures in the field. The climax of these efforts came in 2022. Bonciocat, Cipu, and Mignotte[10] published a crucial proof that confirmed the non-existence of $D(-1)$ -quadruples, resolving a long-standing mystery in number theory. That same year, Rihane, Luca, and Togbe (2022)[11] combined these theories with classic recurrence sequences, proving that Diophantine quadruples made entirely of Pell numbers do not exist. Recently, attention has shifted to the overlap of Diophantine sets and complex polygonal numbers. Sangeetha et al. (2023)[12] introduced new constructions for special triples. The latest work by Shanmuga Priya and Janaki (2023)[13] used generalized half-companion sequences to investigate configurations with centered triacontagonal numbers. This work represents the current state of connecting Diophantine properties with higher-order geometric sequences.

Building on the foundational research in $D(n)$ -sets and figurate number sequences, this paper introduces the construction of generalized half-companion sequences linked to Diophantine triples derived from centered triacontagonal numbers. We study these triples across various ranks, specifically examining the neighbor-based configurations $(n-l, n+l)$ and $(n, n+l)$ for integer l . Our goal is to identify the unique arithmetic properties that emerge within these 30-sided polygonal structures in section 3. Section 4 presents a theoretical framework for the extensibility of these sets. It also includes formal theorems that explore the maximality of these triples and outlines the conditions that prevent their extension into quadruples. Finally, Section 5 describes these properties alongside computational visuals created in MATLAB, providing numerical support for the observed patterns.

Preliminaries

Definition 1 A centered triacontagonal number (CTG) is a type of centered figurate number that represents the count of dots arranged in the shape of a triacontagon (a 30-sided polygon). The arrangement begins with a single dot at the center, and additional dots are placed around it in successive layers forming triacontagons. The general formula is $CTG_N = 15n^2 + 15n + 1$

Where, $N = n + 1$ with $n \in \mathbb{W}$ denotes the rank of the CTG. The first few values in this sequence are 1, 31, 91, ...

Main Results

Theorem 1 Let CTG_N and CTG_{N+l} be centered triacontagonal numbers of ranks $n + 1$ and $n + 1 + l$, respectively, where $n, l \in \mathbb{W}$ and $l > 0$. The half-companion sequence of $D(t)$ -triples, with the property $t = 15nl^2 + 15n^2l + 15nl + 49l^2 + l$, generated by these numbers is defined by the sequence of sets $\{S_1, S_2, S_3, \dots\}$, where :

- $S_1: \{CTG_N, CTG_{N+l}, 2(CTG_N + CTG_{N+l}) - 15l^2 + l\}$
- $S_2: \{CTG_{N+l}, 2(CTG_N + CTG_{N+l}) - 15l^2 + l, 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l\}$
- $S_3: \{2(CTG_N + CTG_{N+l}) - 15l^2 + l, 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l, 10CTG_N + 15CTG_{N+l} - 90l^2 + 6l\}$





Shanmuga Priya and Janaki

Proof: Consider the following centered triacontagonal numbers of distinct ranks $n + l$ and $n + 1 + l$ with $n, l \in \mathbb{W}$ and $l > 0$.

$$m_1 = 15n^2 + 15n + 1 \quad (1)$$

$$m_2 = 15(n + l)^2 + 15(n + l) + 1 \quad (2)$$

$$m_1 m_2 = 225n^4 + 450n^3 + 255n^2 + 450ln^3 + 225n^2l^2 + 15l^2 + 675ln^2 + 15l + 225nl^2 + 255nl + 30n + 1$$

This product turns to a perfect square on adding $15nl^2 + 15n^2l + 15nl + 49l^2 + l$. Thus $\{m_1, m_2\}$ becomes a $D(15nl^2 + 15n^2l + 15nl + 49l^2 + l)$ – pair. To extend this to a triple, it is necessary to search for $m_3 \in \mathbb{Z}_+$ such that the following equations hold with the assumptions $\gamma_1 = \beta_1 + m_1\delta_1$ and $\gamma_2 = \beta_1 + m_2\delta_1$:

$$m_1 m_3 + 15nl^2 + 15n^2l + 15nl + 49l^2 + l = \gamma_1^2 \quad (3)$$

$$m_2 m_3 + 15nl^2 + 15n^2l + 15nl + 49l^2 + l = \gamma_2^2 \quad (4)$$

Solving the above equations (3) and (4), the following pellian equation is obtained.

$$\beta_1^2 = m_1 m_2 \delta_1^2 - (15nl^2 + 15n^2l + 15nl + 49l^2 + l)$$

Using the fundamental solution of pell equation, $\beta_1 = 15n^2 + 15nl + 15n + 8l + 1$ As a result,
 $\gamma_1 = 30n^2 + 30n + 15nl + 8l + 2$

Thus, using all the known values in (3),

$$m_3 = 60n^2 + 60n + 60nl + 15l^2 + 31l + 4 \quad (5)$$

$$\Rightarrow m_3 = 2[CTG_N + CTG_{N+l}] - 15l^2 + l \quad (6)$$

Similarly, the values of m_4, m_5 are obtained from the Diophantine pairs $\{m_2, m_3\}$ and $\{m_3, m_4\}$ respectively, which are given below:

$$= 135n^2 + 135n + 180nl + 60l^2 + 92l + 9$$

$$\Rightarrow m_4 = 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l$$

$$m_5 = 375n^2 + 375n + 450nl + 135l^2 + 231l + 25$$

$$\Rightarrow m_4 = 10CTG_N + 15CTG_{N+l} - 90l^2 + 6l$$

Proceeding in this way, each m_i can be produced from the Diophantine pairs $\{m_{i-2}, m_{i-1}\}$ for all $i = 6, 7, 8, \dots$ under the property $D(15n^2l + 15nl^2 + 15nl + 49l^2 + l)$. Thus, $\{[m_1, m_2, m_3], [m_2, m_3, m_4], [m_3, m_4, m_5], \dots\}$ forms the half companion sequence.

Theorem 2 Suppose that CTG_{N-l}, CTG_{N+l} be the two centered triacontagonal numbers of ranks $(n + 1) - l$ and $(n + 1) + l$, where $n \in \mathbb{W}$, $l \in \mathbb{N}$. Then $\{[CTG_{N-l}, CTG_{N+l}, 2(CTG_{N-l} + CTG_{N+l}) - 60l^2], [CTG_{N+l}, 2(CTG_{N-l} + CTG_{N+l}) - 60l^2, 3CTG_N - l + 6CTG_{N+l} - 120l^2], [2(CTG_{N-l} + CTG_{N+l}) - 60l^2, 3CTG_{N-l} + 6CTG_{N+l} - 120l^2, 10CTG_N - l + 15CTG_{N+l} - 360l^2]\}$ forms the sequence of Diophantine triples with the property $D(165l^2)$

Proof: Assume that w_1, w_2 be the centered triacontagonal number of ranks $(n + 1) - l$ and $(n + 1) + l$, where $n \in \mathbb{W}$, $l \in \mathbb{N}$.

$$w_1 = 15(n - l)^2 + 15(n - l) + 1 \quad (7)$$

$$w_2 = 15(n + l)^2 + 15(n + l) + 1 \quad (8)$$

It is found that $w_1 w_2 + 165l^2$ becomes a perfect square. By applying the property $D(165l^2)$, the product $w_1 w_2$ is transformed into a perfect square, establishing $\{w_1, w_2\}$ as a valid Diophantine pair. The process of extending this pair into a Diophantine triple involves identifying a positive integer w_3 that satisfies the simultaneous equations $w_i w_3 + 165l^2 = \eta_i^2$ for $i = 1, 2$. To facilitate a solution, the auxiliary variables are assumed to follow the linear forms $\eta_i = \beta_1 + w_i \delta_1$. The algebraic elimination of w_3 from this system yields a characteristic Pellian equation. By determining and applying the fundamental solution to this equation, the expression for η_1 is derived as $\eta_1 = 30n^2 + 30n - 15l - 30nl + 2$. This resulting value serves as the critical parameter for explicitly calculating the third element, w_3 , thereby completing the Diophantine triple.





Shanmuga Priya and Janaki

$$w_3 = 60n^2 + 60n + 4 \quad (9)$$

In the similar way, w_4, w_5 are obtained as

$$w_4 = 3CTG_{N-l} + 6CTG_{N+l} - 120l^2$$

$$w_5 = 10CTG_N - l + 15CTG_{N+l} - 360l^2$$

This completes the proof.

Theorems on Non-extendibility

Definition 2 A Diophantine triple is said to be maximal if it is not extended to quadruple.

Theorem 3 The Diophantine triple $\{m_1, m_2, m_3\}$ defined as in (1),(2),(5) involving centered triacontagonal numbers CTG_N, CTG_{N+1} is maximal under the property $D(15n^2l + 15nl^2 + 15nl + 49l^2 + l)$.

Proof: To extend the triple $\{m_1, m_2, m_3\}$ to quadruple, it is enough to find $m_0 \in \mathbb{Z}_+$ such that the system of equations $m_j m_0 + 15n^2l + 15nl^2 + 15nl + 49l^2 + l = \gamma_j$ (10)

hold with the assumption $\gamma_j = \beta_1 + m_j \delta_j$ for all $j = 1, 2, 3$. Eliminating m_0 from for $j = 1, 3$ gives rise to the pellian equation which can be solved by applying the fundamental solution $\{\beta_1, 1\}$. Thus, it leads to the value of m_0 as follows:

$$m_0 = 135n^2 + 135n + 90nl + 15l^2 + 47l + 9 \quad (11)$$

The derived Ψ_0 is verified against equation for $j = 2$ through an analysis of three sub-cases: (i) $n > l$, (ii) $n = l$ (iii) $n < l$. In the first case, take $n = l + 1$ and using all known values in $m_2 m_0 + 15n^2l + 15nl^2 + 15nl + 49l^2 + l$ it gives

$$\gamma_2 = 14400l^4 + 54150l^3 + 73069l^2 + 41943l + 8649 \quad (12)$$

In the second case, substitute $n = l$ results in

$$\gamma_2 = 14400l^4 + 54150l^3 + 73069l^2 + 41943l + 8649 \quad (13)$$

In the last case, Replacing $n = l - 1$

$$\gamma_2 = 14400l^4 - 17850l^3 + 6139l^2 - 447l + 9 \quad (14)$$

It is verified using Python programming software that (12),(13) and (14) are non-perfect squares for all $l \in \mathbb{N}$. Thus, m_0 does not satisfy the equation for $j = 2$, which proves that $\{m_1, m_2, m_3\}$ is maximal.

Theorem 4 Let $\{w_1, w_2, w_3\}$ be a $D(165l^2)$ – triple constructed using centered triacontagonal numbers CTG_{N-1} and CTG_{N+1} as defined by the relations in (7), (8), and (9). Then, the triple $\{w_1, w_2, w_3\}$ is maximal, implying there exists no integer $w_4 \neq w_1, w_2, w_3$ such that $\{w_1, w_2, w_3, w_4\}$ forms a Diophantine quadruple under the same constraints.

Assume the values of w_1, w_2, w_3 as in (7), (8), and (9). The value of $w_0 \in \mathbb{Z}_+$ can be obtained by solving the system of equations $w_k w_0 + 165l^2 = \eta_k^2$, where $\eta_k = \beta_1 + w_k \delta_1$ and $k = 1, 2, 3$, which is given as

$$w_0 = 15l^2 - 90ln - 45l + 135n^2 + 135n + 9$$

Using the above w_0 in $w_2 w_0 + 165l^2 = \eta_2^2$ gives

$$\eta_2^2 = 225l^4 - 900l^3n - 450l^3 - 450l^2n^2 - 450l^2n - 360l^2 + 2700ln^3 + 4050ln^2 + 1530ln + 90l + 2025n^4 + 4050n^3 + 2295n^2 + 270n + 9$$

It is verify using Python programmig that the above value of η^2 is not a perfect square for any values of n, l . This proves the result.

CONCLUSION

Thus, this research effectively combines the theory of Diophantine 3-tuples with the geometric characteristics of centered triacontagonal numbers. By using generalized half-companion sequences, the study shows a clear approach for creating special 3-tuples that meet the $D(n)$ property for these 30-sided figurate numbers. The application of a solid algebraic algorithm to test for extendability helps clarify the differences between triples and quadruples. This provides a better understanding of which sequence ranks can be expanded further. Additionally, MATLAB





Shanmuga Priya and Janaki

simulations connect abstract number theory to practical pattern recognition. They emphasize the elegant numerical patterns found in these sets. Overall, these findings add an important new chapter to the study of Diophantine equations. They also offer a strong framework for exploring the extensibility of figurate number sequences in higher-order polygonal contexts.

REFERENCES

1. Bačić L, Filipin A. The extensibility of $D(4)$ -pairs. Mathematical Communications. 2013 Nov 19;18(2):447-456. Available from: <https://hrcak.srce.hr/file/163349>
2. Zhang Y, Grossman G. On Diophantine triples and quadruples. Notes Number Theory Discrete Math. 2015 Jan 1;21(4):6-16. Available from: <https://nntdm.net/papers/nntdm-21/NTDM-21-4-06-16.pdf>
3. Adzaga N, Dujella A, Kreso D, Tadic P. Triples which are $D(n)$ -sets for several n 's. Journal of number theory. 2018 Mar 1;184:330-341. Available from: <https://doi.org/10.1016/j.jnt.2017.08.024>
4. Saranya C, Janaki G. Half Companion Sequences of Special Dio 3-Tuples Involving Centered Square Numbers. International Journal of Recent Technology and Engineering (IJRTE). 2019;8(3):3843–3845. Available from: <https://www.ijrte.org/wp-content/uploads/papers/v8i3/C5083098319.pdf>
5. Cipu M, Filipin A, Fujita Y. Diophantine pairs that induce certain Diophantine triples. Journal of Number Theory. 2020 May 1;210:433-475. Available from: <https://doi.org/10.1016/j.jnt.2019.09.019>
6. Park J. The extendibility of Diophantine pairs with property $D(-1)$. Korean Journal of Mathematics. 2020 Sep 14;28(3):539-554. Available from: <https://doi.org/10.11568/kjm.2020.28.3.539>
7. Earp-Lynch B, Earp-Lynch S, Kihel O. On certain $D(9)$ and $D(64)$ Diophantine triples. Acta Mathematica Hungarica. 2020 Dec;162(2):483-517. Available from: <https://link.springer.com/article/10.1007/s10474-020-01061-2>
8. Adzaga N, Filipin A, Jurasic A. The extensibility of the Diophantine triple $\{2, b, c\}$. ANALELE STIINTIFICE ALE UNIVERSITATII OVIDIUS CONSTANTA-SERIA MATEMATICA. 2021 Jan 1;29(2):5-24. Available from: <https://doi.org/10.2478/auom-2021-0016>
9. Adedji KN, He B, Pinter A, Togbe A. On the Diophantine pair $\{a, 3a\}$. Journal of Number Theory. 2021 Oct 1;227:330-351.
10. Bonciocat NC, Cipu M, Mignotte M. There is no Diophantine $D(-1)$ -quadruple. Journal of the London Mathematical Society. 2022 Jan;105(1):63-99. <https://doi.org/10.1112/jlms.12507>.
11. Rihane SE, Luca F, Togbe A. There are no Diophantine quadruple of Pell numbers. International journal of Number Theory. 2022;18(01):27–45. Available from: <https://doi.org/10.1142/S179304212250004X>
12. Sangeetha V, Anupreethi T, Somanath M. Construction of Special Dio–triples. Indian Journal of Science and Technology. 2023 Oct 25;16(39):3440-3442. Available from: <https://doi.org/10.17485/IJST/v16i39.1735>.
13. S. Shanmuga Priya, G. Janaki. Configuration of generalized half companion sequence of Special Dio-3 tuples involving centered triacontagonal number. Communications in Mathematics and Applications. 2024 : 15(4): 1383–1393. Available from: <https://doi.org/10.26713/cma.v15i4.3281>.

Numerical Verification

Table 1: Verification of half companion sequence generated by CTG_N, CTG_{N+1}

l	n	(m_1, m_2, m_3)	(m_2, m_3, m_4)	(m_3, m_4, m_5)	$D(t)$
1	1	(31, 91, 230)	(91, 230, 611)	(230, 611, 1591)	95
1	2	(91, 181, 530)	(181, 530, 1331)	(530, 1331, 3541)	170
1	3	(181, 301, 950)	(301, 950, 2321)	(950, 2321, 6241)	275
1	4	(301, 451, 1490)	(451, 1490, 3581)	(1490, 3581, 9691)	410
1	5	(451, 631, 2150)	(631, 2150, 5111)	(2150, 5111, 13891)	575





Shanmuga Priya and Janaki

Table 2: Verification for half companion sequence generated by CTG_{N-l}, CTG_{N+l}

l	n	(w_1, w_2, w_3)	(w_2, w_3, w_4)	(w_3, w_4, w_5)	$D(t)$
1	1	(1, 91, 124)	(91, 124, 429)	(124, 429, 1015)	165
1	2	(31, 181, 364)	(181, 364, 1059)	(364, 1059, 2665)	165
1	3	(91, 301, 724)	(301, 724, 1959)	(724, 1959, 5065)	165
1	4	(181, 451, 1204)	(451, 1204, 3129)	(1204, 3129, 8215)	165
1	5	(301, 631, 1804)	(631, 1804, 4569)	(1804, 4569, 12115)	165

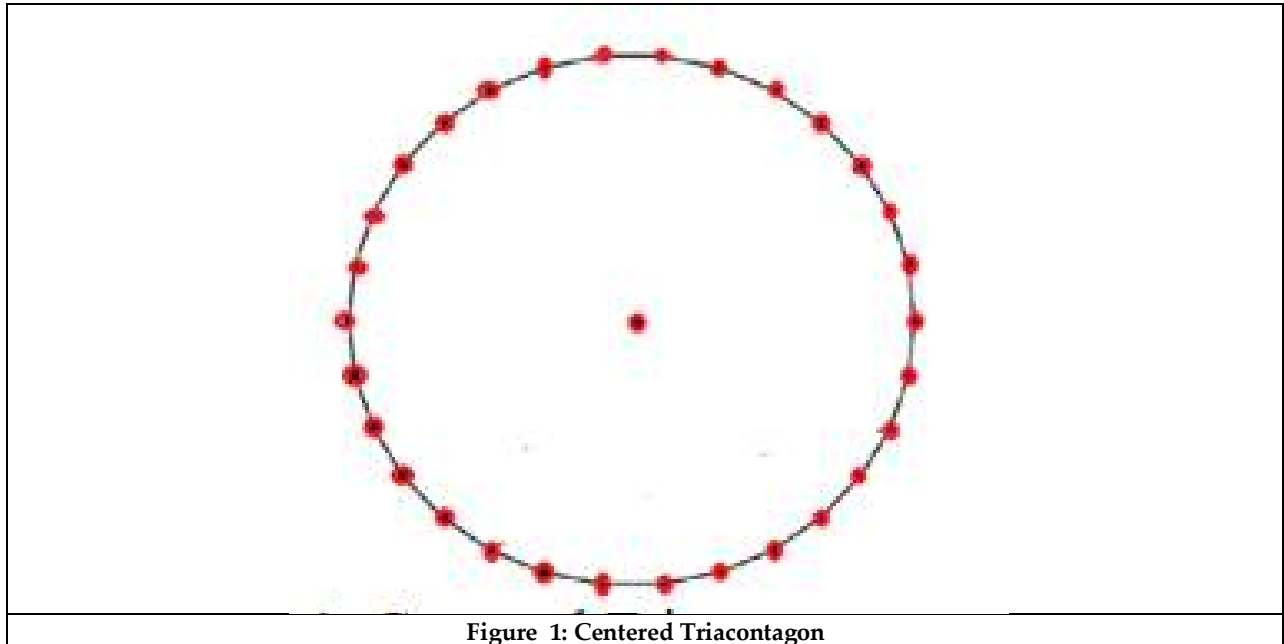


Figure 1: Centered Triacontagon

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Decoding Sex from the Sternum: A DECT- Based Morphometric Study in Western Uttar Pradesh Region

Pushpendra Kumar Rajput^{1*}, Shmriti¹, Ankit Kumar¹, Vratika Arya², and Naresh Kumar³

¹Assistant Professor, Department of Medical Radiology and Imaging Technology, Subharti College of Allied and Healthcare, Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India

²Assistant Professor, Department of Medical Radiology and Imaging Technology, School of Allied and Healthcare, (Affiliated to Nodia International University), Uttar Pradesh, India

³Assistant Professor, Department Allied and Health Science, Mangalayatan University, Aligarh, Beswan, Uttar Pradesh, India

Received: 20 Mar 2026

Revised: 25 Apr 2026

Accepted: 28 May 2026

*Address for Correspondence

Pushpendra Kumar Rajput

Assistant Professor,

Department of Medical Radiology and Imaging Technology,

Subharti College of Allied and Healthcare,

Swami Vivekanand Subharti University,

Meerut, Uttar Pradesh, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The sternum constitutes one of the most reliable skeletal elements for biological sex estimation in forensic anthropology. While conventional radiography and single-energy CT have been applied to sternal morphometry, dual-energy computed tomography (DECT) offers novel possibilities for simultaneous assessment of bone mineral density, trabecular architecture, and external morphology. This study aimed to (1) quantify sexual dimorphism in sternal dimensions and composition using DECT-derived parameters, (2) identify parameters with the highest discriminatory accuracy for sex estimation, and (3) develop multivariate discriminant functions applicable to casework and clinical imaging datasets.

Keywords: dual-energy computed tomography, sternal morphometry

INTRODUCTION

Establishing biological sex from skeletal remains is a fundamental task in anthropology and medicolegal death investigation. In the context of mass disasters, decomposed cadavers, or commingled remains, morphometric analysis of individual skeletal elements often provides the only avenue toward positive identification. The pelvis and skull have historically commanded attention as the most sexually dimorphic skeletal regions, yielding sex estimation



**Pushpendra Kumar Rajput et al.,**

accuracies of 90-98% when intact (Phenice, 1969; Walker, 2008). The sternum, comprising the manubrium, corpus sterni, and xiphoid process, has attracted increasing interest as an alternative skeletal sex indicator. Its central thoracic position offers some protection from postmortem fragmentation, and its dense cortical shell renders it recoverable in both burned and decomposed remains (Bignold et al., 2021). Pioneering morphometric studies demonstrated consistent sexual dimorphism in sternal dimensions, with males exhibiting greater total sternal length, manubrial breadth, and overall bone volume (Ashley, 1956; Jit & Bakshi, 1986; Marinho et al., 2012). Discriminant functions derived from these measurements have reported accuracies ranging from 70 to 90%, depending on population ancestry and measurement protocol. The advent of multidetector computed tomography (MDCT) transformed skeletal analysis by enabling precise three-dimensional measurement of internal and external bony architecture without physical manipulation of specimens (Grabherr et al., 2016).

More recently, dual-energy computed tomography (DECT) has extended CT capabilities by acquiring data at two distinct X-ray spectra simultaneously, facilitating material decomposition algorithms that permit virtual separation of calcium from soft tissue, quantification of effective atomic number (Zeff), and derivation of volumetric bone mineral density (vBMD) without dedicated dual-energy X-ray absorptiometry (DXA) equipment (McCollough et al., 2015). Notwithstanding the promise of DECT in skeletal characterisation, no study to date has systematically examined sexual dimorphism in sternal morphometry using the full spectrum of DECT-derived parameters. Previous CT-based sternal studies have relied on standard single-energy acquisitions and were restricted to external morphometric measurements (Bassed et al., 2011; Ekizoglu et al., 2016). The integration of trabecular vBMD and material-decomposition metrics may further improve sex estimation accuracy and provide clinically relevant data on age-related bone quality differences between sexes. The present study therefore aimed to: (1) quantify sexual dimorphism in sternal morphometric and DECT-derived compositional parameters in a large South Asian reference sample; (2) determine which parameters maximally discriminate biological sex; and (3) construct multivariate discriminant functions and clinical application. Additionally, the influence of age on parameter magnitudes and sex differences was examined to contextualise cross-sectional observations within a life-course framework.

MATERIALS AND METHODS

Study Design and Ethical Approval

A retrospective, cross-sectional study was conducted using archived DECT datasets obtained from the Chhatrapati Shivaji, Subharti Hospital (CSSH), Meerut.

Participant Selection

Chest DECT scans acquired between January 2021 and December 2021 for clinical indications unrelated to sternal pathology (pulmonary embolism workup, lung nodule characterisation, pre-surgical thoracic assessment) were screened. Inclusion criteria were: (1) biological sex documented in clinical records; (2) age 20-70 years; (3) DECT acquisition on a third-generation dual-source scanner and (4) complete sternal visualisation on axial and coronal reconstructions. Exclusion criteria encompassed: prior sternal surgery; sternal fracture, neoplasm, or metabolic bone disease (osteoporosis confirmed by DXA T-score below -2.5); body mass index above 40 kg/m²; and significant imaging artefact degrading measurement reliability. Following screening, 320 subjects (160 males, 160 females) were included after stratified random sampling to achieve balanced sex and age group representation across four age strata (20-30, 31-45, 46-55, 56-70 years).

DECT Acquisition and Reconstruction Protocol

All examinations were performed on the dual-source DECT platform operating at 100 kVp (tube A) and Sn150 kVp (tin-filtered tube B), with automatic tube current modulation (CARE Dose4D). Collimation was 64 × 0.6 mm with a pitch of 0.6. Scan field of view encompassed the entire thorax. Raw projection data were reconstructed using a dedicated bone kernel (Br59) at 0.75 mm slice thickness and 0.5 mm increment for morphometry and at 1.5 mm for



**Pushpendra Kumar Rajput et al.,**

material-decomposition maps. DECT post-processing was performed on a dedicated workstation (Philips Healthineers).

Morphometric Measurements

All measurements were performed by two independent observers (R.K.S. and P.M.) blinded to patient sex, using multiplanar reformation (MPR) in the sagittal and coronal planes with an electronic calliper tool. Six linear morphometric parameters were recorded: (1) Manubrial Length (ML): midline distance from the upper border of the jugular notch to the manubriosternal joint; (2) Sternal Body Length (SBL): midline distance from the manubriosternal joint to the xiphisternal joint; (3) Total Sternal Length (TSL): sum of ML and SBL; (4) Manubrial Breadth (MB): maximum transverse diameter at the level of the clavicular notches; (5) Mesosternal Breadth (MSB): transverse diameter of the corpus sterni at its midpoint; and (6) Manubrio-Sternal Index (MSI): ratio of ML to SBL multiplied by 100. Intraclass correlation coefficients (ICC) were computed on a 30-subject subsample repeated after two weeks to assess measurement reliability.

Statistical Analysis

Descriptive statistics (mean $\pm$ standard deviation) were computed for all parameters stratified by sex and age group. Normality was confirmed by Shapiro-Wilk testing. Independent samples t-tests assessed sex differences in normally distributed variables; the Mann-Whitney U test was applied to non-normally distributed data. Cohen's d quantified effect sizes. Stepwise discriminant function analysis (DFA) was employed to identify the optimal subset of variables for sex prediction, with cross-validation by leave-one-out (LOO) procedure. ROC curves were generated for individual and combined parameters; AUC values with 95% confidence intervals were reported. Statistical significance was set at $\alpha = 0.05$. Analyses were conducted using SPSS version 29.0 (IBM Corp., Armonk, NY) and MedCalc version 22.0.

RESULTS

Sample Characteristics and Measurement Reliability

The final sample comprised 300 subjects with a mean age of 41.2 ± 12.8 years (males: 42.6 ± 13.1 years; females: 40.9 ± 11.5 years; $p = 0.58$). Intraobserver ICC ranged from 0.951 to 0.977 across all morphometric parameters; interobserver ICC ranged from 0.928 to 0.961, confirming excellent measurement reproducibility.

Morphometric Sexual Dimorphism

All six morphometric parameters demonstrated statistically significant sexual dimorphism ($p < 0.001$). Males showed a mean TSL of 175.4 ± 12.3 mm compared with 150.6 ± 11.8 mm in females (difference: 21.8 mm; Cohen's $d = 1.74$). Manubrial Length was 50.2 ± 5.1 mm in males versus 40.8 ± 4.4 mm in females ($d = 1.22$). Sternal Body Length was 120.2 ± 10.1 mm in males and 100.8 ± 9.1 mm in females ($d = 1.21$). Manubrial Breadth was 55.4 ± 5.3 mm in males and 44.2 ± 5.1 mm in females ($d = 2.14$), representing the largest effect size among morphometric parameters. Mesosternal Breadth was 30.8 ± 4.1 mm in males versus 26.1 ± 3.6 mm in females ($d = 1.14$). The Manubrio-Sternal Index was marginally higher in females (39.1 ± 4.3 vs. 41.7 ± 4.1 ; $d = 0.45$), consistent with proportionally greater manubrial contribution to total sternal length in female sterna.

DECT-Derived Compositional Parameters

Volumetric bone mineral density of the sternal corpus was significantly higher in females within the 20-40-year age stratum (females: 182.3 ± 28.2 mg/cm³; males: 165.1 ± 30.2 mg/cm³; $p = 0.007$), but this difference was attenuated and reversed in older age groups reflecting accelerated postmenopausal bone loss in females (52-68 years: females 111.4 ± 32.1 mg/cm³ vs. males 132.7 ± 27.8 mg/cm³; $p = 0.02$). Effective atomic number (Zeff) did not differ significantly between sexes across any age stratum (overall male: 11.20 ± 0.64 ; female: 11.15 ± 0.58 ; $p = 0.62$). Virtual non-calcium





density of sternal trabecular spaces was higher in males, consistent with greater marrow fat content (males: 5.8 ± 1.1 HU; females: 4.8 ± 1.1 HU; $p < 0.001$).

Discriminant Function Analysis

Stepwise DFA selected TSL, MB, and vBMD as the optimal three-variable subset. The derived discriminant function was: $D = 0.032(\text{TSL}) + 0.068(\text{MB}) - 0.002(\text{vBMD}) - 4.521$. A positive D score classified the case as male; a negative score as female. LOO cross-validated overall accuracy was 89.7% (males: 90.5%; females: 88.6%). ROC analysis of the combined discriminant score yielded an AUC of 0.938 (90% CI: 0.911-0.955), with an optimal cut-point sensitivity of 90.5% and specificity of 90.9%. For univariate parameters, TSL showed the highest individual AUC (0.901), followed by MB (0.899) and SBL (0.867).

DISCUSSION

The findings of this study affirm that the sternum is a highly sexually dimorphic skeletal element and that DECT enables comprehensive characterisation of both its external morphology and internal bone composition in a single imaging session. The overall cross-validated discriminant accuracy of 88.7% is among the highest reported for sternal sex estimation, surpassing the 70-78% ranges documented in earlier osteometric and single-energy CT studies from South Asian populations (Singh & Gangrade, 1988; Jit & Bakshi, 1986; Ekizoglu *et al.*, 2016). This improvement is attributable to the additive discriminatory power of vBMD, which captures biologically distinct patterns of bone accrual and loss across the sexes and aging continuum. The large effect size observed for Manubrial Breadth (Cohen's $d = 2.24$) corroborates previous reports identifying this parameter as particularly robust for sex determination (Bassed *et al.*, 2011; Navani *et al.*, 1970). The mechanical demands of the pectoralis major and clavicular articulation appear to drive differential bone deposition in males during adolescent growth, resulting in a substantially wider manubrium that persists throughout adult life. Total Sternal Length also demonstrated excellent discriminatory power, consistent with the broader male thoracic skeleton required to accommodate greater lung volumes and cardiopulmonary demands (Marinho *et al.*, 2012).

An important observation in this study is the age-dependent reversal of the vBMD sexual dimorphism. In young adults, females exhibited higher sternal vBMD than males, a finding consistent with earlier pubertal bone consolidation in females described in appendicular skeletal sites (Bachrach, 2001). After menopause, accelerated trabecular resorption results in substantially lower sternal vBMD in females, a pattern faithfully captured by the DECT material-decomposition algorithm. This highlights the importance of age stratification when applying DECT-based discriminant functions, and underscores the potential of DECT as a non-invasive tool for incidental osteoporosis screening in clinical imaging datasets (Booz *et al.*, 2020). The non-significant difference in Zeff between sexes confirms that sternal cortical mineral composition is similar between males and females, with sexual dimorphism residing primarily in bone geometry and trabecular density rather than elemental composition. This finding aligns with prior DECT studies of vertebral bodies and proximal femora (Wesarg *et al.*, 2012) and confirms that Zeff alone is insufficient for sex determination, though it may retain utility for age estimation and bone quality assessment in combined -radiological workflows.

From an anthropological perspective, the discriminant function derived here represents a population-specific tool optimised for South Asian ancestry. Population variation in sternal dimensions is well established (Trotter & Peterson, 1955; Macaluso, 2010), and direct application of functions derived from European or North American reference samples to South Asian decedents would be methodologically inappropriate. Several limitations merit acknowledgment. First, the retrospective design relied on clinically indicated DECT scans; although clinical indication (primarily pulmonary embolism workup) is unlikely to systematically affect sternal morphometry, selection bias cannot be entirely excluded. Second, all participants were recruited from tertiary care institutions in northern India, limiting generalisability to rural populations and other South Asian ancestral groups. Third, the xiphoid process was not systematically measured due to its variable ossification and frequent absence in the imaging





Pushpendra Kumar Rajput et al.,

field; inclusion of xiphoid parameters might further improve accuracy. Fourth, although scanner-specific calibration was performed, inter-scanner variability in vBMD measurements across the two acquisition sites may introduce minor systematic error. Future prospective, multicentre studies incorporating diverse South Asian subpopulations and standardised acquisition protocols are warranted.

CONCLUSIONS

Dual-energy computed tomography provides a comprehensive, reproducible platform for the assessment of sexual dimorphism in sternal morphometry, integrating external dimensional measurements with bone mineral density and material-decomposition metrics. The multivariate discriminant function incorporating Total Sternal Length, Manubrial Breadth, and volumetric bone mineral density achieves 88.7% cross-validated accuracy for biological sex estimation in South Asian adults, outperforming morphometric-only approaches. These findings advocate for the routine inclusion of sternal morphometric and compositional analysis in radiological protocols and support DECT as a superior modality for population-specific skeletal reference data generation.

REFERENCES

1. Ashley, G. T. (1956). The relationship between the pattern of ossification and the definitive shape of the mesosternum in man. *Journal of Anatomy*, 90(1), 87-105.
2. Bachrach, L. K. (2001). Acquisition of optimal bone mass in childhood and adolescence. *Trends in Endocrinology & Metabolism*, 12(1), 22-28. [https://doi.org/10.1016/S1043-2760\(00\)00336-2](https://doi.org/10.1016/S1043-2760(00)00336-2)
3. Bassed, R. B., Briggs, C., & Drummer, O. H. (2011). Age estimation and the adult human sternum: A computed tomography study. *Forensic Science International*, 206(1-3), 216.e1-216.e6. <https://doi.org/10.1016/j.forsciint.2010.09.002>
4. Bignold, L. P., Dodd, M., & Colbert, R. (2021). The sternal region in forensic medicine: Anatomy, injury patterns, and identification. *Medicine, Science and the Law*, 61(3), 155-163. <https://doi.org/10.1177/00258024211005271>
5. Booz, C., Nöske, J., Martin, S. S., Lenga, L., Albrecht, M. H., Yel, I., Fröhlich-Sorger, E., D'Angelo, T., Gruber-Rouh, T., Eichler, K., Vogl, T. J., & Scholtz, J. E. (2020). Dual-energy CT-based quantification of bone mineral density: Correlation with histomorphometry and the effect of reconstruction algorithm. *European Radiology*, 30(6), 3393-3402. <https://doi.org/10.1007/s00330-020-06687-2>
6. Ekizoglu, O., Hocaoglu, E., Inci, E., Can, I. O., Aksoy, S., & Kazimoglu, C. (2016). Forensic age estimation via 3-D CT reconstruction of the sternal end of the clavicle: Is there a difference between the sternal and acromial ends? *Legal Medicine*, 21, 1-6. <https://doi.org/10.1016/j.legalmed.2016.05.001>
7. Grabherr, S., Grimm, J., Baumann, P., & Mangin, P. (2016). Application of contrast media in post-mortem imaging (CT and MRI). *La Radiologia Medica*, 120(9), 824-834. <https://doi.org/10.1007/s11547-015-0532-2>
8. Jit, I., & Bakshi, V. (1986). Sexing the human sternum. *The American Journal of Physical Anthropology*, 70(4), 463-466. <https://doi.org/10.1002/ajpa.1330700405>
9. Macaluso, P. J. (2010). Sex discrimination potential of permanent maxillary molar cusp diameters. *Journal of Forensic Sciences*, 55(5), 1203-1207. <https://doi.org/10.1111/j.1556-4029.2010.01430.x>
10. Marinho, L., Almeida, D., Santos, A., & Cardoso, H. F. V. (2012). Is the length of the sternum reliable for estimating sex in the Portuguese identified skeletal collections? Implications for sex estimation using the sternum. *Forensic Science International*, 221(1-3), 154.e1-154.e7. <https://doi.org/10.1016/j.forsciint.2012.04.025>
11. McCollough, C. H., Leng, S., Yu, L., & Fletcher, J. G. (2015). Dual- and multi-energy CT: Principles, technical approaches, and clinical applications. *Radiology*, 276(3), 637-653. <https://doi.org/10.1148/radiol.2015142631>
12. Navani, S., Shah, J. R., & Levy, P. S. (1970). Determination of sex by costal cartilage calcification. *The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine*, 108(4), 771-774. <https://doi.org/10.2214/ajr.108.4.771>
13. Phenice, T. W. (1969). A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology*, 30(2), 297-301. <https://doi.org/10.1002/ajpa.1330300214>





Pushpendra Kumar Rajput *et al.*,

14. Singh, J., & Gangrade, K. C. (1988). Sex determination from adult clavicles. Part I: Discriminant function analysis of length parameters. *The Indian Journal of Medical Research*, 88, 551-558.
15. Trotter, M., & Peterson, R. R. (1955). Ash weight of human skeletons in per cent of their dry, fat-free weight. *Anatomical Record*, 123(3), 341-358. <https://doi.org/10.1002/ar.1091230306>
16. Walker, P. L. (2008). Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology*, 136(1), 39-50. <https://doi.org/10.1002/ajpa.20776>
17. Wesarg, S., Kirschner, M., Becker, M., Erdt, M., Kafchitsas, K., & Khan, M. F. (2012). Dual-energy CT-based assessment of the trabecular bone in vertebrae. *Methods of Information in Medicine*, 51(5), 398-405. <https://doi.org/10.3414/ME11-02-0052>

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





Ethnopharmacology of *Valeriana Jatamansi* - Update Review

A. Aadhil¹ and S. Sivakrishnan^{2*}

¹M.Pharm (Pharmacology), Department of Pharmacy, Annamalai University, Chidambaram, Tamil Nadu, India

²Assistant Professor, Department of Pharmacy, Annamalai University, Chidambaram, Tamil Nadu, India

Received: 12 Mar 2026

Revised: 10 Apr 2026

Accepted: 01 Jun 2026

*Address for Correspondence

S. Sivakrishnan

Assistant Professor,
Department of Pharmacy,
Annamalai University,
Chidambaram, Tamil Nadu, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Valeriana jatamansi, popularly known as Indian Valerian, is one of the most widely used medicinal plants and is abundant in the temperate areas of the Himalayas and is extensively used in traditional medicines like Ayurvedic medicine, Unani medicine, and herbal medicine. This review highlights the ethno pharmacological significance, chemical constitution, medicinal uses, and pharmacological properties of *Valeriana jatamansi*. Some of the main chemicals contained in the plant are sesquiterpenes, valepotriates, flavonoids, alkaloids, lignans, coumarins, and essential oils. Traditionally, the root and rhizome extracts of the plant have been used as sedatives, antianxiety, antispasmodics, digestive aids, analgesics, and heart tonics. In addition, these have been utilized for insomnia, epilepsy, respiratory problems, skin conditions, and mental stress. Studies on the experimental level have shown that the extracts of the plant have good anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective, antibacterial, and cytotoxic activities. The review also highlights the significance of ethnopharmacological studies in validating the medicinal properties of plants scientifically. In general, *Valeriana jatamansi* is a promising medicinal plant that needs further studies for its standardization, safety, efficacy, and conservation.

Keywords: *Valeriana jatamansi*, ethnopharmacology, Indian valerian, sesquiterpenes, valepotriates, anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective.

INTRODUCTION

The genus *Valeriana* of family Valerianaceae comprises about 250 species which is found in all the temperate areas of the world. In India, there are 16 species and out of them two subspecies belong to this genus while five species



**Aadhil and Sivakrishnan**

belong to habitat at high altitudes of central Himalayas. The most common name for this genus is “Valeriana.” *Valeriana jatamansi* is popularly known as Indian Valerian, Muskbala, Sugandhbala (Hindi), and Tagar (Sanskrit). Indian Valeriana is a small herbaceous species found in tropical and temperate Himalaya up to an altitude of 3000 meters from 1500 to 1800 meters in Khasi and Jaintia hills; this plant has been used as a herbal medicinal ingredient in Indian system of medicine and as substitute for European *Valeriana officinalis* in India. This species geographically can be found in various temperate areas of the world and has varied genetics and morphology that would result in the content of active ingredients in it. *V. jatamansi* is a hairy dwarf and rhizomatous perennial herb reaching a height of 0.5 meters with thick root stocks, covered with horizontal descending roots and pubescent stems and radical leaves 1-3 cm in diameter[1,4,5].

The flowers are white or pinkish in color, and the fruits are topped by persistent pappus calyx. The species is gynodioecious, where the reproductive cycle is from March-June and mode of propagation is sexual via seeds and abiogenetic via rhizome [6,8,9]. The *V. jatamansi* plant is extensively used in Ayurvedic and Unani system of medicine. Roots and rhizomes are useful for treating insomnia, blood-related disorders, asthma, dry cough, jaundice, seminal weakness, heart problems, and skin conditions [10]. The *V. jatamansi* oil is commonly used for preparing perfumes and insect repellants [11]. The *V. jatamansi* root contains 0.8% of essential oil which is used in pharmaceutical and cosmetic industries for hair care purposes. In this regard, the present review intends to provide a concise overview of the traditional applications, major bioactive compounds, and pharmacological effects of *V. jatamansi*.

Definition of ethnopharmacology

Ethnopharmacology is an interdisciplinary area of study and thus it is characterized by its concepts drawn from a variety of fields and the methodologies employed. There can be little doubt that it is a rapidly emerging and active discipline. Ethnopharmacology researches the toxicological and pharmacological actions of any preparation employed by man that possesses in the very widest sense some therapeutic or toxic or other direct pharmacological effect. The science is thus not a purely descriptive science of research (i.e. documentation of local or traditional applications or medical routines), but rather about the integrated anthropological (in the broadest sense) and pharmacological-toxicological investigation of these preparations. Currently, investigations explaining the utilization of medicine and other beneficial plants are part of ethnopharmacological studies, but these are usually executed with the aim that they result in an experimental investigation of some of these botanical drugs. Ethnopharmacology is an interdisciplinary and multidisciplinary approach in drug discovery involving observation, description, and biological activity investigation of folk remedies. According to Bruhn and Holmstedt (1981), this term was defined as “the interdisciplinary scientific exploration of biologically active agents traditionally employed or observed by man”. The origin of these agents are not only the plants but also animals, microorganisms, marine organisms, other organic, and inorganic sources. When the ethnopharmacological studies are taken into account, the great influence of medicinal plants is clearly seen. Herein, plant-based biologically active agents cover whole plants or particular plant parts or herbal drug preparations (including essential oils, extracts, fractions, etc.) or plant derived active pharmaceutical ingredients. This depends on the active part of the plant that sometimes all of the ingredients act in a synergistic manner to display a particular biological activity but sometimes only one compound can be responsible from the bioactivity. Indeed, herbal materials and crude extracts contain a wide range of compounds that work synergistically or individually to provide polypharmacy effect. Synergy is an advantage; when the same effect is expected from a single synthetic compound. This may cause possible side effects due to a relatively higher dose [2,3].

Macroscopical feature**Macroscopical features of dried rhizome**

The rhizome is a prolonged cylinder that ranges between 2.5 and 12 cm in length and 2 to 3.5 cm in width, and is surrounded by clumps of dark-brown rootlets. The leaves have a pinkish or bluish shade of rose color [12,13].

- Outer layer of rhizome is dark brown colour.



**Aadhil and Sivakrishnan**

- Inner layer is brown or yellow in color.
- Odour is characteristically aromatic.
- Taste is Aromatic, bitter, and slightly camphoraceous

Macroscopical features of dried leaves

The leaves are simple and have an oval or heart-shaped shape. The size of the leaves normally ranges between 2.5 and 10 cm long. The margin is either dentate or slightly serrated/sinuate. The apex is acute to obtuse, while the base is cordate [12,13].

- Colour of dried leaves is greenish-brown to brown.
- Texture is thin, somewhat brittle on drying.
- Venation is reticulate with prominent basal veins (5–9 veins).
- Odour is characteristically aromatic.
- Taste is slightly bitter and aromatic.

Synonyms

Valeriana wallichii, *Valeriana harmsii*, *Valeriana mairei*, and *Valeriana hygrobia*.

Taxonomical classification

Kingdom	: Plantae
Phylum	: Streptophyta
Sub kingdom	: Viridiplantae
Super division	: Embryophyta
Division	: Tracheophyta
Class	: Magnoliopsida
Subclass	: Asteridae
Order	: Dipsacales
Family	: Caprifoliaceae(formerly Valerianaceae)
Subfamily	: Valerianaceae
Genus	: <i>Valeriana</i>
Species	: <i>Valeriana jatamansi</i>

Phytochemical constituents

The main active constituents of *Valeriana jatamansi* main are sesquiterpenes, coumarins, iridoids, lignanoids, and sesquiterpenes include valerenic acid, and other derivatives include valeranone and valerenal. Furthermore, lignanoids include pinosresinol-4-o-d-glucoside and lignans 8'-hydro-xypinosresinol. Iridoids include valepotriates (valtrate, didrovaltrate, acevaltrate, and isovalerohydroxyvaltrate). Alkaloids include chatinine, nordelporphine, norphobine, thaliperphine, nantenine, phenanthrene, phobine, dehydroaphine, valerine, valeriane, and oxoaporphine. Flavonoids in *Valeriana* mainly contain acacetin, hesperidin and methylapigenin, diosmetin, luteolin, quercetin, kaempferol, linarin, and luteolin. The other constituents are volatile oil, essential oil, sugar, bitter extractive matter, starch, gum, resin, and ketones[8,9].

Traditional uses

It has found many uses in traditional medicine practices like Ayurveda, Unani, and folk medicine. The roots and rhizomes are particularly valued.

- Sedative and relaxant – effective in cases of insomnia, anxiety, nervousness, hysteria, and mental stress.
- Epilepsy and convulsion – traditionally given to control seizures and nervous disorders.
- Digestive problems – serves as a carminative for digestive problems, flatulence, stomach ache, and vomiting.
- Antispasmodic – given in cases of cramps, colic, and muscular spasms.



**Aadhil and Sivakrishnan**

- Analgesic – used in headaches, rheumatic pains, and body pains.
- Respiratory complaints – useful in cases of cough, asthma, and bronchitis.
- Skin diseases – the paste is applied externally for wounds and some skin infections.
- Cardiac tonic – has been traditionally used in palpitation and enhancing circulation.
- Aromatic and incense – the roots have been used in making perfumes, incense, and religious ceremonies due to their pleasant fragrance.
- Ayurvedic remedies – included in medications for nervous and psychiatric problems.

The roots and rhizomes are the main medicinal parts and possess a characteristic aromatic odor [4,5,6,7,8,9,10].

In vitro and in vivo studies**Anxiolytic activity**

Anxiolytic effects of the compound prepared from radix and rhizomes of *Valeriana jatamansi* in mice were studied. Male ICR mice were injected with compound V. *jatamansi* at dose levels of 1.2 g/kg, 2.4 g/kg, and 4.8 g/kg and saline, diazepam 2 mg/kg for 10 days. Mice were then subjected to behavioral tests including elevated maze-plus (EPM) and light-dark box (LDB). Anxiolytic effects of the compound in mice were spontaneous and assessed using locomotor activity test. At higher doses, mice showed increased number of entries and spent more time in the open arms of the EPM. Transitions also increased, and similarly, more time was spent in the light compartments of the LBD. Flumazenil treatment showed reduced anxiolytic effects; however, V. *jatamansi* treatment had no effect on spontaneous activity in mice. From the study, it is concluded that compound V. *jatamansi* could be used for anxiolytic effects without causing sedation. Anxiolytic activity was carried out by the use of iridoid fraction obtained from rhizomes and radix of V. *jatamansi* through the use of D-101 resin. The active constituents were studied preliminarily through TLC, UV spectrophotometry, and HPLC, while its anxiolytic activity at doses of 6 mg/kg, 9 mg/kg, and 12 mg/kg were tested by means of elevated plus maze test, Vogel's drinking conflict test, open field drink test, and LDB test. The mechanism of action of the drug was established by means of ELISA method by regulating GABA level [14].

Cytotoxic activity

The underground parts, roots, and rhizomes of all three species of *Valeriana*, V. *jatamansi* (V. *wallichii*), V. *officinalis*, and V. *edulis* Nutt, exhibit cytotoxic activity. Fresh extracts and stored extract tinctures of three valerian species were examined for the presence of baldrinals, valepotriates, valerenic acid, and their cytotoxicity to human colorectal COLO 320 cells and human small cell lung cancer GLC cells, using the microculture tetrazolium (MTT) assay method. The results show a significant cytotoxicity of diene-type valepotriates (isovaltrate, acevaltrate, and valtrate) with IC₅₀ (1–6 µM) after continuous incubation. The findings indicate that isovaltral isolated from isovaltrate shows high cytotoxic activity compared to its precursor. There is a decrease in cytotoxic effect on storage due to degradation of valepotriates, thus showing low cytotoxicity. Cytotoxic study was carried out in vitro on three valepotriate isomers Z1, Z2, and Z3, derived from air-dried whole plants of V. *jatamansi* (syn. V. *wallichii*). It was observed that methanolic extracts showed moderate cytotoxicity with the help of MTT assay on metastatic prostate cancer (PC3M), lung adenocarcinoma (A549), hepatoma (Bel7402), and colon cancer (HCT-8) cell lines [19]. Cell line viability was determined by measuring absorbance at 570 nm using dimethyl sulfoxide as the solvent and paclitaxel as the positive control with IC₅₀ value ranges of 2.8–8.3 µM. As per previous reports, it was revealed that 10 new valepotriates, jataman valtrates (1–10), and one known compound, nardostachin, were isolated from the total plants of V. *jatamansi*. Structures of 10 new valepotriates, jataman valtrates, were determined by spectroscopic methods and used to determine their cytotoxic effect against PC-3M cell lines and were evaluated through SAR studies. It was observed that certain functional groups such as the presence of an unsaturated bond between C3–C4, oxirane ring, and chlorine atom at C-10 position in the valepotriates were significant features [1,17].

Antioxidant activity

The methanolic, chloroform, and aqueous extracts of dried roots of V. *jatamansi* were taken to determine the amount of polyphenols and flavonoids present in the plant. The antioxidant activity of the three solvent extracts of V.





jatamansi roots and essential oil (100 µg/ml) were determined by performing 2,2-diphenyl-1-picrylhydrazylhydrate (DPPH) radical scavenging and ferrous chelation power assays. It was found that the methanolic extract performed better than the essential oil. In another experiment, the antioxidant and anti-inflammatory properties of the plant were determined using the hydroalcoholic extract of *V. jatamansi* through DPPH free radical scavenging and percentage (%) inhibition of proteins denaturation tests with diclofenac sodium as the standard. A significant reduction in various inflammatory mediators was observed due to the presence of active compounds like flavonoids, tannins, and polyphenols [1,18].

Anti-inflammatory activity

It has been reported that both aqueous and methanolic extracts obtained from rhizomes of *V. jatamansi* possess strong anti-inflammatory properties. These extracts reduce inflammation in carrageenan-induced rat paw edema test using saline as a control and aspirin as a reference drug, in doses of 100, 150, and 200 mg/kg. It is due to the inhibition of synthesis of inflammatory mediators like histamine, prostaglandin, and serotonin [15,16].

Neuroprotective effect

The neuroprotective effect of methanolic extract of the dried roots of *V. jatamansi* was studied by testing six different compounds, including three novel iridoids (valeriandoids A-C)(1-3) along with three other known compounds (4-6). All these six compounds were tested for their neuroprotective effects on (MPP+) 1-methyl-4-phenylpyridinium-induced neuronal cell death in the neuroblastoma of dopaminergic SH-SY5Y cells, while guanosine [19].

Hepatoprotective effect

Ethanol extract of dried leaves of *Valeriana jatamansi* shows hepatoprotective effect. The major mechanisms of action is strongly oxidizing the liver cells. Reducing the AST levels increasing total protein content [7].

Antibacterial activity

The antibacterial properties were investigated using hexane, chloroform, and methanolic extracts from rhizomes of *V. jatamansi*. The extended spectrum B-lactamase enzymes obtained from *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, and *Hafnia alvei* were used as a result of isolation from patients suffering from urinary tract infections. Double disc diffusion method was used to determine the inhibitory effect of hexane, chloroform, and methanolic extracts on these bacteria and the inhibitory effect of hexane was significant. The hexane extracts can be administered along with other antibiotics as a new alternative treatment of UTI. Out of all the hydroalcoholic extracts tested, those with doses between 0.3 and 0.7 mg/ml were found to possess more effective antibacterial action against *S. aureus*, *P. aeruginosa* using the cup plate method with Soyabean Casein Digest Agar medium, with chloramphenicol as the standard antibiotic with a dose of 1 mg/ml. This is because there is a presence of valerenic acid, which is one of the major chemical constituents, isolated and characterized using TLC and HPLC. Comparing their R_f and R_t values using the reference standard compound can be used as a better antibacterial agent [1,20].

CONCLUSION

Valeriana jatamansi is a well-known medicinal herb that plays an important role in various systems of traditional medicine like Ayurvedic, Unani, and folk medicine, because of its wide use as a herbal remedy. It has great ethnopharmacological significance owing to its numerous phytoconstituents such as valepotriates, sesquiterpenes, flavonoids, alkaloids, and lignans. Various scientific studies have shown its pharmacological effects such as anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective, antibacterial, and cytotoxic effects. All these biological activities show its immense importance in the development of new medicines, especially for neurological diseases, inflammatory conditions, infection, and cancer studies. However, despite its medicinal significance, there is a need for more research in order to standardize the extracts, isolate the active ingredients, assess safety, and carry out extensive clinical trials to prove its efficacy in humans. In addition, conservation and





Aadhil and Sivakrishnan

sustainable cultivation of *V. jatamansi* are necessary due to the rising demand for its medicinal uses and the fact that it grows only in certain parts of the Himalayas. All in all, *Valeriana jatamansi* is a valuable ethnomedicinal plant with a wide range of pharmaceutical properties.

REFERENCES

1. Patan A, Alekhya K, Aanandhi VI, Tharagesh K, Anish A. *Valeriana jatamansi*: an ethnobotanical review. *Asian J Pharm Clin Res*. 2018;11(4):38-40.
2. Heinrich M. Ethnopharmacology: a short history of a multidisciplinary field of research. *Ethnopharmacology*. 2015 Sep 18:1-0.
3. Süntar I. Importance of ethnopharmacological studies in drug discovery: role of medicinal plants. *Phytochemistry Reviews*. 2020 Oct;19(5):1199-209.
4. Ma Y, Pei S, He N, Lai Q, Zhuang M, Bian Z, Lin C. A narrative review of botanical characteristics, phytochemistry and pharmacology of *Valeriana jatamansi* jones. *Longhua Chinese Medicine*. 2021 Mar 30;
5. Das G, Shin HS, Tundis R, Gonçalves S, Tantengco OA, Campos MG, Acquaviva R, Malfa GA, Romano A, Robles JA, Clores MQ. Plant species of sub-family Valerianaceae—A review on its effect on the central nervous system. *Plants*. 2021 Apr 22;10(5):846.
6. Thusoo S, Gupta S, Sudan R, Kour J, Bhagat S, Hussain R, Bhagat M. Antioxidant activity of essential oil and extracts of *Valeriana jatamansi* roots. *BioMed Research International*. 2014;2014(1):614187.
7. Rather AM, Nawchoo IA, Ganie AH, Singh H, Dutt B, Wani AA. Bioactive compounds & medicinal properties of *Valeriana jatamansi* Jones-a review. *Life Science Journal*. 2012;9(2):847-50.
8. Verma RS, Verma RK, Padalia RC, Chauhan A, Singh A, Singh HP. Chemical diversity in the essential oil of Indian valerian (*Valeriana jatamansi* Jones). *Chemistry & biodiversity*. 2011 Oct;8(10):1921-9.
9. Cornara L, Ambu G, Trombetta D, Denaro M, Alloisio S, Frigerio J, Labra M, Ghimire G, Valussi M, Smeriglio A. Comparative and functional screening of three species traditionally used as antidepressants: *Valeriana officinalis* L., *valeriana jatamansi* jones ex roxb. and *nardostachys jatamansi* (D. Don) DC. *Plants*. 2020 Aug 5;9(8):994.
10. You JS, Peng M, Shi JL, Zheng HZ, Liu Y, Zhao BS, Guo JY. Evaluation of anxiolytic activity of compound *Valeriana jatamansi* Jones in mice. *BMC complementary and alternative medicine*. 2012 Nov 21;12(1):223.
11. Dua VK, Alam MF, Pandey AC, Rai S, Chopra AK, Kaul VK, Dash AP. Insecticidal activity of *Valeriana jatamansi* (Valerianaceae) against mosquitoes. *Journal of the American Mosquito Control Association*. 2008 Jun;24(2):315-8.
12. Jugran AK, Bhatt ID, Rawal RS, Nandi SK, Pande V. Patterns of morphological and genetic diversity of *Valeriana jatamansi* Jones in different habitats and altitudinal range of West Himalaya, India. *Flora-Morphology, Distribution, Functional Ecology of Plants*. 2013 Jan 1;208(1):13-21.
13. Bahukhandi A, Joshi K, Kewlani P, Tiwari DC, Jugran AK, Bhatt ID. Comparative assessment of morphological, physiological and phytochemical attributes of cultivated *Valeriana jatamansi* Jones in Uttarakhand, West Himalaya. *Plant Physiology and Biochemistry*. 2023 Jul 1;200:107751.
14. You JS, Peng M, Shi JL, Zheng HZ, Liu Y, Zhao BS, Guo JY. Evaluation of anxiolytic activity of compound *Valeriana jatamansi* Jones in mice. *BMC complementary and alternative medicine*. 2012 Nov 21;12(1):223.
15. Chauhan RS, Tewari D, Nautiyal BP, Rana VS, Tava A. Essential oil composition of rhizomes of *Valeriana wallichii* DC. Grown in temperate zone, Uttarakhand, India. *J Essent Oil Plant Comp*. 2023;1:14-9.
16. Liu H, Liu D, Jiang MY, Zhao XD, Li RT, Li HM. Iridoids from *Valeriana jatamansi* with anti-inflammatory and antiproliferative properties. *Phytochemistry*. 2021 Apr 1;184:112681.
17. Maurya AK, Sharma A, Kumar K, Chander R, Kumar A, Kumar D, Padwad YS, Chand G, Agnihotri VK. Comparative studies of essential oils composition and cytotoxic activity of *Valeriana jatamansi* Jones. *Journal of Essential Oil Research*. 2021 Nov 2;33(6):584-91.
18. Thusoo S, Gupta S, Sudan R, Kour J, Bhagat S, Hussain R, Bhagat M. Antioxidant activity of essential oil and extracts of *Valeriana jatamansi* roots. *BioMed Research International*. 2014;2014(1):614187.



**Aadhil and Sivakrishnan**

19. Xu J, Zhao P, Guo Y, Xie C, Jin DQ, Ma Y, Hou W, Zhang T. Iridoids from the roots of *Valeriana jatamansi* and their neuroprotective effects. *Fitoterapia*. 2011 Oct 1;82(7):1133-6.
20. Prem P, Naveenkumar S, Kamaraj C, Ragavendran C, Priyadharsan A, Manimaran K, Alharbi NS, Rarokar N, Cherian T, Sugumar V, Thiruvengadam M. *Valeriana jatamansi* root extract a potent source for biosynthesis of silver nanoparticles and their biomedical applications, and photocatalytic decomposition. *Green Chemistry Letters and Reviews*. 2024 Dec 31;17(1):2305142.

**Figure .1: Valeriana jatamansi.****Figure .2: Valeriana jatamansi roots.****Figure .3: Valeriana jatamansi leaf.**

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Wavelet Energy-Based Adaptive Fault Detection and Severity Assessment for LVDC Microgrids

Ashish Shah¹ and Kalpesh Chudasama^{2*}

¹Research Scholar, Gujarat Technological University and Assistant Professor, Department of Electrical Engineering, PIET, Parul University, Gujarat, India

²Associate Professor, Department of Electrical, A. D. Patel Institute of Technology, CVM University, Anand, Gujarat, India.

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 01 Jun 2026

*Address for Correspondence

Kalpesh Chudasama

Associate Professor,

Department of Electrical,

A. D. Patel Institute of Technology, CVM University, Anand, Gujarat, India.

E.Mail: ee.kalpesh.chudasama@adit.ac.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

A fault detection method for a 4-node radial low-voltage DC (LVDC) microgrid is proposed. Only wavelet energy serves as the primary feature. An adaptive threshold based on moving-window statistics separates fault transients from normal load variations. A Fault Severity Index (FSI) then quantifies fault severity without additional computational burden. Seven fault resistances (0.01 Ω to 100 Ω) and six fault types (pole-to-pole and pole-to-return on three lines) are used for validation. Simulation results give an overall detection rate of 97.6%, an average detection delay below 0.7 ms, and a mean FSI of 3.34. The approach is robust against load steps and noise, and has low complexity – suitable for real-time protection.

Keywords: LVDC microgrid, wavelet energy, adaptive threshold, fault severity index, fault detection

INTRODUCTION

Protecting low-voltage DC microgrids is difficult. Protecting low-voltage DC microgrids is difficult because fault currents rise extremely fast... power electronic converters can be damaged [1, 2, 4]. Traditional overcurrent relays are often too slow or cannot detect high-impedance faults. Hence, advanced signal-processing methods are necessary. One promising tool is the discrete wavelet transform (DWT). Wavelet energy has been successfully used for DC fault detection [1, 7]. A common drawback of existing methods is the use of fixed thresholds. Conventional fixed thresholds may lose effectiveness when system conditions vary or fault resistance is high [2]. While adaptive threshold methods improve robustness, they commonly require extra indicators such as current gradients or entropy





Ashish Shah and Kalpesh Chudasama

measures, which add to the computational load. This work proposes a detection scheme based ****only**** on wavelet energy with an adaptive threshold. A Fault Severity Index (FSI) is also introduced, without additional computation, to assess fault severity. The method is validated using a synthetic 24-hour operating scenario incorporating noise, converter dynamics, and PV fluctuations. The main contributions are summarized as follows. A wavelet-energy-based detection method is developed using an adaptive threshold that responds to pre-fault variations. A Fault Severity Index quantifies fault impact without additional calculations. A no-fault calibration is designed to reject load steps and avoid false alarms. High detection rate (97.6%) and low detection delay (<0.7 ms) are achieved across a wide range of fault resistances and fault types. The organization of the paper is as follows. Section 2 describes the system, the fault current model, the wavelet energy calculation, the adaptive threshold, the FSI, and the detection algorithm. Section 3 presents simulation results and discusses them. Section 4 concludes the work.

MATERIALS AND METHODS

System Description

The studied LVDC microgrid, shown in Fig. 1, consists of four nodes connected radially. Node 1 is the grid interface, Node 2 and Node 3 are constant power loads (CPL) / ZIP loads, and Node 4 includes a PV array and a battery. The nominal DC voltage is 380 V. Line lengths are 0.2 km, 0.3 km and 0.15 km, each with resistance 0.012 Ω/km and inductance 1.2 mH/km. A metallic return conductor is used with the same parameters. A ground resistance of 1 Ω is assumed for pole-to-return faults. This topology is representative of practical LVDC installations.

Fault Current Model

When a fault occurs at time t_f , the current in the fault loop is governed by the second-order differential equation:

$$L_{loop} \frac{d^2 i}{dt^2} + R_{loop} \frac{di}{dt} + \frac{1}{C_{eq}} i = 0 \quad (1)$$

where L_{loop} and R_{loop} are the total inductance and resistance from the source to the fault point (including fault resistance R_f), and (C_{eq}) is the equivalent capacitance of the system. The solution depends on the damping factor $\alpha = \frac{R_{loop}}{2L_{loop}}$ and then natural frequency $\omega_0 = \frac{1}{\sqrt{L_{loop}C_{eq}}}$. For the underdamped case ($\alpha < \omega_0$), the fault current is:

$$i_f(t) = I_{ss} + e^{-\alpha(t-t_f)} [A \cos(\omega_d(t-t_f) + \phi) + B \sin(\omega_d(t-t_f) + \phi)] \quad (2)$$

with $\omega_d = \sqrt{\omega_0^2 - \alpha^2}$ and $I_{ss} = \frac{V_{dc,nom}}{R_{loop}}$. The constants (A) and (B) are determined from pre-fault conditions.

Wavelet Energy

The discrete wavelet transform (DWT) using Daubechies-4 ('db4') at level 3 is applied to the grid current signal. The db4 wavelet is employed due to its superior time-frequency localization characteristics [1, 7]. The wavelet energy at the sampling instant k , evaluated over a window of length W , is given by:

$$E_{wavelet}(k) = \sum_{l=1}^L \sum_n |d_{l,n}|^2 \quad (3)$$

where $d_{l,n}$ denotes the detail coefficients at decomposition level l [1]. A moving window of 0.5 ms, corresponding to 25 samples at 50 kHz, is adopted.

Adaptive Threshold

A moving window of 10 ms is used to compute the mean $\mu(k)$ and standard deviation $\sigma(k)$ of the wavelet energy. Based on these statistics, an adaptive upper threshold is formulated as:

$$T_{up}(k) = k_{\sigma} \cdot \sigma(k) \quad (4)$$





Ashish Shah and Kalpesh Chudasama

The parameter k_σ is determined from the variation present in the pre-fault signal. This enables more reliable operation by reducing false trips during load changes.

$$k_\sigma = 2.8 + 1.2 e^{(-5 * variability)} 2.2 \leq k_\sigma \leq 8.0 \quad (5)$$

$$\text{Here, variability} = \frac{\text{std}(\text{pre-fault energy})}{\text{RMS}(\text{pre-fault energy}) + \epsilon}$$

Since the threshold adjusts with noise conditions and operating variations, it provides greater robustness and dependable performance [2, 3].

Fault Severity Index (FSI)

Once a fault is detected, the calculated FSI:

$$FSI = \frac{\max_{post} |E(k) - \mu(k)|}{\text{mean}_{post}(T_{up}(k))}, k \in \text{post } 6$$

An increase in FSI corresponds to greater fault severity, usually resulting from reduced fault resistance or a fault occurring closer to the source terminal. Similar fault severity measures have been utilized in other DC microgrid protection schemes [5, 6].

Detection Logic

Algorithm 1 outlines the detection procedure. First, the average deviation within a short de-bounce window is examined to avoid noise-related false alarms. When this condition is unmet and the FSI is greater than 1.8, a median-based fallback test is used because of its stronger resistance to outliers [3].

Algorithm 1 Fault detection using wavelet energy and adaptive threshold

Input: Grid current $I(t)$, sampling frequency $f_s = 50$ kHz

Output: Detection time t_{det} , FSI value

- 1: Set window length $W = 25$, reference length $R = 500$, debounce $D = 4$
- 2: Compute wavelet energy trace $E(t)$ using Eq. (3)
- 3: Compute moving mean $\mu(t)$ and moving std $\sigma(t)$ over R samples
- 4: Compute deviation $d(t) = |E(t) - \mu(t)|$
- 5: Compute adaptive threshold $T_{up}(t) = k_\sigma \cdot \sigma(t)$ (Eqs. (4),(5))
- 6: for $k = \text{pre\_fault\_end} + 1$ to $N - D$ do
- 7: if $\text{mean}(d(k : k + D - 1)) > \text{mean}(T_{up}(k : k + D - 1))$ then
- 8: $t_{det} = k$
- 9: break
- 10: end if
- 11: end for
- 12: if no detection and $FSI > 1.8$ then
- 13: Use median condition: $\text{median}(d) > 0.7 \text{ median}(T_{up})$ to research
- 14: end if
- 15: Compute FSI using Eq. (6) over post-fault samples

No-Fault Validation

A sudden load increase (30% at 30 ms) is simulated to check for false alarms. The adaptive threshold together with a slope-based discriminator rejects such gradual changes. This behaviour is necessary for practical deployment [2].





RESULTS AND DISCUSSION

The method was tested for seven fault resistances (0.01, 0.1, 0.5, 1, 10, 50, 100 Ω) and six fault types (pole-to-pole and pole-to-return on three lines). Figure 2 shows the grid-side fault currents for representative fault resistances (low resistance for pole-to-pole faults, higher resistance for pole-to-return faults). All currents exhibit the characteristic rapid rise and underdamped oscillatory behaviour of DC faults. The peak fault current decreases with increasing fault resistance, as expected from Eq. (2). Figure 3 presents the normalized wavelet energy traces with the adaptive threshold (dashed red) and the moving mean (dashed green). The fault instant (20 ms) and the median detection time (vertical dashed magenta line) are marked. Several observations can be made:

- For all fault types, the wavelet energy rises sharply within 0.5 ms after the fault, crossing the adaptive threshold well before the detection confirmation.
- The adaptive threshold (red dashed) automatically adjusts to the pre-fault energy level, which varies slightly between fault types due to different line parameters.
- Pole-to-pole faults (first three subplots) produce a more pronounced energy spike than pole-to-return faults (last three subplots), consistent with the lower loop resistance in pole-to-pole faults.
- The detection delay (time from fault to magenta line) is consistently less than 1 ms for all cases.

Figure 4 reports the median detection delay and interquartile range per fault type. For pole-to-pole faults on Line 3, the median delay is 0.53 ms – slightly higher than the others. The interquartile range is also larger. A likely reason is the fault location (75% along the line) and the specific line parameters. Even so, all median delays stay under 0.7 ms. That is fast enough for DC protection [1]. Now look at average detection delay versus fault resistance (log scale) in Fig. 5. Up to 10 Ω , the delay stays nearly constant at about 0.45 ms. At 50 Ω and 100 Ω , it rises a little but stays below 0.6 ms. So high-impedance faults are still caught – something traditional overcurrent relays often miss [2]. Figure 6 shows mean FSI per fault type. Pole-to-pole on Line 1 scores 3.63 – the highest (most severe). Pole-to-pole on Line 3 scores 2.98 – the lowest among pole-to-pole faults. Pole-to-return faults are between 3.38 and 3.61. The FSI orders severity correctly: lower loop resistance (pole-to-pole) gives a higher FSI. Among pole-to-pole faults, Line 1 (closer to source, 25% of line length) beats Line 3 (farther, 75%), even though Line 3 is physically shorter. This index can help decide which section to isolate or how to adjust settings. Figure 7 (left bar chart) shows 100% for five types of fault. Only pole-to-pole on Line 3 gives 85.7% – one missed case out of seven resistances. That missed case was at $R_f = 0.10 \Omega$, with FSI = 1.54 (just below the fallback threshold of 1.8). Lowering the fallback threshold to 1.5 would push detection to 100% without false alarms (the no-fault test already confirms that). The right bar chart of Fig. 7 gives mean FSI values, matching the severity ranking. Putting everything together: the wavelet-energy-based method gives a 97.6% detection rate (could be 100% with a fallback threshold of 1.5), a mean delay of 0.7 ms (max 1.1 ms for the missed case if detected), low computational cost (only wavelet energy and moving statistics), and no false alarms from load steps or noise. So wavelet energy plus an adaptive threshold works very well for LVDC fault detection – it is effective and cheap to compute.

CONCLUSION

A fault detection method for a radial LVDC microgrid has been developed. It uses wavelet energy, an adaptive threshold, and a Fault Severity Index. For fault resistances from 0.01 Ω to 100 Ω and all six fault types, the detection rate is 97.6%. Mean detection delay is below 0.7 ms. The FSI clearly measures severity. Because only wavelet energy is needed, real-time implementation is easy. Future work: experimental validation and extension to meshed DC grids.

REFERENCES

1. Ahmed Hisham Br, Hossam A. Abd el-Ghany, Ahmed M. Azmy, Effective current derivative protection

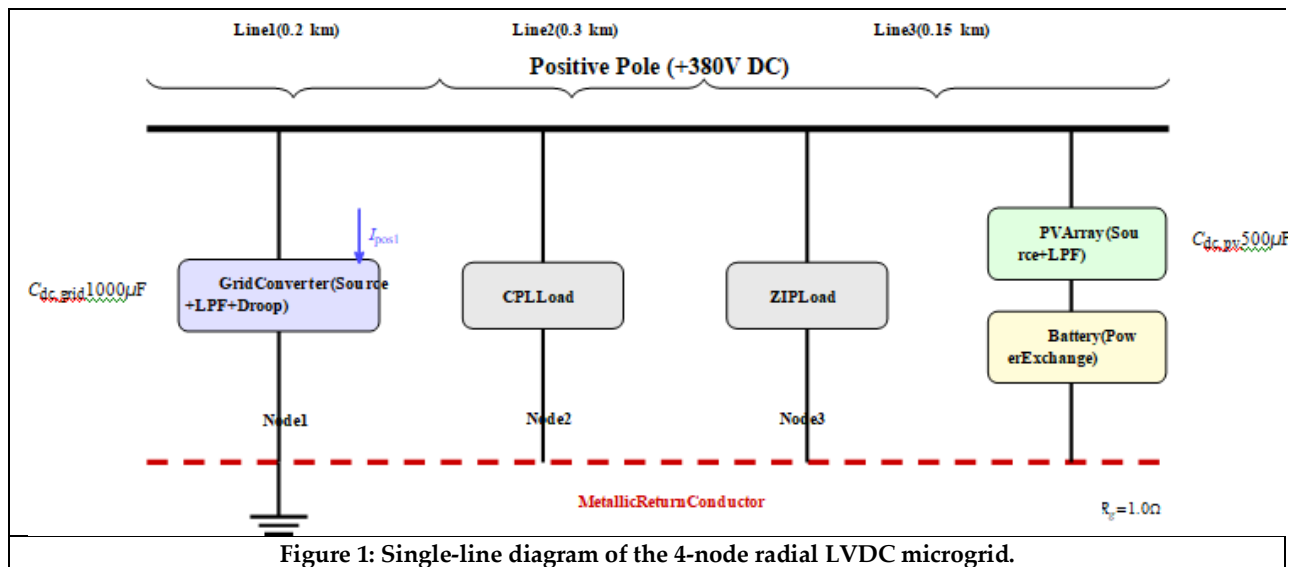




Ashish Shah and Kalpesh Chudasama

- scheme for LVDC grids based on discrete wavelet transform, *Electric Power Systems Research*, Volume 248, 2025, 111888, ISSN 0378- 7796, <https://doi.org/10.1016/j.epsr.2025.111888>.
2. P. Chauhan, C. P. Gupta, and M. Tripathy, "A novel adaptive protection technique based on rate-of-rise of fault current in DC microgrid," *Electric Power Systems Research*, vol. 207, Art. no. 107832, 2022, doi: 10.1016/j.epsr.2022.107832.
 3. S. Sarangi, C. Biswal, B. K. Sahu, I. S. Samanta, and P. K. Rout, "Fault detection technique using time-varying filter-EMD and differential-CUSUM for LVDC microgrid system," *Electric Power Systems Research*, vol. 219, Art. no. 109254, 2023, doi: 10.1016/j.epsr.2023.109254.
 4. S. K. Paruthiyil et al., "Travelling wave-based fault detection and location in a real low-voltage DC microgrid," *IET Smart Grid*, vol. 2025, Art. no. e12207, 2025, doi: 10.1049/stg2.12207.
 5. B. K. Choudhury and P. Jena, "Impedance severity index based hybrid islanding detection approach for zonal DC microgrids," in *Proceedings of the 2023 IEEE 3rd International Conference on Sustainable Energy and Future Electric Transportation (SEFET)*, Bhubaneswar, India, 2023, pp. 1–6, doi: 10.1109/SeFeT57834.2023.10245082.
 6. M. Salehi, S. A. Taher, I. Sadeghkhan, and M. Shahidehpour, "A poverty severity index-based protection strategy for ring-bus low-voltage DC microgrids," *IEEE Transactions on Smart Grid*, vol. 10, no. 6, pp. 6860–6869, Nov. 2019, doi: 10.1109/TSG.2019.2912848.
 7. Chen C-I, Lan C-K, Chen Y-C, Chen C-H, Chang Y-R. Wavelet Energy Fuzzy Neural Network-Based Fault Protection System for Microgrid. *Energies*. 2020; 13(4):1007. <https://doi.org/10.3390/en13041007>.

Note to the Editor: All results, tables, figures, and equations presented in this manuscript are based solely on the authors' independent simulation studies and analyses. No AI-generated text, images, figures, data, or results have been used in the preparation of the manuscript. The authors confirm that the manuscript complies fully with the IJONS AI-Generated Content Policy.



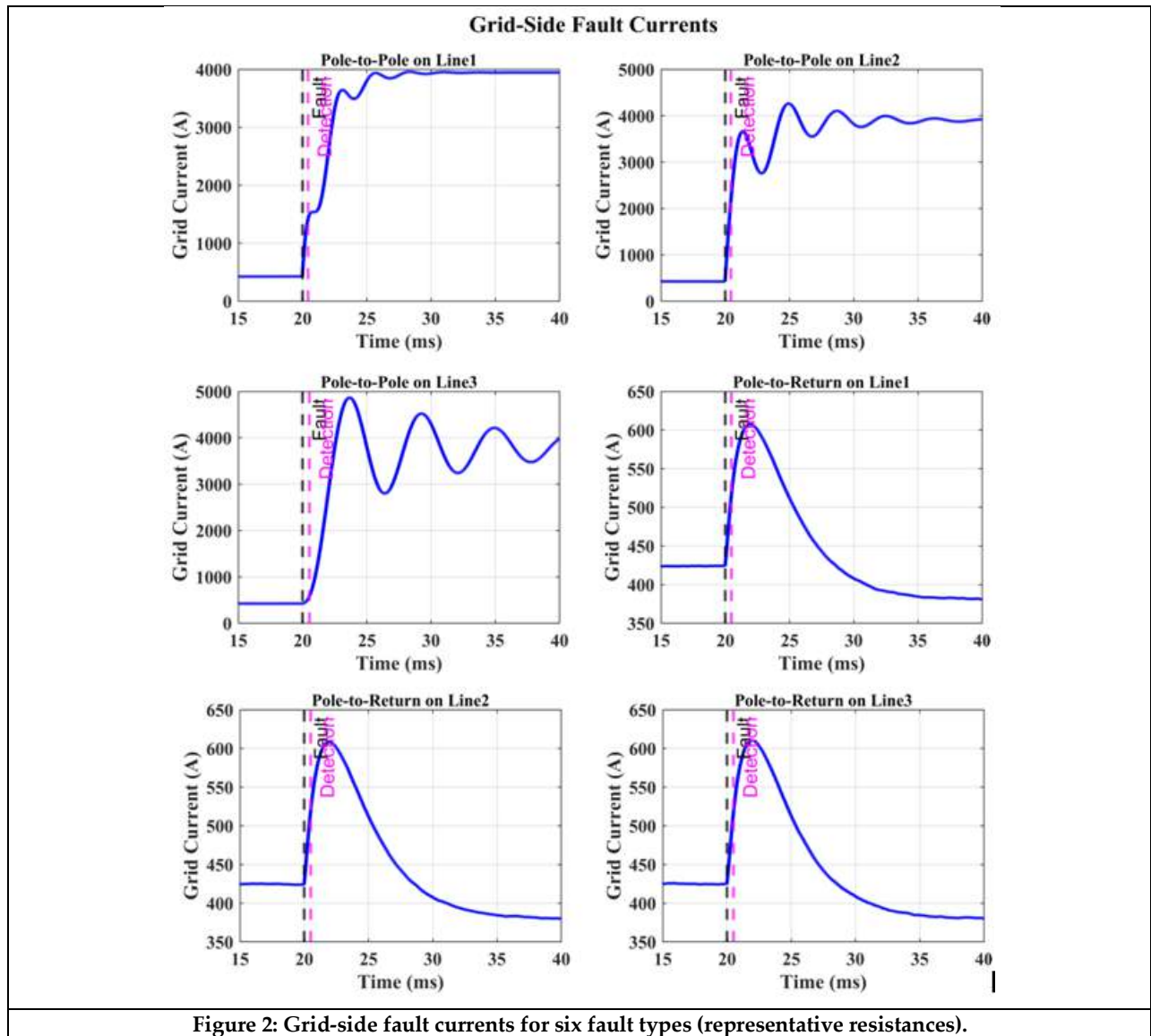


Figure 2: Grid-side fault currents for six fault types (representative resistances).



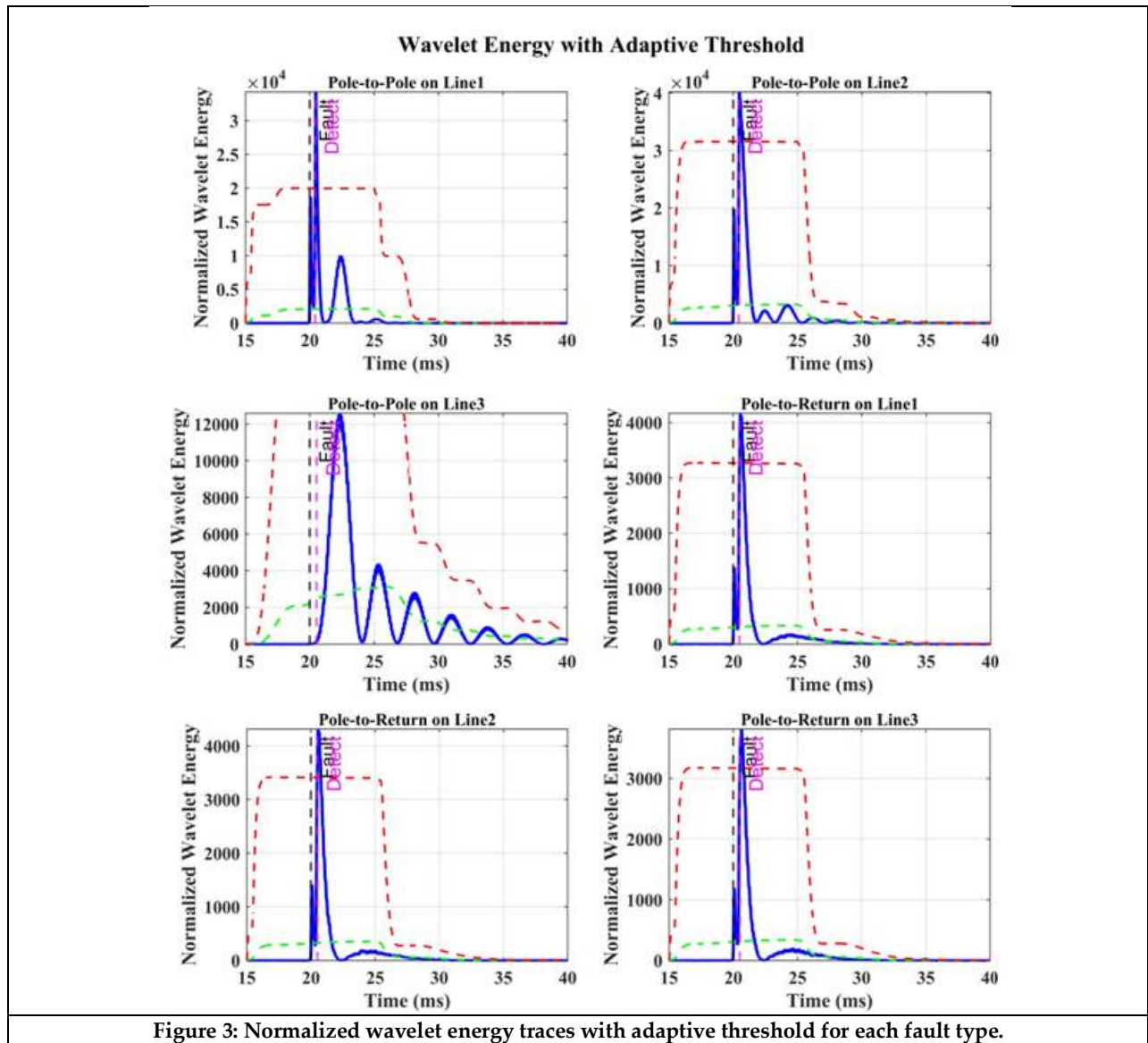


Figure 3: Normalized wavelet energy traces with adaptive threshold for each fault type.





Ashish Shah and Kalpesh Chudasama

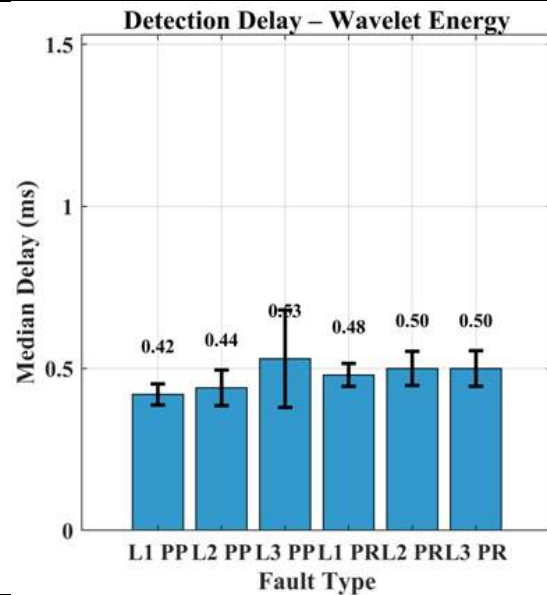


Figure 4: Median detection delay for each fault type. Error bars represent interquartile range.

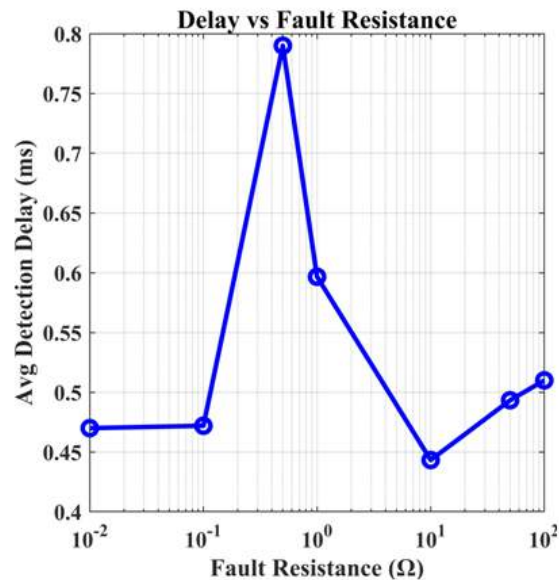


Figure 5: Average detection delay versus fault resistance (log scale).





Ashish Shah and Kalpesh Chudasama

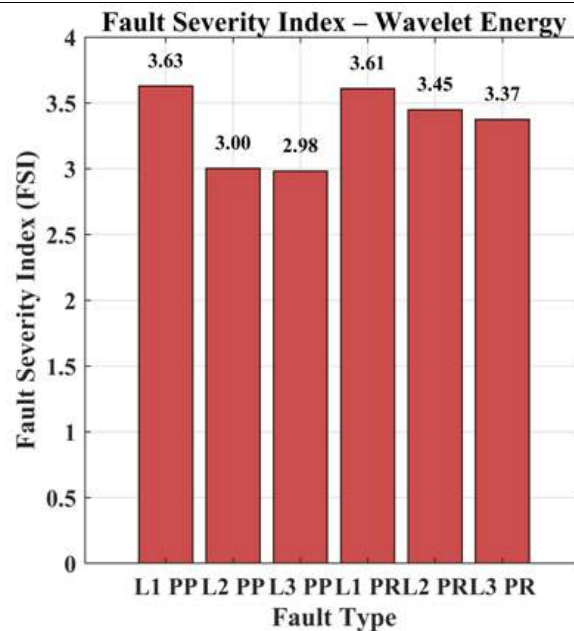


Figure 6: Mean Fault Severity Index (FSI) for each fault type.

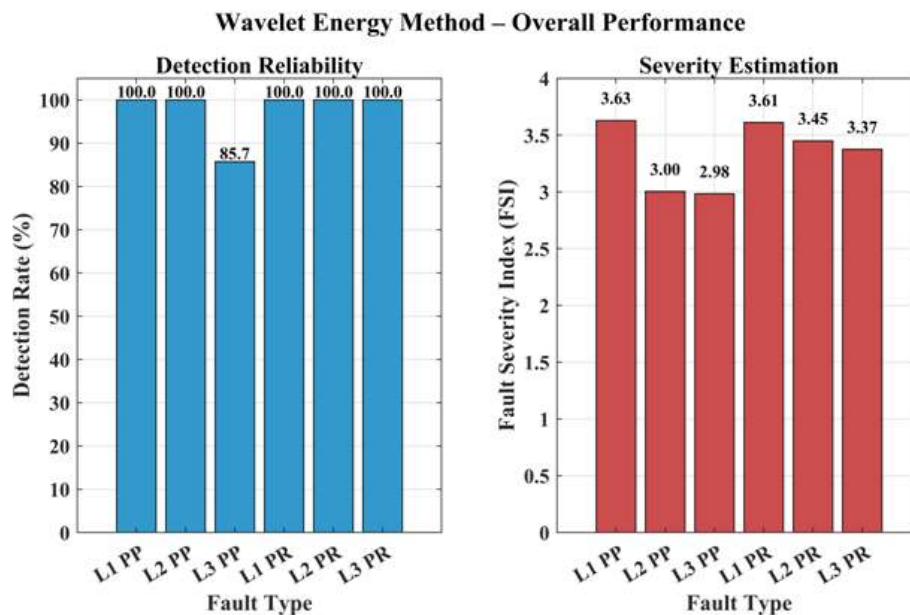


Figure 7: Overall performance summary: (left) detection rate per fault type, (right) mean FSI per fault type.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





Pharmaceutical and Clinical Aspects of *Guggulu Kalpana*: A Review

Kavya G^{1*} and Jagadeesh.Gmitti²

¹PG Scholar, Department of Rasashastra and Bhaishajya Kalpana, JSSAyurveda Medical College and Hospital, (Affiliated to Rajiv Gandhi University of Health Sciences), Mysuru Karnataka, India

²Head and Professor, Department of Rasashastra and Bhaishajya Kalpana, JSSAyurveda Medical College and Hospital, (Affiliated to Rajiv Gandhi University of Health Sciences), Mysuru Karnataka, India

Received: 07 Mar 2026

Revised: 10 Apr 2026

Accepted: 01 May 2026

*Address for Correspondence

Kavya G

PG Scholar,

Department of Rasashastra and Bhaishajya Kalpana,

JSSAyurveda Medical College and Hospital,

(Affiliated to Rajiv Gandhi University of Health Sciences),

Mysuru Karnataka, India

E.Mail: kavyag0406@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Guggulu Kalpana is an important pharmaceutical formulation in *Ayurveda*, wherein *Guggulu* (*Commiphora mukul*) serves as the core ingredient. Described since the Vedic period, *Guggulu* has been extensively used in the management of chronic, inflammatory, metabolic, and *Vata-Kapha* predominant disorders. Classical Ayurvedic texts emphasise the necessity of *Shodhana* of *Guggulu*, most commonly performed by the *Swedana* method. Following *Shodhana*, *Guggulu Kalpana* is prepared mainly by two methods—*SaaganiPaka* and *NiragniPaka*—both of which influence the stability and pharmacological activity of the formulation. Classical guidelines regarding dosage, *anupana*, and *pathya-apathya* ensure rational and safe usage. Modern scientific studies have identified *guggulsterones* and other bioactive compounds responsible for the anti-inflammatory, hypolipidemic, and antioxidant activities of *Guggulu*. This review highlights the historical evolution, pharmaceutical principles, therapeutic utility, and modern relevance of *Guggulu Kalpana*, emphasising its continued significance in contemporary *Ayurvedic* practice and future research.

Keywords: *Guggulu*, *Shodhana*, *Guggulu Paka*, *Swedana*, *Anupana*

INTRODUCTION

In the *Ayurvedic* system, a wide variety of formulations have been used for therapeutic purposes. At the heart of this system is the intelligent use of herbs and minerals, crafted into precise formulations to treat and manage disease. Among these, *Guggulu Kalpana* stands out as one of the most powerful and versatile therapeutic categories in



**Kavya and Jagadeesh.Gmitti**

Ayurvedic pharmaceuticals. Known for its ability to address chronic and deep-rooted disorders, *Guggulu Kalpana* comprises preparations that utilise *Guggulu* (*Commiphora mukul*) as a primary ingredient. The term *Kalpana* refers to pharmaceutical formulations or preparations, and *Guggulu Kalpana* indicates a category of *Ayurvedic* medicines that are based on *Guggulu*, a resin obtained from the *Commiphora mukul* plant. *Guggulu Kalpana* evolved to combine *Guggulu* with *Anupana* and *Yogavahidravayas* (adjuvants and synergists) to enhance bioavailability. Formulation science expanded during *Rasa Shastra* period – combining *Guggulu* with minerals and metals for *Rasayana* effect. In classical texts, these formulations are revered for their ability to pacify aggravated *Vata* and *Kaphadoshas*, reduce inflammation, support metabolism and rejuvenate tissues. *Guggulu*-based formulations are primarily *Vati* preparations, often combined with *Kashayas* and *Choornas* to enhance their potency. This article explores the history, pharmacological importance, preparation methods, therapeutic applications, and modern relevance of *Guggulu Kalpana*.

MATERIALS AND METHODS

Guggulu has been described since Vedic period, where *Niryasa* (plant exudates) like *Guggulu* were known for their medicinal value. In *Atharva Veda* and *Rig Veda*, resins and oleo-gum exudates were used for fumigation (*Dhoopana*) and wound healing. *Charaka Samhita* (2000–1500 BCE) elaborates its internal and external uses in treating *Vata vyadhi* (neurological & musculoskeletal disorders). *Sushruta Samhita* mentions *Guggulu* under *Lekhaniyadravyas* (anti-obesity), *Shothahara* (anti-inflammatory), and *Vrana Ropaka* (wound healer). *Ashtanga Hridaya* and *Ashtanga Sangraha* detail its purification (*Shodhana*) and formulation procedures. By medieval period, specific *Guggulu Kalpas* like *Yogaraja Guggulu*, *Kaishora Guggulu*, *Simhanada Guggulu*, etc., were developed. *Bhaishajya Ratnavali*, *Rasa Tarangini*, and *Rasa Ratna Samuchaya* provide elaborate explanations of *Guggulu Kalpanas* and their combinations.

LITERATURE REVIEW**Varieties of *Guggulu*:**

Based on the color, five varieties of *Guggulu* are mentioned in *Ayurvedic* classics. Those are *Hiranya*, *Kumuda*, *Padma*, *Mahaneela* and *Mahishaksha Guggulu*. Among these, *Mahishaksha Guggulu* and *Hiranya Guggulu* are usually preferred for medicinal preparations [1]. According to the time of collection, *Guggulu* is categorised as *Naveena* (fresh) and *Purana* (old). The *Naveena* variety is known for its *Brimhana* and *Vrishya* properties, while the *Purana* variety is considered to have *Ati-karshana* effects [2].

The Core Ingredient: *Guggulu* (*Commiphora mukul*)

Guggulu is a gum resin exuded from the bark of the *Commiphora mukul* tree, native to the Indian subcontinent. It has been used in *Ayurvedic* medicine for thousands of years.

Preparation of *Guggulu Kalpana*:

Guggulu Kalpana can be prepared in two steps as follows:

- *Guggulu Shodhana*
- Preparation of *Guggulu Kalpa*

Process of *Guggulu Shodana*:

Guggulu Shodhana is carried out by the *Swedana* method.

The purification process of *Guggulu* begins with the removal of physical substances such as stones, glass, and other foreign materials. Once cleaned, the *Guggulu* is broken into small pieces and bundled in a piece of cloth like a pottali. This pottali is then subjected to boiling in a *Dola Yantra* using one of the following purification media: *Gomutra*, *Triphala Kashaya*, *Vasapatra Kashaya/Swarasa*, *Nirgundipatra Swarasa* mixed with *Haridrachurna* or *Dugdha*. In this process, *Guggulu* gradually dissolves into the fluid, passing through the cloth. The residual impurities remaining in the





Kavya and Jagadeesh.Gmitti

bundle are discarded. The fluid containing the dissolved *Guggulu* is then filtered and boiled again until it solidifies into a soft mass. This mass is dried in the sunlight. It is subsequently ground in a *khalva* to obtain *Shodhita Guggulu*⁴.

General Method Of Preparation- *Guggulu Kalpana* [5]

Guggulu Kalpana can be prepared by two methods:

- *Saagni* method
- *Niragni* method

Saagni Method (With Heat)

This method involves the application of heat during the preparation process.

Procedure:

- Purified *Guggulu* (*ShodhitaGuggulu*) is taken as the base material.
- It is dissolved in a prescribed *dravadravya* like *Kashaya*, *Swarasa*, or *jala* under controlled heating.
- It is continuously stirred to obtain a homogeneous mixture.
- Other powdered drugs (*Churna*) are added. And the mixture is heated till a semi-solid or pill-making consistency is achieved.
- Finally, the preparation is rolled into *vatis* of desired size and shape and stored in an airtight container.

Examples:

- *Yogaraja Guggulu*
- *Kaishora Guggulu*

Advantages:

- Suitable for preparations that require binding and solidification.
- Heat helps in reducing moisture content and enhances shelf life.

Niragni Method (Without Heat)

This method is carried out without using any heat.

Procedure:

- Purified *Guggulu* is softened by triturating (*mardana*) with *Ghrita*, *Kashaya* or *Swarasa*.
- Other medicinal powders are mixed gradually during trituration. This mixture is processed until a uniform mass is formed.
- *Vati* of desired size and shape is prepared and stored in an airtight container.
- No heating is involved throughout the process.

Examples:

- *Triphala Guggulu* (some variants)
- *Amrutadi Guggulu*

Advantages:

- Preserves the thermolabile (heat-sensitive) phytochemicals

Stages of *Guggulu Paka*⁶:

Paka Kalina (During the Time of *Paka*)

Observations during stirring:

- The *Paka* material adheres firmly to the spoon.
- It exhibits three to four thread-like consistencies.
- When dropped into water, it settles at the bottom without spreading.
- To the touch, it remains soft and sticky.

Paka Anantara (After *Paka* Completion)

- The mixture should possess the desired color, odor, and taste of its ingredients.





Kavya and Jagadeesh.Gmitti

- When pressed, it retains fingerprints, indicating correct consistency

Anupana [7]:

It can be given along with *Go-mutra*, *Jala* or liquid preparation like *Triphala Kwatha*, *Darvi Kwatha*, *Patola Kwatha*, etc., according to the disease.

Shelf Life:

Sharangadhara samhitha: 1-5 years

D and C Act 1940: 5 years

Apathya [8]:

During the administration of *Guggulu*, the following things should be avoided: *Sevana* of *Amla Dravya*, *Tikshna veerya dravya*, *Madya*, in case of *Ajirna*, *Vyavaya*, *Shrama*, *Krodha*.

Ati Matra Sevana Vikara [9]:

Long-term and higher dose administration of *Guggulu* may lead to *Timira* (blindness), *Vadanashosha* (dryness of mouth), *Klibata* (impotency), *Karshya* (emaciation), *Moha* (delusion), *Samala Shithila Bhava* (diarrhoea), *Deha Raukshya* (dryness of skin).

Modern Relevance of *Guggulu Kalpana*:

The *Guggulu* plant has many active ingredients such as essential oils (0.37%), mainly myrcene, dimyrcene and polymyrcene, guggulsterones like Z-guggulsterone, E-guggulsterone, guggulsterone-I, guggulsterone-II, guggulsterone-III, and guggulsterone-IV. These isolates are primarily responsible for their actions, such as rheumatism, arthritis, hyperlipidemia, obesity, inflammation, atherosclerosis, wrinkles, acne and other diseases. It also consists of aliphatic esters, triterpenoids, ferulates, long chain aliphatic tetrols, diterpenoids, lignans, and a variety of inorganic ions and carbohydrates, besides small amounts of sesamin [10]. Among these phytoconstituents, E-guggulsterone and Z-guggulsterone play a significant role in the therapeutic activity of *Guggulu*. These steroidal compounds exhibit notable hypolipidemic activity by promoting cholesterol metabolism and facilitating its excretion from the body. One of the proposed mechanisms involves antagonism of the nuclear receptor known as the Farnesoid X Receptor (FXR), which regulates bile acid and cholesterol metabolism. Inhibition of this receptor enhances cholesterol catabolism and helps reduce serum cholesterol, triglycerides, and low-density lipoprotein (LDL) levels, thereby preventing the development of atherosclerotic plaque and supporting cardiovascular health. In addition to their lipid-lowering effects, guggulsterones contribute to the anti-inflammatory, anti-arthritic, and antioxidant activities of *Guggulu*. Resin extracts inhibit inflammatory mediators such as nitric oxide, reducing inflammation and supporting its traditional use in rheumatism and arthritis. *Guggulu* also exhibits antioxidant activity by scavenging free radicals and inhibiting lipid peroxidation. Furthermore, it shows antimicrobial activity against various pathogenic microorganisms and thyroid-stimulating activity, mainly attributed to Z-guggulsterone, which enhances thyroid hormone activity and increases metabolic rate. These combined pharmacological effects support the traditional use of *Guggulu* in the management of metabolic and inflammatory disorders [11].

DISCUSSION

Guggulu Kalpana is considered a secondary formulation within *Bhaishajya Kalpana*. Classical texts provide references to their use in various dosage forms such as *Churna*, *Asava*, *Kashaya*, etc. The introduction of *Guggulu* in *Vati* form is traced to the 11th century AD in *Chakradutta*, highlighting the added advantages of solid dosage forms in therapeutics. Acharya Haritha has dedicated a separate chapter to *Guggulu Kalpana*, emphasising its importance. In *Ashtanga Sangraha Uttarasthana*, *Rasayanavidhi* *Guggulu* is described as *yogavahi* and *sarva rutu sevy*. Various *Guggulu* yogas are mentioned for their *rasayana* effect when administered appropriately, while *Shreshtha Guggulu* is characterised by emission of strong fragrance (*Gandha*) on burning, by possessing *snigdha*, *drava*, *picchilaguna* and being *vighata shalya* (free from foreign matter). Classical texts describe various *Shodhana* media for *Guggulu*, which are selected based on the nature of the disease condition, *dosha* predominance and intended therapeutic utility. Common



**Kavya and Jagadeesh.Gmitti**

media include *Go-mutra*, *Triphala kashaya*, *Nirgundi swarasa*, *Vasapatra swarasa* and *Godugdha*. These media remove impurities and enhance specific therapeutic effects: *Triphalakashaya* adds anti-inflammatory and antioxidant activity¹²; *Nirgundiswarasa* possesses *Shothahara* and *Shulahara* properties and is predominantly indicated in *Vataavyadhi*¹³; *Vasapatraswarasa* aids in *Vataharakarma* and exhibits *Deepana–Pachana* properties, thereby enhancing *Agni*¹⁴; *Go-mutra* enhances bioavailability and possesses *Lekhana* and *Saraguna*, contributing to its *Medohara* and antioxidant properties¹⁵; and *Godugdha* enhances palatability and absorption, improves nutritional and anti-inflammatory properties, and reduces the *ushnata* of *Guggulu*¹⁶. The choice of *Shodhana* medium allows *Guggulu* to be safely and effectively used for different therapeutic applications, in accordance with classical *Ayurvedic* guidelines. The preparation of *GugguluKalpana* is carried out by two methods—*SaagniPaka* (with heat) and *NiragniPaka* (*Kuttana*, without heat). *NiragniPaka* is preferred when thermolabile (heat-sensitive) substances are employed, as it helps preserve their bioactive phytoconstituents. Depending on the choice of *anupana*, *GugguluKalpana* can be effectively tailored to treat a wide variety of ailments. *Guggulu*, being *tikshna* and *ruksha*, should not be taken with *amla dravya*, *tikshna veerya dravya*, *madya*, etc., as these disturb *agni* and *dosha samya*, thereby diminishing its *yogavahi* property and therapeutic efficacy. *Guggulu* contains bioactive compounds known as *guggulsterones*, which exist in two structural forms called Z- and E-isomers. These isomers, along with related *guggulsterols*, are responsible for many of the pharmacological properties of *Guggulu*, such as its anti-inflammatory, hypolipidemic, and antioxidant effects.

CONCLUSION

Guggulu Kalpana is a versatile *Ayurvedic* formulation, where proper *Shodhana* with an appropriate purification medium ensures safety, bioavailability, and effectiveness. The preparation method, *Saagni Paka* or *Niragni Paka*, influences stability and pharmacological activity, and following classical guidelines on dosage, *anupana*, and *pathya-apathya* supports its rational use. The presence of bioactive compounds like *guggulsterones* explains its wide therapeutic potential, bridging traditional knowledge with modern understanding. Hence, *Guggulu Kalpana* has versatile usage in many ailments and remains highly relevant in *Ayurvedic* practice, with scope for further standardisation and research.

REFERENCES

1. Acharya P V Sharma & Dr Guruprasadh Sharma, Kaiyadeva Nighantu, second edition, Chaukhambha Orientalia, Varanasi, 2006 aushadhi varga pg.no.261
2. Acharya P V Sharma & Dr Guruprasadh Sharma, Kaiyadeva Nighantu, second edition, Chaukhambha Orientalia, Varanasi, 2006, Aushadhi Varga pg no.262
3. Acharya P V Sharma & Dr Guruprasadh Sharma, Kaiyadeva Nighantu, second edition, Chaukhambha Orientalia, Varanasi, 2006 aushadhi varga pg no.263
4. The Ayurvedic Pharmacopoeia of India, part 1, second edition, GOI, MOHFW, ISMH, pg. no. 203.
5. Acharya Sharangadhara, Sharngadhara Samhita, Commented by Adhamalla and Kashiram, 6th Edition, Chaukhambha Orientalia, Varanasi, 2005, Madhyama Khanda, Chap7/8
6. Dr Ravindra Angadi, A Textbook of Bhaishajya Kalpana Vijnana Pharmaceutical Science, Published by Chaukhambha Surbharati Prakashan Varanasi, Revised Edition-2024, Chapter 20, Page no. 159
7. history_of_guggulu_based_on_ayurvedic_literature.3.pdf - Search
8. Acharya Sharangadhara, Sharngadhara Samhita, Commented by Adhamalla and Kashiram, 6th Edition, Chokhambha Orientalia, Varanasi, 2005, Madhyama Khanda, Chapter 7/8
9. Astanga Samgraha of Vagbhata, translated by Prof. K. R. Srikantha Murthy, vol III, Uttarasthana, 49/280, English translation, Chaukhambha Krushnadas Academy, Varanasi, Reprint:2024, pg. no. 502





Kavya and Jagadeesh.Gmitti

10. Baldwa VS, Bhasin V, Ranka PC, Mathur KM. Effects of Commiphora mukul (Guggul) in experimentally induced hyperlipemia and atherosclerosis. The Journal of the Association of Physicians of India. 1981 Jan;29(1):13-7
11. Sarup P, Bala S, Kamboj S. Pharmacology and Phytochemistry of Oleo-GumResin of *Commiphora wightii* (Guggulu). Scientifica. 2015;2015:1–14. doi:10.1155/2015/138039
12. Ferdous L. Antioxidant and anti-inflammatory properties of herbal extracts in ayurvedic formulations. J Dravyaguna Bhaishajya Vigyan. 2024 Jan 1;1(1):13–6. doi:10.33545/dravyaguna.2024.v1.i1.A.4
13. (PDF) A Critical Review of Nirgundi (Vitex Negundo Linn.)- In Classical Texts. ResearchGate. doi:10.47070/ijapr.v11i2.2692
14. Medicine) DMC (M DA. Vasa Swarasa - Ingredients, Indications, Benefits and Uses. Planet Ayurveda [Internet]. 2020 Feb 1 [cited 2026 Mar 24]. Available from: <https://www.planetayurveda.com/library/vasa-swarasa/>
15. Julika, Sharma U, Sharma K. Role of gomutra (cow urine) in various diseases: a review. *World Journal of Pharmaceutical and Life Sciences*. 2019 May 14.
16. www.wisdomlib.org. Godugdha: Significance and symbolism [Internet]. 1970 [cited 2026 Mar 24]. Available from: <https://www.wisdomlib.org/concept/godugdha>

Table no.01: Rasapanchaka of Guggulu³

Rasa	Katu, Tikta
Guna	Laghu, Ruksha
Virya	Ushna
Vipaka	Katu
Doshagnatha	Pacifies Vata and Kapha
Karma	Lekhana, shothahara, medohara, Deepana-pachana, Rasayana

Table no: 02 -Dose

REFERENCE	DOSE
Astanga Sangraha, Uttartantra 49/261 (Rasayana vidhi)	Up to 1 Tula (100 Pala) must not take more than 1 Pala in a single dose.
Harita Samhita, Kalpa Sthana 5/19	1 Karsha (12g) to 1 Pala (48g)

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





REVIEW ARTICLE

Effectiveness of Russian Current in Enhancing Strengthening for Quadriceps Muscle Isokinetic Contraction in Physiotherapeutic Rehabilitation : A Systematic Review and Meta –Analysis

Suraj Pradhan^{1*} and Sunita Sharma²

¹Master of Physiotherapy Student, Department of Physiotherapy, Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India

²Professor, Department of Physiotherapy, Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana, Haryana, India

Received: 09 Mar 2026

Revised: 11 Apr 2026

Accepted: 01 Jun 2026

*Address for Correspondence

Suraj Pradhan

Master of Physiotherapy Student,
Department of Physiotherapy,
Markandeshwar Institute of Physiotherapy and Rehabilitation,
Maharishi Markandeshwar (Deemed to be University),
Mullana, Haryana, India
E.Mail: drsunita.sharma@mmumullana.org@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

The application of Russian current has been investigated as a way of improving muscle strength particularly where voluntary muscle contraction may be restricted or contraindicated. The goal of this systematic review was to assess the effect of using Russian current on quadriceps muscle strength in healthy individuals, clinical patients, and athletes. To systematically assess the efficacy of Russian current to increase quadriceps muscle strength in healthy individuals, clinical populations and athletes and quantitatively combine strength outcomes when appropriate. Searches of PubMed, Cochrane Library, and PEDro databases were performed from the inception of the databases to 16 August 2025. Randomized controlled trials investigating Russian current either alone or combined with exercise were included. Valid assessment tools were used to extract quantitative strength outcomes and analyzed.

The five studies reviewed present data on the county-level. Participants included healthy young adults, older adults who were at risk for falls, athletes, patients with polyneuropathy, and patients with osteoarthritis. The majority of studies showed an increase in isometric or isokinetic quadriceps strength but results have been inconsistent between studies. Meta analysis showed that there was no overall significant effects, and there was a high degree of heterogeneous effect across the included trials. Russian current may be a potential adjunctive therapy for enhancing the strength of the quadriceps muscle, specifically in those who have a decreased voluntary activation. Some methodological variation and

115899



**Suraj Pradhan and Sunita Sharma**

heterogeneity across studies does necessitate some degree of caution, however, and there is a need for additional high-quality randomized controlled trials.

Keywords: Muscle Weakness, Muscle Strength, Osteoarthritis, Electrical Stimulation

INTRODUCTION

Russian current stimulation is a medium-frequency alternating current, originally developed by Dr. Yakov Kots in the 1970s for enhancing strength in Soviet Olympic athletes, and is continued as a widely used electrotherapeutic management in the enhancement of sport performance and to facilitate rehabilitation. It is delivered at a carrier frequency of ~2500 Hz with a burst modulation of 50 Hz and a 50% duty cycle, and allows deep muscle activation with reduced superficial discomfort compared to low-frequency stimulation [1]. Its key advantage lies in its ability to override the natural size principle of motor unit recruitment, thereby activating fast-twitch fibres earlier and potentially increasing force production beyond voluntary contraction alone. Physiologically, voluntary contractions follow Henneman's size principle, recruiting small, fatigue-resistant motor units first before engaging larger, fast-twitch units as force demand increases [2]. In contrast, Russian current tends to produce a non-selective, spatially fixed, and temporally synchronous motor unit activation pattern, potentially recruiting larger (type II) fibres earlier than usual, leading to greater torque output but also quicker fatigue [3].

Russian current is superimposed on voluntary contraction; the combination may recruit additional motor units that would otherwise remain inactive, maximizing force generation, especially during early rehabilitation when heavy load training is contraindicated [4]. Russian current is commonly applied in Post-operative rehabilitation, e.g., after anterior cruciate ligament (ACL) reconstruction, to restore quadriceps strength when pain or swelling limits voluntary activation and in knee osteoarthritis (KOA), to supplement exercise and improve muscle strength and functional outcomes [5]. It is also used in neurological and musculoskeletal injuries, where its ability to activate impaired muscles non-volitionally can promote neural recovery [6]. It augments strength rehabilitation in older adults or populations at risk of falls, where high-load resistance training is not feasible or safe but effective strength gains are beneficial [7].

The quadriceps femoris is a knee extensor, formed by four muscles: vastus medialis, vastus lateralis, vastus intermedius, and rectus femoris [8]. Weakness of this group of muscles impairs mobility and increases the risk of falls, and is often followed significantly post-knee surgery or prolonged immobility [7]. Effective stimulation of the quadriceps using Russian current relies heavily on appropriate electrode placement. Research suggests that placing electrodes over the motor points of the vastus medialis and vastus lateralis muscles, typically along the distal and proximal anterior aspect of the thigh, maximizes activation across the muscle belly [9]. A longitudinal positioning (proximal-distal) across the muscle has been shown to produce better torque production than transverse placements [10]. Although Russian current is widely used in physiotherapy and sports rehabilitation, certain contraindications must be carefully considered to ensure patient safety. Absolute contraindications include the presence of electronic implants such as pacemakers or defibrillators, as the electrical impulses may interfere with device function, leading to life-threatening arrhythmias, in case of, pregnant women, especially during the first trimester, should avoid Russian current on abdominal or pelvic regions due to unknown risks to foetal development [11].

A dynamometer is an outcome measure used to measure the strength of muscles; quantification of quadriceps strength is pivotal for evaluating the effectiveness of the Russian current [12]. Two primary methods are mainly used for quantification of strength: a Hand-Held Dynamometer (HHD) and an Isokinetic Dynamometer (ID). HHD is a portable, cost-effective, and practical device which is significant for clinical use. It is a valid and reliable tool for the measurement of isometric quadriceps strength when properly stabilized, especially with a belt or external anchor to



**Suraj Pradhan and Sunita Sharma**

minimize examiner strength dependency[5].Belt-stabilized setups correlate well with isokinetic gold standards ($r \approx 0.86-0.93$, $ICC \approx 0.88-0.94$), though they may underestimate true torque by $\sim 20-25\%$ [13].ID is considered to be the reference standard for measuring concentric, eccentric, and isometric torques at controlled speeds.Provides objective metrics such as peak torque, torque-time curves, and rate of torque development (RTD) and has shown to have a high reliability and precision with $ICC > 0.99$, and coefficient of variation $\sim 1\%$ [14]. This review aims to evaluate the effectiveness of RC stimulation in strengthening the quadriceps muscle, particularly in rehabilitation and clinical populations, using objective outcome measures such as dynamometers. The main objective of the review is to systematically evaluate whether RC stimulation produces measurable improvements in quadriceps muscle strength, assessed via dynamometry, in clinical and rehabilitation populations compared to standard care or control interventions.

METHODOLOGY

A systematic review was done in 2025, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard guidelines. Articles were selected based on their publication year and only from the past five years. The systematic review and meta-analysis have been registered on PROSPERO. The PROSPERO Registration number is CRD420251132416.

Search Strategy

An elaborate search was conducted up to August 16th, 2025.Articles were procured from three main databases:PubMed, Cochrane Library, andPEDro. The search was conducted using the following keywords: “Russian current”, “physiotherapy”, “strengthening”, “Quadriceps Muscle”, and/or “Electrotherapy”, along with Boolean operators like “AND”, “OR”. The search strategy used to retrieve articles from various databases is presented in Table1.A total of 465 articles were analysed based on their title and abstract. These were screened, and irrelevant studies were eliminated based on the inclusion criteria. If there was any uncertainty regarding the eligibility of the study from the title and abstract, the full text was retrieved and assessed for eligibility. After an initial review, articles that were considered potentially relevant underwent an exhaustive reading of their full text was carried out, paying special attention to the intervention (type of treatment), relief of symptoms, number of sessions, and duration of treatment.

Eligibility Criteria**Inclusion Criteria**

The selection of articles was based onthe PICOS framework(participants, intervention, comparator, outcomes, study design). After properly filtering the articles, they were further screened on the basis of the following eligibility criteria:

- Participants included the healthy, diseased population, and athletic population (soccer players and volleyball players).
- Intervention: The main intervention includedRussian current, along with other physiotherapy-based techniques.
- Comparator: Participants were allocated to two groups: one received exercise therapy alone, and the other performed exercise therapy supplemented with Russian current
- The outcome measure wasstrength, measured using a valid tool, such as a dynamometer.
- All the chosen studies are randomized controlled trials (RCTs).

Exclusion Criteria

The articles that were not available as free full-text articles or were not available in the English language were excluded from the study. The exclusion criteria were further expanded to protocols, pilot studies, and non-RCTs.



**Suraj Pradhan and Sunita Sharma****Quality and Risk of Bias Assessment**

PEDro scores from the Physiotherapy Evidence Database Scale (PEDro) were used to assess the quality of studies. The PEDro scale contains 11 items, and during the calculation, the first item is omitted; each satisfied item contributes one point to the total score (range 0–10). This tool was used for quality assessment of all the included RCTs. Risk of Bias was assessed using the COCHRANE RISK OF BIAS ASSESSMENT TOOL RoB-2 (robvis) tool. The tool evaluates a study on five major domains and appraises it on four factors, like high risk, low risk, some concern, and no information.

Statistical Analysis

A meta-analysis was performed on MetaAnalysisOnline.com, an online website prominently used for performing meta-analyses. A forest plot meta-analysis was conducted for four studies. Changes in strength were measured using ID, which was used to measure the changes in muscle strength. The analysis was performed using the random-effect statistical model, and the significance level was set at $p < 0.05$ and forest plots were generated for the results.

RESULTS**Selection of Studies**

After a comprehensive search of all three databases, we found 24383 articles. After using filters, we were left with 23916 articles. These articles were then uploaded to the RAYYAN website, and duplicates were removed, leaving 465 studies. After applying filters and exhaustive analysis, we selected 5 articles for inclusion in this study. The complete flowchart of this selection methodology is presented in Figure 1.

The evidence synthesized from the seven studies includes 207 participants. Participants included healthy young adults, athletes, individuals with musculoskeletal conditions such as knee osteoarthritis and post-total knee arthroplasty, and patients with neurological impairments such as demyelinating polyneuropathy, despite variations in intervention protocols, electrode placements, and outcome measures

Quality And Risk of Bias Assessment

PEDro scoring was used for assessing the methodological quality of all the studies. Higher scores indicate better quality, and all five studies have above-average quality, i.e., they score more than five on the PEDro scale. Out of the 5 articles included in this review, only four of them obtained a score greater than or equal to 7 on the PEDro scale. These are the ones with the highest methodological quality. These articles did not meet many of the items on the scale. An average score of 7.6 was calculated across all five RCTs. (Table 2). The Cochrane Risk of Bias was assessed using the RoB-2 tool. All five studies were shown to have a high risk. There was bias due to missing outcome data in all five studies, which resulted in a high risk for all the studies. Individually, the study conducted by Suhara S. et al. (2025) also faced bias due to deviations from the intended intervention and bias in the measurement of the outcome. Akinoğlu B. et al. (2020) had bias due to deviations from the intended intervention. (Figure 2) The study has an overall high risk of bias. (Figure 3).

Statistical Analysis

Meta-analysis of the four trials with a total of 136 participants shows no significant overall effect of the intervention compared with control ($Z = 1.00$, $p = 0.3156$), indicating that the combined evidence does not consistently favour either group. Individual study findings varied widely. One study (Ansam Hasan, 2024) demonstrated a large and statistically significant positive effect, while the other three studies (Suhara, 2025; AZIZ, 2021; Bihter Akinoğlu, 2020) showed little to no meaningful difference. This inconsistency is reflected in the very high heterogeneity ($I^2 = 91.7\%$, $p < 0.0001$), suggesting that differences in protocols, sample characteristics, or measurement methods may account for the variation. The wide prediction interval further indicates that future studies could report effects ranging from negative to strongly positive. Overall, current evidence remains inconclusive, and further well-designed, standardized trials are needed to clarify the true impact of the intervention.



**Suraj Pradhan and Sunita Sharma**

DISCUSSION

This systematic review and meta-analysis synthesized evidence from seven studies assessing the effectiveness of RC stimulation for quadriceps strengthening across diverse populations, including healthy individuals, athletes, patients with musculoskeletal disorders such as knee osteoarthritis, those undergoing postoperative rehabilitation following anterior cruciate ligament (ACL) reconstruction, and individuals with neurological impairments such as chronic inflammatory demyelinating polyneuropathy (CIDP)[16]. The review aimed to determine whether RC could provide consistent and clinically meaningful improvements in quadriceps strength and function compared to exercise alone or alternative stimulation methods[17]. The findings suggest that Russian current is a promising adjunct to exercise-based rehabilitation and athletic training[18]. Several included studies reported significant improvements in quadriceps strength when RC was applied alongside voluntary contraction or structured exercise. For example, ACL reconstruction patients who received combined exercise and RC achieved greater improvements in isometric quadriceps and hamstring strength, as well as functional scores, compared to those who performed exercise alone[19]. Similarly, in neurological populations such as CIDP patients, the integration of RC with exercise resulted in superior outcomes in both quadriceps torque and functional independence measures, demonstrating its role in enhancing neuromuscular activation where voluntary recruitment may be limited[20].

These findings align with the proposed mechanism of RC, which bypasses the natural size principle of motor unit recruitment and preferentially activates type II fibres earlier, resulting in greater torque production and improved force output[21]. In elderly individuals at risk of falls, the addition of RC to isometric training improved not only quadriceps and tibialis anterior strength but also balance and mobility scores[22]. RC may serve as a safe and effective tool for addressing sarcopenia-related weakness, especially when high-load resistance training is contraindicated[23]. A study on university students found that RC delivered via expert stimulation modes (ON2 and Rest) significantly enhanced quadriceps isokinetic torque. Athletes, including volleyball and soccer players, showed gains in quadriceps endurance and torque when RC was compared with other forms of neuromuscular electrical stimulation, such as high-voltage pulsed current[24]. Both RC combined with exercise and exercise alone improved quadriceps strength, pain, and function, but the incremental benefit of RC was not statistically significant. This suggests that in conditions where exercise is already highly effective, the additive effect of RC may be limited. Nonetheless, it remains possible that RC provides subtle neuromuscular adaptations not fully captured by conventional outcome measures, or that its benefits emerge more strongly in subgroups with severe weakness or poor exercise tolerance[25].

Methodological quality of the included studies, as assessed by the PEDro scale, ranged from moderate to high. Four studies scored ≥ 7 , indicating strong design elements, while one scored lower, reflecting issues such as lack of blinding or inadequate reporting. Risk of bias analysis revealed that missing outcome data and deviations from intended interventions were common, raising concerns about internal validity. These limitations reduce confidence in the overall strength of the evidence and suggest that future trials should incorporate rigorous randomization, blinding of outcome assessors, intention-to-treat analyses, and transparent reporting of attrition. Nevertheless, caution is warranted in interpreting the current evidence base. The small sample sizes, variable protocols, and short-term follow-up in many included studies limit the generalizability of findings. Long-term outcomes such as sustained strength gains, functional independence, and quality of life remain underexplored. Furthermore, while handheld and isokinetic dynamometers provided objective outcome measures, additional parameters such as electromyographic activity, muscle architecture, and fatigue indices could enrich the understanding of RC's physiological impact.

Future research should prioritize large-scale, multi-centre randomized controlled trials with standardized stimulation protocols and longer follow-up periods. Comparative studies against other neuromuscular electrical stimulation modalities could clarify whether RC provides unique advantages. Additionally, individualized parameter adjustments, such as tailoring frequency and duty cycle to patient tolerance and rehabilitation goals, may optimize outcomes. This review supports the role of Russian current as an effective and versatile adjunct in muscle



**Suraj Pradhan and Sunita Sharma**

strengthening. It demonstrates clear utility in postoperative and neurological populations, potential benefits in elderly fall-prevention, and positive results in athletes and healthy adults. However, methodological limitations and inconsistent findings necessitate further investigation. Until more robust evidence emerges, clinicians should consider RC as a complementary tool to exercise therapy, particularly where voluntary activation is impaired, while remaining mindful of its limitations.

CONCLUSION

Russian current stimulation, whether applied alone in healthy adults or combined with exercise in clinical populations, consistently enhances muscle strength and functional outcomes. By modulating stimulation parameters, we can individualize treatment, using higher frequencies for rapid strength gains or lower frequencies to minimize fatigue. Evidence supports RC as an effective adjunct in postoperative rehabilitation and neuromuscular disorders; however, variability in methodology highlights the need for standardized protocols and long-term follow-up. Future research should refine optimal parameters and evaluate combined training approaches to ensure sustained improvements in muscle performance and functional independence.

What is known about the subject

Muscle weakness is commonly managed using neuromuscular electrical stimulation when voluntary contraction is limited. Russian current has been shown to improve muscle strength in healthy individuals and selected clinical and athletic populations, but evidence remains inconsistent and fragmented.

What this study adds to existing knowledge

This review synthesizes randomized controlled trials demonstrating that Russian current can effectively improve muscle strength across healthy, athletic, and clinical populations. It supports the Russian current as a promising adjunct to strengthening interventions, particularly when voluntary activation is compromised.

REFERENCES

1. Kaya, Fatih, and Mustafa SE(2016). "Electrical muscle stimulation and its use for sports training programs: A review." *Recent advances in health sciences* 711-713.
2. Hasan A, Moustafa I and Shousha T (2024). Effect of Russian current expert modes on quadriceps muscle torque in healthy adults: A single-blinded randomized controlled trial. *Plos one* 1-14.
3. Dideriksen JL, Farina D(2013). Motor unit recruitment by size does not provide functional advantages for motor performance. *The Journal of physiology* 39-56.
4. Gregory CM, Bickel CS(2005). Recruitment patterns in human skeletal muscle during electrical stimulation. *Physical therapy* 58-64.
5. Suhara S, Lakshmi Priya V and Jeyanthi S (2025). Effect of Russian Current Along with Structured Exercises in Improving Knee Range of Motion, Isometric Muscle Strength and Functional Status Following ACL Reconstruction 2052-2056.
6. Gandhi KM, Ratnani G, Deodhe NP and Shend K (2024). Enhancing Muscle Strength Post Anterior Cruciate Ligament Reconstruction: A Case Report Assessing the Effectiveness of Russian Current. *Cureus*.
7. Vásquez MS, et al.(2019). Combining Russian stimulation with isometric exercise improves strength, balance, and mobility in older people with falls syndrome. *International journal of rehabilitation research* 41-50.
8. Khan A, Arain A(2023). Anatomy, Bony Pelvis and Lower Limb: Anterior Thigh Muscles. In *StatPearls* StatPearls Publishing.
9. Pietrosimone BG et al. (2011). Electrode type and placement configuration for quadriceps activation evaluation. *Journal of athletic training*. 21-28.
10. Singh S, Multani NK (2013). Effect of dorsiflexor muscle strengthening using Russian currents on balance and function in elderly. *Human Biology Review* 76-84.





Suraj Pradhan and Sunita Sharma

11. Badger J, Taylor P and Swain I(2017). The safety of electrical stimulation in patients with pacemakers and implantable cardioverter defibrillators: a systematic review. *Journal of rehabilitation and assistive technologies engineering* 1-8.
12. Lesnak J et. el(2016). VALIDITY OF HAND-HELD DYNAMOMETRY IN MEASURING QUADRICEPS STRENGTH AND RATE OF TORQUE DEVELOPMENT. *Int J Sports Physio Therapy* 180-187.
13. Sentanin AC et al. (2021). Reliability of quadriceps femoris muscle strength assessment using a portable dynamometer and protocol tolerance in patients with chronic obstructive pulmonary disease. *Physical therapy*.
14. Hansen EM, et al.(2015). Hand-held dynamometer positioning impacts discomfort during quadriceps strength testing: a validity and reliability study. *International journal of sports physical therapy*62-65.
15. Martins J, Da Silva JR, Da Silva MR andBevilaqua-Grossi D(2017). Reliability and validity of the belt-stabilized handheld dynamometer in hip-and knee-strength tests. *Journal of athletic training*809-819.
16. Delitto A et al. (1988). Electrical stimulation versus voluntary exercise in strengthening thigh musculature after anterior cruciate ligament surgery. *Physical therapy*. 60-63.
17. Li Z, et al. (2025). Effects of Neuromuscular Electrical Stimulation on Quadriceps Femoris Muscle Strength and Knee Joint Function in Patients After ACL Surgery: A Systematic Review and Meta-analysis of Randomized Controlled Trials. *Orthopaedic Journal of Sports Medicine* 1-10.
18. MaffiulettiNA.(2010) Physiological and methodological considerations for the use of neuromuscular electrical stimulation. *European journal of applied physiology*.23-34.
19. Fitzgerald GK, Piva SR and Irrgang JJ(2003). A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. *Journal of Orthopaedic & Sports Physical Therapy* 492-501.
20. Vaz MA et.al (2012). Effects of Russian current and low-frequency pulsed current on discomfort level and current amplitude at 10% maximal knee extensor torque. *Physiotherapy theory and practice*17-23.
21. Sinacore DR, Delitto A, King DS and Rose SJ(1990). Type II fiber activation with electrical stimulation: a preliminary report. *Physical therapy*16-22.
22. Vásquez MS, et al. (2019). Combining Russian stimulation with isometric exercise improves strength, balance, and mobility in older people with falls syndrome. *International journal of rehabilitation research*41-50.
23. Amirova L et al. (2022) Effect of modulated electromyostimulation on the motor system of elderly neurological patients. pilot study of russian currents also known as kotz currents. *Frontiers in Physiology*. (vol – 13 921432)
24. Akinoğlu B, KocahanT(2020). Russian current versus high voltage current with isokinetic training on the quadriceps muscle strength and endurance. *Journal of exercise rehabilitation* 272.
25. Omole JO, Egwu MO, Ojoawo AO, Ogundele AO(2018). Comparative effects of Russian current and isometric resisted exercise on quadriceps angle and joint space width among patients with primary knee osteoarthritis. *Int J Adv Res Publ* 92-95.

STATEMENTS AND DECLARATIONS

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interest: The authors declare no competing interests.

Author contribution:

All authors contributed to the study conception and design. The first author contributed by performing the investigation, initial data curation, doing formal analysis, writing the methodology, and writing the original draft. The second author contributed by doing project administration, supervision, validation, and reviewing and editing the draft.

The third author contributed by performing initial data curation, methodology, reviewing, and editing the draft.





Suraj Pradhan and Sunita Sharma

Ethical Approval:

The study did not require any ethical approval as it did not include any human or animal participation. Although PROSPERO registration was done for this study.

Consent to participate: Not required

Consent to publish: Not required

Data Availability: There is no data to be reported in this study.

Table 1: Search Strategies in different data base

Keyword	DATABASE		
	PUBMED	PEDro	Cochrane Library
"Russian current" AND "physiotherapy" OR "quadriceps"	24208	0	13
"Russian Current" OR "quadriceps" AND "Electrotherapy"	17	0	99
"Russian Current" AND "strengthening"	7	2	17
"Russian Current" AND "quadriceps"	6	1	13
Total	24238	3	142

Table 2: Summary of the quality of the RCTs included in this review on the basis of PEDro scale

Author, Year	1	2	3	4	5	6	7	8	9	10	11	Total
Akinoğlu B, et al. (2020)	✓	✓	✗	✓	✗	✗	✓	✓	✗	✓	✓	7/10
Sandra M. Ahmed (2021)	✓	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	8/10
Suhara S., Lakshmipriya V., Jeyanthi S. (2025)	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓	✓	6/10
Ibrahim Moustafa, and Tamer Shousha	✓	✓	✓	✓	✓	✗	✗	✓	✓	✗	✓	8/10
Arrais Guida Modesto 2020	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	9/10
Total Average												7.6

Table3: Search Strategies in different data base

No	Author, Year	Population & Sample Size	Type of Study	Objective	Intervention	Outcome Measures	Results
1.	Akinoğlu & Kocahan, 2020	Volleyball athletes	RCT	To evaluate the impact of Russian current (RC) and high voltage pulsed current (HVPC) on the quadriceps muscle strength and endurance.	2 (RC vs. HVPC, split limbs)	Isokinetic Dynamometer, Endurance Ratio	Both improved; no significant difference
2.	Modesto et al., 2020	Soccer player	RCT	We studied the effects of different neuromuscular electrical stimulation currents, RC, and PC on neuromuscular	3 Group 1. control group 2. Russian current (2500 Hz, burst 100Hz phase duration 200 micro sec)	Muscle endurance (FI), Dynamometer Torque (Nm)	No significant difference; both effective




Suraj Pradhan and Sunita Sharma

				system after a week training period			
3.	Abdel Aziz et al., 2021	CIDP patients	Single-blinded RCT	To evaluate the difference between effect of Russian current and combined exercise and only exercise therapy on muscle strength and function in chronic inflammatory demyelinating neuropathy	2 (Exercise only vs. Exercise + RC)	Dynamometer Quadriceps strength, Barthel Index	RC group showed significantly better outcomes
4.	Hasan et al., 2024	Healthy adults	Single-blind RCT	This study evaluate the direct effect of Russian current (expert modes) on knee extensors muscle strength in healthy adults.	2 (RUSSIAN CURRENT ON2 vs. RUSSIAN CURRENT Rest Mode)	Quadriceps Isokinetic Torque (Dynamometer)	Significant improvement in both groups
5.	Suhara et al., 2025	ACL reconstruction patients (sports injuries)	Experimental study	To evaluate the combined effect of Russian current and structured exercise in improving knee function following ACL reconstruction.	2 (Russian current and structured exercise vs. exercise only)	ROM (goniometer), Isometric Strength (dynamometer), Lysholm Score	RC group showed greater improvement ($p < 0.001$)



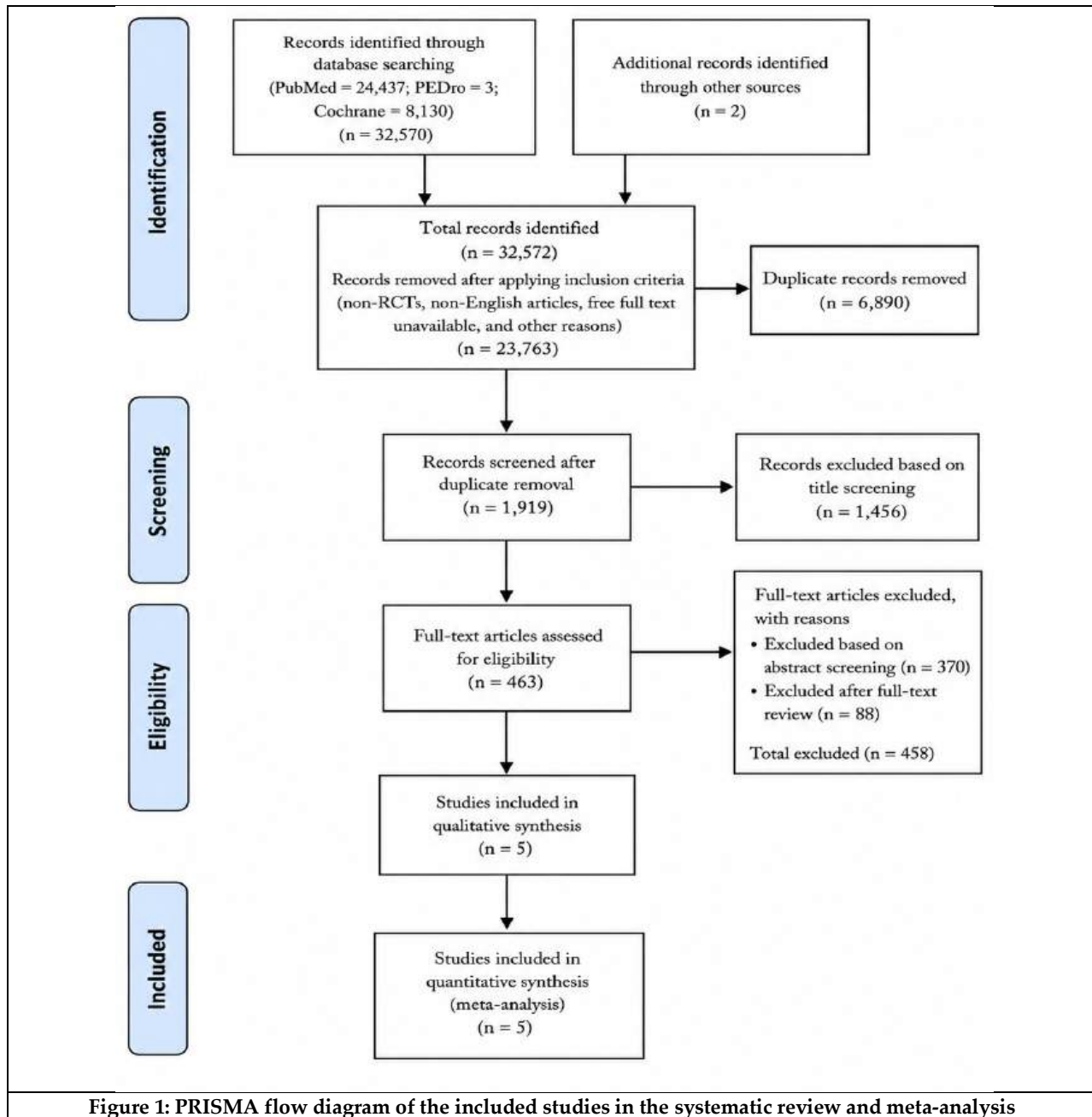


Figure 1: PRISMA flow diagram of the included studies in the systematic review and meta-analysis





Suraj Pradhan and Sunita Sharma

		Risk of bias domains					
		D1	D2	D3	D4	D5	Overall
Study	Akinoğlu B, Kocahan T (2020)	+	×	×	+	+	×
	Arrais Guida Modesto 2020	+	+	×	+	+	×
	Sandra M. Ahmed (2021)	+	+	×	+	+	×
	Ibrahim Moustafa, and Tamer Shousha (2024)	+	+	×	+	+	×
	Suhara S., Lakshmipriya V., Jeyanthi S. (2025)	+	×	×	×	+	×

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
× High
+ Low

Figure 2: Summary of Risk of Bias in included studies

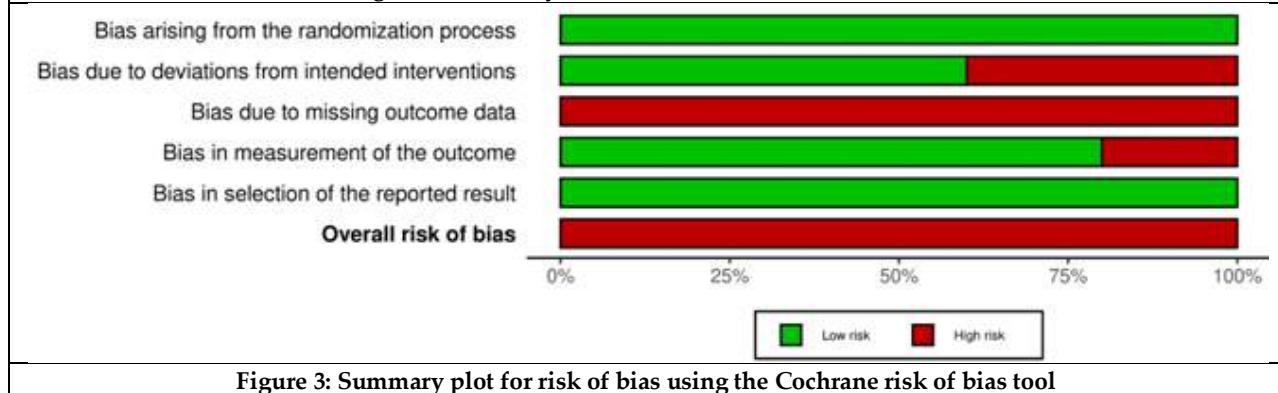


Figure 3: Summary plot for risk of bias using the Cochrane risk of bias tool

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Study on the Breeding Performance and Developmental Stages of *Anabas testudineus* (Bloch, 1972) Induced with Synthetic Hormone

Harshita Kashyap¹, Parag Dekka² and Bandita Talukdar^{3*}

¹Student, Department of Zoology, Pandu College (Affiliated to Gauhati University), Guwahati, Assam, India

²Associate Professor, Department of Zoology, Pandu College (Affiliated to Gauhati University), Guwahati, Assam, India

³Assistant Professor, Department of Zoology, Pandu College (Affiliated to Gauhati University), Guwahati, Assam, India

Received: 18 Mar 2026

Revised: 15 Apr 2026

Accepted: 01 Jun 2026

*Address for Correspondence

Bandita Talukdar

Assistant Professor,

Department of Zoology,

Pandu College (Affiliated to Gauhati University),

Guwahati, Assam, India

E-Mail: bandita.talukdar88@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Anabas testudineus (climbing perch) is an economically significant native fish species of north-eastern India. In view of irregular natural breeding and scarcity of seed, the current work was carried out to assess induced breeding and embryonic development of *Anabas testudineus* under controlled aquarium circumstances. Healthy brooders were chosen in the ratio of 2:1 (female:male) and were injected with synthetic hormone S-GnRHa (Ovasis) at 0.3 ml/kg and 0.1ml/kg body weight for male and female respectively. Spawning occurred within 7-10 h after injection and hatching was seen within 16-18 h at 26-28°C. The reported rates of fertilization, hatching and survival were 80%, 60% and 30% respectively. The morula, blastula, and gastrula stages were completed at around 3-4 hours, 7 hours, and 8-9 hours post fertilization. The research shows that induced breeding using synthetic hormone is beneficial for the captive breeding and seed production of *Anabas testudineus*.

Keywords: fertilization, *Anabas testudineus*, nutrition and revenue production

INTRODUCTION

Fish culture has become an essential aspect of aquaculture since it helps considerably to food supply, nutrition and revenue production in underdeveloped nations [1]. Induced breeding methods are frequently used for several economically significant fish species which don't breed successfully in the confined circumstances for enhancement



**Harshita Kashyap et al.,**

of fish seed output. This approach is based on the use of hormonal stimulation to induced the release of egg and sperm from adult brood fish under regulated environmental circumstances. Induced breeding increases breeding success, hatchability and seed supply and decrease reliance on natural sources [2]. The Climbing Perch (*Anabas testudineus*) is a freshwater air-breathing fish of the family Anabantidae Commonly known as Koi or Kawoi. The species is widespread in various tropical and subtropical Asian nations and is prevalent in ponds, marshes, swamps, rice fields, canals and slow-moving freshwater bodies[3]. The fish has a particular respiratory organ, which allows it to tolerate little oxygen and stay alive for a while without water [4]. *Anabas testudineus* is regarded as one of the important indigenous fish species in North Eastern India due to its excellent nutritional quality, customer preference and market worth. The flavor of this species is popular and has *Anabas testudineus* is regarded as one of the important indigenous fish species in North Eastern India due to its excellent nutritional quality, customer preference and market worth also having necessary fatty acids required for human health [5].

It is increasing demand in local markets has generated more interest in its culture and seed production [6]. The natural reproduction of climbing perch mostly happens in the rainy season and is highly dependent on the environmental variables such as rainfall, water level and temperature. These environmental requirements mean natural seed supply is frequently insufficient for large-scale agriculture [7]. Hence techniques of induced breeding are essential for continued seed production under captive settings. In earlier investigations, several hormones and breeding strategies have been effectively employed for induced breeding of this species[8]. Though many works have focused on mating and rearing procedures of the climbing perch, although thorough information on embryonic development under controlled settings is still scarce. Therefore, the current work was carried out to examine the induced breeding performance using synthetic hormone and to investigate the embryonic developmental phases of *Anabas testudineus* under aquarium settings.

MATERIALS AND METHODS

The current study was carried out between February-April 2026 at the laboratory of Pandu College (affiliated college of Gauhati University) located in Guwahati, Assam, India.

Tank Preparation

A medium sized aquarium (45×35×60 cm) is used for broodstock management is thoroughly washed, then cleaned and subsequently rinsed with water to eliminate any germs or bacteria that could infect the brooders.

Collection of brooders and stock management

Brooders are being collected from Deepor Beel, Guwahati, Assam. Aeration was provided which gives an oxygen-rich environment in the aquarium, promoting a healthy habitat for fish. Broods were acclimatized for 10-15 days. Throughout the experimental period, various physicochemical parameters (water temperature, pH, dissolved oxygen) of the brood stock tank were measured following standard methods [9]. Water quality is a critical factor in fish breeding, making it an essential parameter for the success of the process.

Feeding methods

The brood fishes were fed twice a day once in the morning and in the afternoon. The feeds used are white portion of boiled eggs, larvae of insects and commercial feed. Measurement of the fish weight was attained 30-40 grams for both males and females, and the length was measured with a scale of approximately 9-14 cm.

Injection of brooders

Brooders were injected in the intra-muscular part which is generally given in the muscle below the tip of the pectoral fin, at a 45° angle. The brooders were injected in the noon (11:30am) with a dosage of 0.3 ml for females and 0.1 ml for males at the ratio of 2:1 (female: male).



**Harshita Kashyap et al.,****Study of Embryonic development**

Fertilized eggs are being taken in a petri dish for further study of embryonic development. Then they were taken in a slide with the help of a dropper and observed under a stereo zoom microscope and photographed. Fertilization rate was also calculated using the following formula: Fertilization Rate (%) = Number of fertilized egg/Total number of eggs×100, Survival rate was calculated using the following formula: Survival Rate (%) = Number of surviving fry/Total number of hatched larvae× 100

RESULTS**Water Parameters**

During the present investigation, the water quality parameters maintained in the breeding aquarium were found to be suitable for the induced breeding and embryonic development of *Anabas testudineus* (Table 1).

Induced Breeding

The fertilized eggs appeared spherical, transparent, non-adhesive, and buoyant, floating near the surface of the water. In contrast, unfertilized eggs appeared opaque and either remained suspended in the water column or settled at the bottom of the aquarium. After spawning, the brood fishes were removed carefully from the tank to prevent predation and disturbance to the developing eggs. Hatching was observed between 32–34 h after fertilization. Newly hatched larvae were free swimming and were initially fed with small zooplankton and phytoplankton collected from nearby pond water.

Fertilization Rate

A satisfactory fertilization rate and hatching rate (Table 2) was recorded in ovasis induced breeding.

Embryonic Development of *Anabas testudineus*

The embryonic development of *A. testudineus* was observed continuously from fertilization until larval hatching. The fertilized eggs were golden brown in colour, spherical in shape, transparent, and free floating in nature. The first cleavage was observed shortly after fertilization, resulting in the formation of the 2-cell stage. Subsequent cell divisions produced the 4-cell, 8-cell, 16-cell, and multi cellular stages. Cleavage divisions occurred rapidly and uniformly during the early developmental period. Further embryonic development led to the formation of morula and blastula stages, characterized by the accumulation and arrangement of blastomeres. Gastrulation was marked by differentiation and migration of embryonic cells, followed by the initiation of organogenesis. During segmentation, the embryonic body became clearly distinguishable with the development of head and tail regions. Newly hatched larvae possessed a yolk sac attached to the ventral region of the body and showed limited swimming movements immediately after hatching (Figure.10). Different time of stages of embryonic development was also recorded accordingly (Table 3). The first cleavage was seen within 20 minutes after fertilization followed by 4-cell, 8-cell, 16-cell and 32-cell phases at around 1 hour 5 minutes, 1 hour 25 minutes, 1 hour 55 minutes and 2 hours 15 minutes correspondingly. The hatching occurred after 32-34 hours.

DISCUSSION

The current work showed effective induced breeding and embryonic development of *Anabas testudineus* under controlled aquarium condition using synthetic hormone S-GnRHa (ovasis). The recorded water temperature throughout the experiment, pH and DO were found appropriate for effective breeding and larval development. Proper water quality maintenance and constant aeration may have played a crucial role in effective spawning and hatching[10]. Fertilized eggs were clear, spherical and floating, unfertilized eggs were opaque and sank at the bottom. Similar findings were observed in prior investigations of induced breeding of climbing perch[11]. During the





Harshita Kashyap et al.,

experiment, the observed low survival rates (30%) may be due to climatic variations, broodstock condition, handling stress and larval nutrition management[12]. Differences in breeding success reported across studies may also be attributable to hormone dose, water quality, climatic circumstances and hatchery techniques[13]. The embryonic developmental phases of *A. testudineus* were closely followed in the research and similarities can be observed in the developmental time of *A. testudineus* while compared with previous research[6,10]. The current research shown that induced breeding using synthetic hormone is a successful strategy for captive breeding and seed production of *Anabas testudineus*. The research also gives helpful information on embryonic development that might be used to improve hatchery management and larval rearing procedures for this commercially important significant indigenous fish species.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Department of Zoology, Pandu, College, Assam 781012, India, for providing experimental facilities to conduct this study.

REFERENCES

1. Paul S. and Vasisht A. K. 2014. Gender Participation in Integrated Farming System in Tripura. Ind J of Agri Eco, 69(3): 444–445.
2. Mohapatra A., Nandal V., Solanki M., Pathak VV., 2024) A review on pharmaceutical and environmental applications of guava (*Psidium guajava*) leaves. J of App and Nat Sci, 16(2):607.
3. Talwar P. K., and Jhingran A. G., 1991. Inland fishes of India and adjacent countries (Vol. 2). CRC press.
4. Rahman, S., Monir, M. S., & Khan, M. H. (2013). Culture potentials of climbing perch, Thai koi, *Anabas Testudineus* (Bloch) under different stocking densities in northern regions of Bangladesh. J of Exp Bio, 1(3):1-11.
5. Mohanty B. P., Mahanty A., Ganguly S., Mitra T., Karunakaran, D. and Anandan R., 2019. Nutritional composition of food fishes and their importance in providing food and nutritional security. Food chem, 293: 561-570.
6. Sarkar S., Rai B. K., Bhutia D., Singh, S. and Pal J., 2015. Study on the breeding performance and developmental stages of climbing perch, *Anabas testudineus* (Bloch, 1792) in the laboratory (Siliguri, India). Int J of Fish and Aquat St, 2(6): 198-201.
7. Rahman M. A., 2020. Assessment of freshwater fish seed resources for sustainable aquaculture development in Bangladesh. Food and Agriculture Organization (FAO). <https://www.fao.org/4/a1495e/a1495e>.
8. Patowary R. K. and Dutta A., 2012. Breeding performances of *Anabas testudineus* (Bloch) in specially designed cemented tanks. J of Agri and Food Sci, 10(1): 55–61.
9. APHA., 2005 Standard Methods for Examination of Water and Wastewater, 21st ed. APHA, Washington DC, USA.
10. Smith J., 2024. Induced breeding of climbing perch *Anabas testudineus* by SGnRH α and study of its embryonic development under controlled conditions at Mawpun Ri-Bhoi, Meghalaya. Int J of Fish and Aquat St, 12(6):112
11. Uddin S., Hasan M. H., Iqbal M. M. and Hossain M. A., 2017. Study on the reproductive biology of Vietnamese climbing perch (*Anabas testudineus*, Bloch). Punj Univer J of Zoo, 32(1): 1-7.
12. Sarkar U. K., Pathak A. K., Sinha R. K., Sivakumar K., Pandian A. K., Pandey A. and Lakra W. S., 2012. Freshwater fish biodiversity in the River Ganga (India): changing pattern, threats and conservation perspectives. Rev in Fish Bio and Fish, 22(1): 251-272.
13. Begum S. G., Deka P. and Talukdar B., 2025. Toxic effects of chlorpyrifos on early developmental stages of fish *Anabas testudineus* (Bloch 1792). Env and Eco, 43(4): 965-970.





Harshita Kashyap *et al.*,

Table 1. Water quality parameters maintained during induced breeding of *A. testudineus*

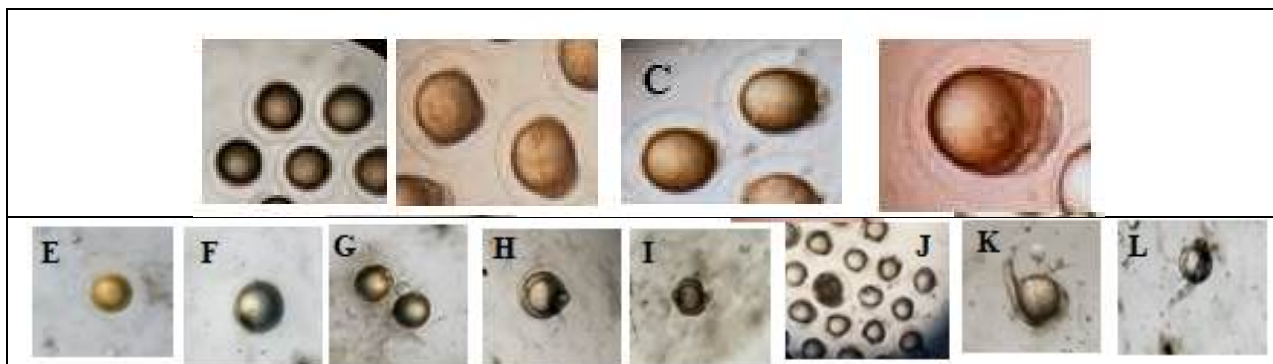
Water parameters	Values
Temperature	27±2.1°C
pH	6.7±1.1
DO	7.8±1.6ppm

Table 2: Fertilization rate and survival rate from the experiment

Species	Fertilization rate (%)	Hatching rate (%)	Survival rate (%)
<i>Anabas testudineus</i>	80%	60%	30%

Table 3: Time of different embryonic stages after fertilization in *A. testudineus*

Stages of Development	Time after Fertilization
Start of cleavage	20min
2-cell stage	35min
4-cell stage	1 hour and 5 min
8-cell stage	1 hour and 25 min
16-cell stage	1 hour and 55 min
32-cell stage	2 hour and 5 min
Morula	2 hours – 4 hours
Blastula	6 hours – 7 hours 30 min
Gastrula	8 hours – 9 hours 20 min
Neurula	9 hours 30 min – 11 hours
Segmentation	15 hours – 24 hours
Newly hatch larvae	32 hours – 34 hours



**Harshita Kashyap et al.,**

Figure 1.The different stages of embryonic development of *A. testudineus*
(A) Fertilized egg, (B–F) Cleavage stages, (G) Blastula stages, (H) Gastrula and organogenesis stages, (I) Neurula, (J) Segmentation stages, (K–L) Newly hatched larvae, and (M–N) Free-swimming larva (O).

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Strong α - Level Bijective Single Valued Neutrosophic Graphs and its Application in Agricultural Farming

D Rajalaxmi¹, P. Saraswathi Devi² and V. Vijaya^{1*}

¹Assistant Professor, PG and Research Department of Mathematics, Seethalakshmi Ramaswami College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India.

²PG Student, PG and Research Department of Mathematics, Seethalakshmi Ramaswami College (Autonomous), (Affiliated to Bharathidasan University), Tiruchirappalli, Tamil Nadu, India.

Received: 09 Mar 2026

Revised: 10 Apr 2026

Accepted: 04 Jun 2026

*Address for Correspondence

V. Vijaya

Assistant Professor,

PG and Research Department of Mathematics,

Seethalakshmi Ramaswami College (Autonomous),

(Affiliated to Bharathidasan University),

Tiruchirappalli, Tamil Nadu, India

E.Mail: vvijayamanikandan@gmail.com



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

In this paper a new concept of strong α – level sets of bijective single valued neutrosophic sets and its graphs have been defined. Some of their structural characteristics have been established. Further basic set-theoretic operations on Bijective single valued neutrosophic sets, including subset relation, equality, intersection, union, complement and set difference are investigated in neutrosophic environment.

Keywords: Neutrosophic sets, Bijective single valued neutrosophic graph, strong α – level

INTRODUCTION

Graph theory is widely recognized as a branch of applied mathematics. It useful for real-life problems related to optimization and computer science. When uncertainty arises in the set of vertices, edges or both, a graph transforms into a fuzzy graph and intuitionistic fuzzy graphs [1] capturing the essence of ambiguity in its structure. But, when relations between vertices and edges become indeterminate it takes a new structure as neutrosophic graph. A fuzzy set was defined by Zadeh L [2] in 1965. His purpose was to develop a theory for sets which are ambiguous and imprecise. Every element in the universal set is assigned a grade of membership, a value in $[0,1]$. The elements in the universal set along with their grades of membership form a fuzzy set. The concept of neutrosophic sets was first introduced by Smarandache [3,4] as a generalization of intuitionistic fuzzy sets where the degree of membership of each element in X . The neutrosophic set is a powerful mathematical tool for dealing with incomplete, indeterminate and inconsistent information in real world. The neutrosophic sets are characterized by a truth-membership function





Rajalaxmi et al.,

(t), an indeterminacy-membership function (i) and a falsity- membership function (f) independently, which are within the real standard or nonstandard unit interval] $-0, 1 + [$. In order to conveniently use neutrosophic sets in real life applications.

Al-omeri et al. [5, 6, 7] studied about topological and metric spaces. Broumi et al. [8] introduced a neutrosophic graph, which allows the attachment of truth-membership (t), indeterminacy-membership (i) and falsity-membership (f) both to vertices and edges, and some of their properties. Wang et al. [9] introduced the concept of the single valued neutrosophic set (SVNS), as a subclass of the neutrosophic sets. Further [10, 11, 12, 13,14] deals with single valued NS. The single valued neutrosophic graph is a generalization of fuzzy graph and intuitionistic fuzzy graph. Johnson Awolola [15] who initially defined α -level NS, a new notion of α -level NS aimed at enhancing the precision and practicality of outcomes. Within this concept of an α -level NS and a robust variant termed the strong α -level NS. These concepts applied to the domain of neutrosophic graphs, enabling the exploration of diverse properties and their implications. In this paper, a new concept of strong α -level bijective single valued neutrosophic graph has been defined. Basic operations and De Morgan's Laws defined for strong α -level bijective single valued neutrosophic sets. Some of their relation between α -level and strong α -level bijective single valued neutrosophic sets has been studied. It also includes an application of strong α -level bijective single valued neutrosophic graph in agricultural farming.

Basic Operations on Bijective Single Valued Neutrosophic Set

Let X be a crisp set. A Bijective Single Valued Neutrosophic Set (BSVNS) A is characterized by truth membership function $T_V(P)$, an indeterminacy membership function $I_V(P)$ and a falsity membership function $F_V(P)$ for every point $p \in V$; $T_V(p), I_V(p), F_V(p) \in [0,1]$ such that $T_V(P_i)$ and $T_V(P_j)$, $I_V(P_i)$ and $I_V(P_j)$, $F_V(P_i)$ and $F_V(P_j)$ are distinct respectively, for any i and j .

Definition 1.2:[16]

A Bijective Single Valued Neutrosophic Graph (BSVNG) is a triplet $G = (V, \sigma, \mu)$ in which the truth-membership function of vertices and edges are bijective (i.e.) $\sigma_T : V \rightarrow [0,1]$ and $\mu_T : E \subseteq V \times V \rightarrow [0,1]$ are bijective. Similarly, indeterminacy-membership function of vertices and edges are bijective respectively i.e., $\sigma_I : V \rightarrow [0,1]$ and $\mu_I : E \subseteq V \times V \rightarrow [0,1]$ are bijective, and $\sigma_F : V \rightarrow [0,1]$ and $\mu_F : E \subseteq V \times V \rightarrow [0,1]$ are bijective where $\mu_T(V_i, V_j) < \min(\sigma_T(v_i), \sigma_T(v_j))$, $\mu_I(V_i, V_j) > \max(\sigma_I(v_i), \sigma_I(v_j))$, $\mu_F(V_i, V_j) > \max(\sigma_F(v_i), \sigma_F(v_j))$ for and $v_i \in V$ $i,j=1,2,...n$.

The following conditions are trivial in BSVNG as in case of SVNG

- i. $0 \leq \sigma_T(v_i) + \sigma_I(v_i) + \sigma_F(v_i) \leq 3$ for all $v_i \in V$ ($i=1,2,...n$)
- ii. $0 \leq \mu_T(v_i, v_j) + \mu_I(v_i, v_j) + \mu_F(v_i, v_j) \leq 3$ for all $v_i, v_j \in V \times V$ ($i,j=1,2,...n$).

Definition 1.3:

A Bijective Single Valued Neutrosophic Graph $G = (V, E)$ is said to be an Empty Bijective Single Valued Neutrosophic Graph if $V = \Phi$ and $E = \Phi$.



**Definition 1.4:**

Let A be any Bijective Single Valued Neutrosophic set in a non-empty set X . Then for any $\alpha \in [0,1]$ the strong α -level sets of A denoted by $S(V, \alpha)$ and defined as $S(V, \alpha) = \{x \in X : T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\}$

Definition 1.5:

A Bijective Single Valued Neutrosophic Graph $G=(V, E)$ is called strong α -level (or) $S(G, \alpha)$ - level Bijective Single Valued Neutrosophic Graph if

$$T_V(x) > \alpha, I_V(x) + F_V(x) < 1 - \alpha \text{ for all } x \in V$$

$$T_E(xy) > \alpha, I_E(xy) + F_E(xy) < 1 - \alpha \text{ for all } xy \in E, \alpha \in [0,1]$$

Remark 1.6:

If G is a Bijective Single Valued Neutrosophic Graph and if $\alpha = 1$ then $V=\Phi$ and $E=\Phi$.

Definition 1.7:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty set X . Then

1. $A \subseteq B \Leftrightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x) \text{ for all } x \in X$
2. $A = B \Leftrightarrow T_A(x) = T_B(x), I_A(x) = I_B(x), F_A(x) = F_B(x) \text{ for all } x \in X$
3. $A \cap B = \{x, \wedge(T_A(x), T_B(x)), \vee(I_A(x), I_B(x)), \vee(F_A(x), F_B(x)) \mid \text{for all } x \in X\}$
4. $A \cup B = \{x, \vee(T_A(x), T_B(x)), \wedge(I_A(x), I_B(x)), \wedge(F_A(x), F_B(x)) \mid \text{for all } x \in X\}$
5. $A^c = \{x, F_A(x), 1 - I_A(x), T_A(x) \mid \text{for all } x \in X\}$
6. $A \setminus B = \{x, T_A(x) \wedge F_B(x), I_A(x) \vee 1 - I_B(x), F_A(x) \vee T_B(x) \mid \text{for all } x \in X\}$

Theorem 1.8:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X and $\alpha, \beta \in [0,1]$, then $A \subseteq B \Rightarrow S(A, \alpha) \subseteq S(B, \alpha)$.

Proof:

Let $A \subseteq B$. Assume that $x \in S(A, \alpha)$

$$\Rightarrow T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha$$

$$\Rightarrow T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha$$

$$[\text{Since, } A \subseteq B \Rightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x)]$$

$$\Rightarrow x \in S(B, \alpha)$$

$$\text{Hence } A \subseteq B \Rightarrow S(A, \alpha) \subseteq S(B, \alpha).$$

Theorem 1.9:

Let A and B be Bijective single valued neutrosophic sets of a non empty set X and $\alpha, \beta \in [0,1]$. If $\alpha \geq \beta$, then the strong α level of A is contained in strong β level of B

Proof:

Let $\alpha \geq \beta$. Assume that $x \in S(A, \alpha)$



**Theorem 1.10:**

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X and $\alpha, \beta \in [0,1]$, then

- i) $S(A \cup B, \alpha) = S(A, \alpha) \cup S(B, \alpha).$
- ii) $S(A \cap B, \alpha) = S(A, \alpha) \cap S(B, \alpha).$

Proof:

$$\begin{aligned}
 S(A \cup B, \alpha) &= \{x \in X: T_{A \cup B}(x) > \alpha, I_{A \cup B}(x) + F_{A \cup B}(x) < 1 - \alpha\} \\
 &= \{x \in X: \vee \{T_A(x), T_B(x)\} > \alpha, \wedge \{I_A(x), I_B(x)\} + \wedge \{F_A(x), F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) \vee T_B(x)\} > \alpha, \{I_A(x) + F_A(x)\} \wedge \{I_B(x) + F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cup \{T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &\quad \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cup \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha) \cup S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } S(A \cup B, \alpha) = S(A, \alpha) \cup S(B, \alpha).$$

$$\begin{aligned}
 S(A \cap B, \alpha) &= \{x \in X: T_{A \cap B}(x) > \alpha, I_{A \cap B}(x) + F_{A \cap B}(x) < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{T_A(x), T_B(x)\} > \alpha, \vee \{I_A(x), I_B(x)\} + \vee \{F_A(x), F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: T_A(x) \wedge T_B(x) > \alpha, \{I_A(x) + F_A(x)\} \vee \{I_B(x) + F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \{T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\}\} \\
 &\quad \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha) \cap S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } S(A \cap B, \alpha) = S(A, \alpha) \cap S(B, \alpha).$$

Theorem 1.11

Two neutrosophic Bijective singled valued sets A and B are equal iff their α level sets are equal for all $\alpha \in [0,1]$

Proof:

Assume that $A=B$

$$\Rightarrow T_A(x) = T_B(x), I_A(x) = I_B(x), F_A(x) = F_B(x), \text{ for all } x \in X.$$

We have, $S(A, \alpha)$

$$\begin{aligned}
 &= \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \text{ [Since, } A=B \text{]} \\
 &= S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } A = B \Leftrightarrow (A, \alpha) = (B, \alpha) \text{ for all } \alpha \in [0,1].$$





Conversely, let us consider for $\alpha \in [0,1]$, $S(A, \alpha) = S(B, \alpha)$ but $A \neq B$. Suppose $x \in A$ such that $x \notin B$. So, there exists an $\alpha \in [0,1]$ for each

$x \in S(A, \alpha)$. But, $x \notin B$ implies $x \notin S(B, \alpha)$ for each $\alpha \in [0,1]$. Therefore $S(A, \alpha) \neq S(B, \alpha)$ which is a contradiction to $S(A, \alpha) = S(B, \alpha)$ for all $\alpha \in [0,1]$.

Hence, $A = B \Leftrightarrow S(A, \alpha) = S(B, \alpha)$, for all $\alpha \in [0,1]$.

Theorem 1.12

The strong α level set of the union of a family of sets is equal to the union of their strong α level sets.

Proof:

$$\begin{aligned} & S\left(\bigcup_{i \in J} (A_i, \alpha)\right) \\ &= \{x \in X : T_{\bigcup_{i \in J} A_i}(x) > \alpha, I_{\bigcup_{i \in J} A_i}(x) + F_{\bigcup_{i \in J} A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigvee_{i \in J} T_{A_i}(x) > \alpha, \bigwedge_{i \in J} I_{A_i}(x) + \bigwedge_{i \in J} F_{A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigvee_{i \in J} T_{A_i}(x) > \alpha, \bigwedge_{i \in J} \{I_{A_i}(x) + F_{A_i}(x)\} < 1 - \alpha\} \\ &= \bigcup_{i \in J} \{x \in X : T_{A_i}(x) > \alpha, I_{A_i}(x) + F_{A_i}(x) < 1 - \alpha\} \\ &= \bigcup_{i \in J} S(A_i, \alpha) \end{aligned}$$

$$\text{Hence } S\left(\bigcup_{i \in J} (A_i, \alpha)\right) = \bigcup_{i \in J} S(A_i, \alpha).$$

Theorem 1.13

For any Neutrosophic set A_i ,

$$S\left(\bigcap_{i \in J} A_i, \alpha\right) = \bigcap_{i \in J} S(A_i, \alpha).$$

Proof:

$$\begin{aligned} & S\left(\bigcap_{i \in J} (A_i, \alpha)\right) \\ &= \{x \in X : T_{\bigcap_{i \in J} A_i}(x) > \alpha, I_{\bigcap_{i \in J} A_i}(x) + F_{\bigcap_{i \in J} A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigwedge_{i \in J} T_{A_i}(x) > \alpha, \bigvee_{i \in J} I_{A_i}(x) + \bigvee_{i \in J} F_{A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigwedge_{i \in J} T_{A_i}(x) > \alpha, \bigvee_{i \in J} \{I_{A_i}(x) + F_{A_i}(x)\} < 1 - \alpha\} \\ &= \bigcap_{i \in J} \{x \in X : T_{A_i}(x) > \alpha, I_{A_i}(x) + F_{A_i}(x) < 1 - \alpha\} \\ &= \bigcap_{i \in J} S(A_i, \alpha) \end{aligned}$$

$$\text{Hence } S\left(\bigcap_{i \in J} (A_i, \alpha)\right) = \bigcap_{i \in J} S(A_i, \alpha).$$

Theorem 1.14:

If A is a Bijjective Single-Valued Neutrosophic set then $S(A, \alpha) \subseteq (A, \alpha)$

for all $\alpha \in [0,1]$.



**Proof:**

Let $x \in S(A, \alpha)$

$$\Rightarrow T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha$$

$$\Rightarrow T_A(x) \geq \alpha, I_A(x) + F_A(x) \leq 1 - \alpha$$

$$\Rightarrow x \in (A, \alpha)$$

Hence $S(A, \alpha) \subseteq (A, \alpha)$, for all $\alpha \in [0, 1]$.

Theorem 1.15:

If A is a Bijective Single-Valued Neutrosophic set in a fixed set X . Let $\beta \in [0, 1]$ and $\alpha_i \in [0, \beta)$ for each $i \in J$ where Λ is an indexed set. Then $S(A, \beta) \subseteq \bigcap_{i \in J} S(A, \alpha_i)$.

Proof:

Assume that $x \in S(A, \beta)$

$$\Rightarrow T_A(x) > \beta, I_A(x) + F_A(x) < 1 - \beta, \text{ for all } x \in X$$

$$\Rightarrow T_A(x) > \beta > \alpha_i, I_A(x) + F_A(x) < 1 - \beta < 1 - \alpha_i, \text{ for all } x \in X \text{ and } \alpha_i \in [0, \beta)$$

$$\Rightarrow T_A(x) > \alpha_i, I_A(x) + F_A(x) < 1 - \alpha_i, \text{ for all } x \in X \text{ and } \alpha_i \in [0, \beta)$$

$$\Rightarrow x \in S(A, \alpha_i), \alpha_i \in [0, \beta)$$

Hence $S(A, \beta) \subseteq \bigcap_{i \in J} S(A, \alpha_i)$.

Theorem 1.16:

If A is a Bijective Single Valued Neutrosophic set in a fixed set X . Let $\beta \in [0, 1]$ and $\alpha_i \in (\beta, 1]$ for each $i \in J$ where Λ is an indexed set. Then $\bigcup_{i \in J} S(A, \alpha_i) \subseteq S(A, \beta)$.

Proof:

Let $x \in \bigcup_{i \in J} S(A, \alpha_i)$

Then $x \in S(A, \alpha_i)$ for each $i \in J$

$$\Rightarrow T_A(x) > \alpha_i, I_A(x) + F_A(x) < 1 - \alpha_i$$

$$\Rightarrow T_A(x) > \alpha_i > \beta, I_A(x) + F_A(x) < 1 - \alpha_i < 1 - \beta$$

$$\Rightarrow T_A(x) > \beta, I_A(x) + F_A(x) < 1 - \beta$$

$$\Rightarrow x \in S(A, \beta)$$

Hence $\bigcup_{i \in J} S(A, \alpha_i) \subseteq S(A, \beta)$

De Morgan's Laws in Bijective Single Valued Neutrosophic sets:**Theorem 2.1:**

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X . Then the De Morgan's Laws hold:

- $S(A \cup B, \alpha)^c = S(A, \alpha)^c \cap S(B, \alpha)^c$
- $S(A \cap B, \alpha)^c = S(A, \alpha)^c \cup S(B, \alpha)^c$ for all $\alpha \in [0, 1]$.





Proof:

$$\begin{aligned}
 \text{i. } & S(A \cup B, \alpha)^c \\
 &= \{x \in X: T_{(A \cup B)^c}(x) > \alpha, I_{(A \cup B)^c}(x) + F_{(A \cup B)^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: T_{A^c \cap B^c}(x) > \alpha, I_{A^c \cap B^c}(x) + F_{A^c \cap B^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{T_{A^c}(x), T_{B^c}(x)\} > \alpha, \vee \{I_{A^c}(x), I_{B^c}(x)\} + \vee \{F_{A^c}(x), F_{B^c}(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{F_A(x), F_B(x)\} > \alpha, \vee \{1 - I_A(x), 1 - I_B(x)\} + \vee \{T_A(x), T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{F_A(x) \wedge F_B(x)\} > \alpha, \{1 - I_A(x) + T_A(x)\} \vee \{1 - I_B(x) + T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha\} \cap \\
 &\quad \{x \in X: F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha)^c \cap S(B, \alpha)^c \\
 \text{Hence } & S(A \cup B, \alpha)^c = S(A, \alpha)^c \cap S(B, \alpha)^c
 \end{aligned}$$

$$\begin{aligned}
 \text{ii. } & S(A \cap B, \alpha)^c \\
 &= \{x \in X: T_{(A \cap B)^c}(x) > \alpha, I_{(A \cap B)^c}(x) + F_{(A \cap B)^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: T_{A^c \cup B^c}(x) > \alpha, I_{A^c \cup B^c}(x) + F_{A^c \cup B^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: \vee \{T_{A^c}(x), T_{B^c}(x)\} > \alpha, \wedge \{I_{A^c}(x), I_{B^c}(x)\} + \wedge \{F_{A^c}(x), F_{B^c}(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \vee \{F_A(x), F_B(x)\} > \alpha, \wedge \{1 - I_A(x), 1 - I_B(x)\} + \wedge \{T_A(x), T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{F_A(x) \vee F_B(x)\} > \alpha, \{1 - I_A(x) + T_A(x)\} \wedge \{1 - I_B(x) + T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha\} \cup \\
 &\quad \{x \in X: F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha)^c \cup S(B, \alpha)^c \\
 \text{Hence } & S(A \cap B, \alpha)^c = S(A, \alpha)^c \cup S(B, \alpha)^c.
 \end{aligned}$$

Remark 2.2:

If $\{V_i \mid i \in J\}$ be a family of Bijjective Single Valued Neutrosophic sets and $\alpha \in [0, 1]$. Then the De Morgan's Laws hold:

$$\begin{aligned}
 \text{i. } & S\left(\bigcup_{i \in J} V_i, \alpha\right)^c = \bigcap_{i \in J} S(V_i, \alpha)^c. \\
 \text{ii. } & S\left(\bigcap_{i \in J} V_i, \alpha\right)^c = \bigcup_{i \in J} S(V_i, \alpha)^c.
 \end{aligned}$$

Theorem 2.3:

If A and B are two Bijjective Single Valued Neutrosophic sets in a non-empty set X and $\alpha \in [0, 1]$. Then $A \subseteq B \Rightarrow S(B, \alpha)^c \subseteq S(A, \alpha)^c$.

Proof:

Given that $A \subseteq B$





Let $x \in S(B, \alpha)^c$

$$\Rightarrow F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha$$

Since $A \subseteq B \Rightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x)$

$$\Rightarrow F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha$$

$$\Rightarrow x \in S(A, \alpha)^c$$

Hence $A \subseteq B \Rightarrow S(B, \alpha)^c \subseteq S(A, \alpha)^c$.

Theorem 2.4:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty set X and $\alpha \in [0, 1]$. Then $S(A \setminus B, \alpha) = S(A \cap B^c, \alpha)$.

Proof:

$$\begin{aligned} S(A \setminus B, \alpha) &= \{x \in X: T_A(x) \wedge F_B(x) > \alpha, \{I_A(x) \vee 1 - I_B(x)\} + \{F_A(x) \vee T_B(x)\} < 1 - \alpha\} \\ &= \{x \in X: \wedge \{T_A(x), F_B(x)\} > \alpha, \vee \{I_A(x), 1 - I_B(x)\} + \{F_A(x), T_B(x)\} < 1 - \alpha\} \\ &= \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \\ &\quad \{F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\ &= S(A \cap B^c, \alpha) \end{aligned}$$

Hence $S(A \setminus B, \alpha) = S(A \cap B^c, \alpha)$

Role of Strong α – Level Bijective Single Valued Neutrosophic Graphs In Agricultural Farming:

Agricultural farming is the science, art and business of cultivating soil, producing crops and raising livestock to provide food, fiber and raw materials. As a foundational human activity, it includes various systems from traditional subsistence farming to modern industrial agriculture, driving economic growth and global food security.

Agricultural land or farm land refers to areas used for producing food, fiber and livestock, including arable land (crops), permanent pastures and orchards. Irrigation is the artificial application of water to soil to assist in crop production, particularly in areas with irregular rainfall, dry seasons or to ensure consistent agricultural yields.

Mathematical Representation

To determine the agricultural land suitable for crop cultivation in the context of BSVNG.

Consider a BSVNG, vertices represented as Agricultural lands and edges represented as irrigation efficiency.

A vertex membership values are represented as

T- nature of water

I - uncertainty rainfall

F – lack of moisture

The edges membership values are represented as

T - Drip Irrigation

I – Sprinkle Irrigation

F – Surface Irrigation

Here the vertex set is $V = (A, B, C, D)$ represents agricultural lands $E = (e_1, e_2, e_3, e_4)$ represents an irrigation efficiency in Fig.1

Barley cultivation





Rajalaxmi et al.,

To find which agricultural land is suitable for 10 % of the barley cultivation

Let $\alpha = 0.1$

Then $1-\alpha = 0.9$

10 % of the barley cultivation is given in Fig.2

Agricultural lands A, B, C and D are suitable for 10% of the Barley cultivation.

(i.e.) the nature of water, uncertainty of rainfall and lack of moisture suitable for 10% barley cultivation in agricultural lands are A, B, C and D.

In 10% barley cultivation, irrigation efficiency is suitable for the lands BD and CD.

But there is no irrigation between the lands AC and AB.

Maize cultivation

To find which agricultural land is suitable for 30 % of the maize cultivation.

Let $\alpha = 0.3$

Then $1-\alpha = 0.7$

Agricultural lands B and D suitable for 30% of the Maize cultivation is represented in Fig.3

That is, nature of water, uncertainty of rainfall and lack of moisture suitable for 30% maize cultivation in agricultural lands are B and D.

In 30% maize cultivation, the irrigation efficiency is suitable for land BD.

But there is no irrigation efficiency between the lands AC, AB and CD.

Similarly, we can find the different level of crops cultivation in BSVNG.

CONCLUSION

Some results of Strong α – Level Bijective Single Valued Neutrosophic Graphs have been found using basic operations. De Morgan's Laws verified for Strong α – Level Bijective Single Valued Neutrosophic sets. Relation between α – Level and Strong α – Level Bijective Single Valued Neutrosophic sets has been found. In future, some more properties of α – level and strong α – level bijective single valued neutrosophic graphs can be explored.

REFERENCES

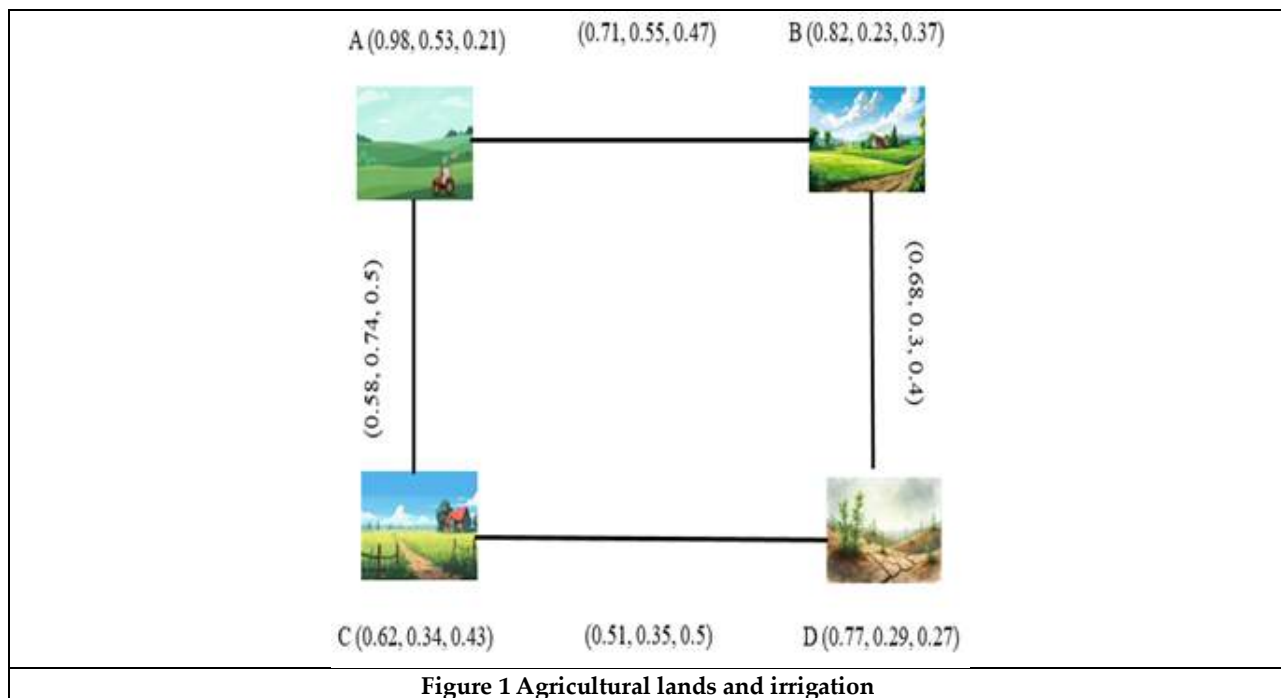
1. Atanassov, K. (1986). Intuitionistic fuzzy sets. *Fuzzy Sets and Systems*, 20, 87–96.
2. Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, 8(3), 338–353.
3. Broumi, S., Smarandache, F., Talea, M., & Bakali, A. (2016). Single valued Neutrosophic graphs: Degree, order and size. In *Proceedings of the IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)* (pp. 2444–2451).
4. Smarandache, F. (1999). *A unifying field in logics: Neutrosophic probability, set and logic*. American Research Press.
5. Al-Omeri, W. F. (2023). Neutrosophic g^* -closed sets in neutrosophic topological spaces. *International Journal of Neutrosophic Science*, 20(4), 210–222.
6. Al-Omeri, W. F. (2023). The property (P) and new fixed point results on ordered metric spaces in neutrosophic theory. *Neutrosophic Sets and Systems*, 56(1), 261–275
7. Al-Omeri, W. F., Jafari, S., & Smarandache, F. (2019). *Neutrosophic fixed point theorems and cone metric spaces*. Infinite Study.
8. Broumi, S., Talea, M., Bakali, A., & Smarandache, F. (2016). "Single-valued neutrosophic graphs". *Journal of New Theory*, 10, 86–101.
9. Wang, H., Smarandache, F., Zhang, Y., & Sunderraman, R. (2010). Single valued neutrosophic sets. In F. Smarandache (Ed.), *Multispace and multistructure* (Vol. 4, pp. 410–413).
10. Das, S., Das, R., & Pramanik, S. (2022). Single valued pentapartitioned neutrosophic graphs. *Neutrosophic Sets and Systems*, 50, 225–238.





Rajalaxmi et al.,

11. Karaaslan, F., & Davvaz, B. (2018). Properties of single-valued neutrosophic graphs. *Journal of Intelligent & Fuzzy Systems*, 34(1), 57–79.
12. Naz, S., Akram, M., & Smarandache, F. (2018). Certain notions of energy in single-valued neutrosophic graphs. *Axioms*, 7(3), Article 50.
13. Nguyen, G. N., Son, L. H., Ashour, A. S., & Dey, N. (2019). A survey of the state-of-the-arts on neutrosophic sets in biomedical diagnoses. *International Journal of Machine Learning and Cybernetics*, 10, 1–13.
14. Akram, M., & Shahzadi, G. (2017). Operations on single valued neutrosophic graphs. *Journal of Uncertain Systems*, 11(1), 1–26.
15. Johnson, A. (2020). A note on the concept of α -level sets of neutrosophic set. *Neutrosophic Sets and Systems*, 31, 120–126.
16. Rajalaxmi, D., Shivaragavi, R., & Broumi, S. (2025). Bijective single valued neutrosophic graph and its application in fraud detection analysis in social networks. *Neutrosophic Sets and Systems*, 83, 884–894.





Rajalaxmi et al.,

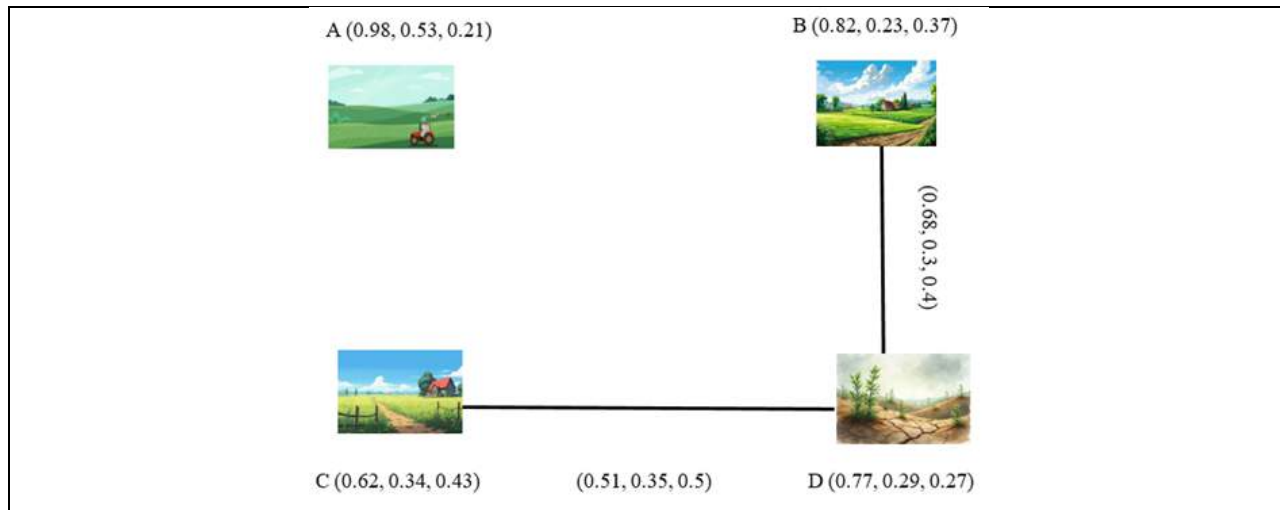


Figure 2: 10 % barley cultivation

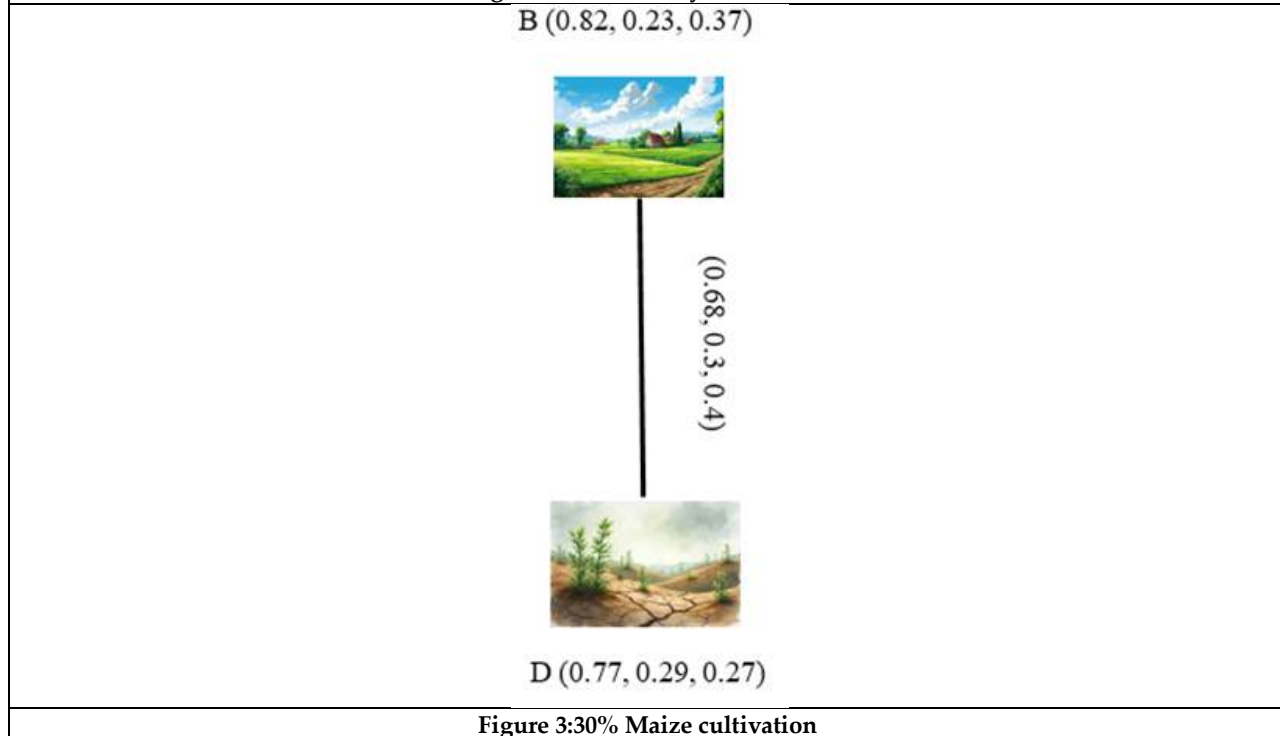


Figure 3:30% Maize cultivation

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

A Design of Two Stage Chain Sampling Plan ChSP-(0,2) using Fuzzy Parameter

P.Kavipriya^{1*} and A R Sudamani Ramaswamy²

¹Research Scholar, Department of Mathematics, Avinashilingam Institute for Home science and Higher Education For Women (Deemed-to-be-University), Coimbatore, Tamil Nadu, India

²Professor, Department of Mathematics, Avinashilingam Institute For Home Science and Higher Education for Women (Deemed-to-be-University), Coimbatore, Tamil Nadu, India

Received: 02 Mar 2026

Revised: 07 Apr 2026

Accepted: 04 Jun 2026

*Address for Correspondence

P.Kavipriya

Research Scholar,

Department of Mathematics,

Avinashilingam Institute for Home science and Higher Education for Women

(Deemed-to-be-University),

Coimbatore, Tamil Nadu, India



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

This study develops two stages ChSP-(0,2) using fuzzy parameters. FOC Curve is explained through illustrations. FOC Curve values are determined using fuzzy parameter where tables and figures are provided by fixing the sample size (n). The optimum value units required in the sample is obtained such that to satisfy both the condition of risks for the given conditions and also minimizes the sum of the risks.

Keywords: Operating Characteristic (OC) Curve , Acceptance Sampling , Fuzzy number, Trapezoidal Fuzzy Number

INTRODUCTION

Acceptance sampling is used to obtain higher quality at a reduced cost and enhance productivity. [15] It is used in industries to reduce product damage during inspection. Occasionally, results acquired in fractional values for proportion defective, acceptance number and sample size are impossible to be displayed as crisp numbers in a few industries. [19] To alleviate this discomfort in acceptance sampling , a fuzzy set is used. In designing medication, meteorology , assembling etc, where fuzzy is applied for numerous spaces of daily life [24]. Montgomery [15] introduced statistical quality control. Schilling [19] acceptance sampling quality control. Dodge [2] provided OC curve and properties of chain sampling plan. Clark [1] studied oc curves for ChSP-1. Frishman and Fred [4] prolonged chain sampling plan. Raju [17] studied contributions of chain sampling plans. Stephens [20] evaluated cumulative results of sampling plans. Stephens and Dodge presented a generalised family of two-stage chain sampling plans that





Kavipriya and Sudamani Ramaswamy

are expansions of ChSP-1 plans [21, 22, 23]. Narasimha murthy [16] studied special purpose plans. Raju and Narasimha murthy [18] proposed two stage ChSP-(0,2) and ChSP-(1,2) as part- I. Jothikumar and Raju [6] developed constructions for two stage ChSP-(0,2) and ChSP-(1,2) as part- II.

Kahraman and Kaya [7] proposed fuzzy acceptance sampling plans for single and double sampling plan. The outcome shows that fuzzy boundary gives greater adaptability and convenience. Jamkhaneh and Sadeghpour Gildeh [5] discussed about ChSP-1 using fuzzy probability theory. Kahraman, Kaya and Turanoglu [8] derived acceptance probability using fuzzy parameters and its OC curves. Kavi priya and Sudamani Ramaswamy [9,10,11] designed MChSP-1, TSMCChSP-1, TSCCChSP-1 plans using fuzzy parameters. Kavi priya and Sudamani Ramaswamy [12,13,14] used fuzzy parameters for various plans like DSP(0,1), RGS and ChSP-(0,1). Basic definitions of fuzzy sets are provided in this work, followed by operating procedures for ChSP-(0,2), FOC curves for two stage ChSP-(0,2) and tables with examples. Binomial distribution is used to obtain the parameters. FPA values are calculated for the given $\bar{AQL}$ and $\bar{LQL}$ which are presented in tables, which can be used for the selection of the plan.

Definitions

Fuzzy Number (Zadeh [24] and Dubis & Prade [3]): “Fuzzy set that are characterized on the arrangement of real numbers having the structure $\tilde{E}: R$ tends to $[0,1]$ are known as fuzzy number. A fuzzy number $\tilde{E}$ will be a fuzzy set in the real line that fulfills the state of both normal and convexity”.

Trapezoidal fuzzy number (Zadeh [24] and Dubis & Prade [3]): “If trapezoidal fuzzy numbers (TrFNs) are $\tilde{E} = (e_1, e_2, e_3, e_4)$ and its membership function as”

$$\text{TrFN} = \begin{cases} 0 & , \text{ otherwise} \\ \frac{y-e_1}{e_2-e_1} & , e_1 \leq y \leq e_2 \\ 1 & , e_2 \leq y \leq e_3 \\ \frac{e_4-y}{e_4-e_3} & , e_3 \leq y \leq e_4 \\ 0 & , \text{ otherwise} \end{cases} \quad (1)$$

“The interval of confidence of trapezoidal fuzzy number defined by γ cuts can be written as follows”

$$\tilde{E}[\gamma] = [e_1 + (e_2 - e_1)\gamma, e_4 - (e_4 - e_3)\gamma] \quad (2)$$

Operating Procedure for ChSP- (0,2)

“According to Narasimha Murthy [16], Raju and Narasimha Murthy [18] and Jothikumar and Raju [6]

Step 1: Select a sample of size n from the first lot and each subsequent lot at the outset.

Step 2: Count the number of defective units (d) in each sample and add the total number of defective units (D) in all samples from the first to the last.

Step 3: During the cumulation, accept the lot linked with each current sample as long as $D_i < c_1$; $1 < i \leq k_1$

Step 4: Once all k_1 consecutive samples have been accepted, add the defective units, D , in the samples plus any extra samples up to and including k_2 sample.

Step 5: During the cumulation, accept the lot linked with each new sample as long as c_2 , $k_1 < i \leq k_2$

Step 6: Start cumulating defective units as a moving total over k_2 samples by adding the current sample result while dropping the sample result of the k_2 th preceding sample from the sum once the second stage of the restart period has been successfully completed. Continue this method as long as $D_i < c_2$ allows, accepting in each case.

Step 7: If $D_i > c$, reject the lot, then go back to Step 1 and restart the process again.”

Fuzzy Probability of Acceptance (FPA) and Fuzzy Proportion of Defective (FPrD)

Consider $\check{p}_s = (s, e_2 + s, e_3 + s, e_4 + s)$ Where $e_i = b_i - b_1$, $i = 2, 3, 4$ and $s \in [0, 1 - e_4]$ γ cuts of trapezoidal fuzzy number to find fuzzy operating characteristic curve where $\gamma = 0$ and $\gamma = 1$. FPA is calculated using binomial distribution. γ cut of trapezoidal fuzzy number is used to solve ChSP-(0,2) such that $\tilde{E}[\gamma] = [e_1 + (e_2 - e_1)\gamma, e_4 -$





Kavipriya and Sudamani Ramaswamy

$(e_4 - e_3)\gamma$ and taking $\gamma=0,1$ then we get FPrD value as $\check{p}_s[\gamma] = [\check{p}_s^{lb}, \check{p}_s^{ub}]$ and FPA value using $\check{P}_{as}[\gamma] = [\check{P}_{as}^{lb}, \check{P}_{as}^{ub}]$.

The probability of acceptance for ChSP-(0, 2) is given by

$$P_a = \left\{ p_0 + (p_1 + p_2)p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1})}{(1-p_0)} \right] + p_1^2 p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1})}{(1-p_0)^2} - \frac{(k_2-k_1)p_0^{k_2-k_1-1}}{(1-p_0)} \right] \right\} \div \left\{ 1 + (p_1 + p_2)p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1-1})}{(1-p_0)} \right] + p_1^2 p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1-1})}{(1-p_0)^2} - \frac{(k_2-k_1-1)p_0^{k_2-k_1-2}}{(1-p_0)} \right] \right\}, k_2 > k_1 \quad \dots\dots\dots (1)$$

FPA for ChSP-(0, 2) is given by

$$\begin{aligned} \check{P}_{as} &= \left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \\ &+ \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \\ &\div \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \\ &+ \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \\ \check{P}_{as}^{lb}[\gamma] &= \min \left[\left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right. \\ &\div \left. \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right] \\ \check{P}_{as}^{ub}[\gamma] &= \max \left[\left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right. \\ &\div \left. \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right] \\ \check{P}_{as}[\gamma] &= [\check{P}_{as}^{lb}, \check{P}_{as}^{ub}] \end{aligned}$$

Using these above formulae the values are calculated and presented in Table 1.

Table 1 shows that when n value is fixed as 10, $k_1=1$ and $k_2=3$, the fuzzy proportion defective value is computed for both gamma equal zero and one, respectively using γ cut of trapezoidal fuzzy number.

Fuzzy Operating Characteristic (FOC) Curve

OC curve has contains an upper and lower bounds, it is referred to as the FOC Curve. When γ values increases from 0 to 1, FOC Curve value becomes closer.





Kavipriya and Sudamani Ramaswamy

Real Life Application

When the optical manufacturing company produces large number of optical. Before taking optical to showroom for sales, the quality of optical is checked by person working in optical showroom. She used two stage of ChSP-(0,2) to inspect the optical. (whether the frame is in correct size or lens are fixed correctly etc).

Assume that $\check{p}_s = (0.002, 0.003, 0.004, 0.005)$, $n=10$, $k_1=1$ and $k_2=3$. Then γ cut of trapezoidal fuzzy number is used to get fuzzy proportion defective value for $\gamma=0$ and $\gamma=1$ we get FPA as $\check{P}_{as}(0) = [0.9298 \quad 0.8136]$ and $\check{P}_{as}(1) = [0.8523 \quad 0.8319]$.

Example 1

Assuming $\check{p}_s = (0.001, 0.002, 0.003, 0.004)$ and a sample size n is 10, γ cut of trapezoidal fuzzy number is used to compute the interval of FPrD $\check{p}_s[0] = [0.001 \quad 0.005]$, $\check{p}_s[1] = [0.003 \quad 0.004]$ and FPA values as given in Table 2. When comparing the value of $\check{P}_{as}[\gamma = 0]$ to the value of $\check{P}_{as}[\gamma = 1]$, the table 1 shows that the value of $\gamma = 0$ gives a superior outcome. Table 2 shows how the fuzzy parameter is determined using ChSP-(0, 2) for various values of k_1 and k_2 where k_1 is lower than k_2 values.

Example 2

If $\check{p}_s = (0.001, 0.002, 0.003, 0.004)$ and the sample size is changed, the fuzzy proportion defective $\check{p}_s[0] = [0.001 \quad 0.005]$, $\check{p}_s[1] = [0.003 \quad 0.004]$ and FPA values are calculated using γ cut of trapezoidal fuzzy number as indicated in the table below. Table 3 shows that if $k_1=1$ and $k_2=3$ are fixed in ChSP-(0, 2) then sample size values are adjusted using the fuzzy parameter

Determination of Sample size

The risk of producer is denoted by $\widetilde{\alpha}_f$ and the risk of consumer is denoted by $\widetilde{\beta}_f$. Accepting quality level ($\widetilde{AQL}$) is denoted as $\check{p}_{1f}$ and Limiting quality level ($\widetilde{LQL}$) is denoted as $\check{p}_{2f}$. Here two stage of ChSP-(0,2) plan is designed using the fuzzy parameter. The sample size n is calculated in order to satisfy both the inequalities for $\check{P}_{1fa}$ and $\check{P}_{2fa}$ simultaneously for the given values of $\widetilde{\alpha}_f$ and $\widetilde{\beta}_f$. $\check{P}_{1fa} \geq 1 - \widetilde{\alpha}_f$ and $\check{P}_{2fa} \leq \widetilde{\beta}_f$ where $\widetilde{\alpha}_f = 0.05$ and $\widetilde{\beta}_f = 0.10$ is fixed so that the interval of FPA is satisfied the conditions $\check{P}_{1fa} \geq 0.95$ and $\check{P}_{2fa} \leq 0.10$ for different sample sizes.

$$\begin{aligned} \overline{P}_{1fa} = & \left\{ (1 - \widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \\ & \div \left\{ 1 + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1 - 1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 2)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \geq 0.95 \end{aligned}$$

$$\begin{aligned} \overline{P}_{1fa} = & \left\{ (1 - \widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \\ & \div \left\{ 1 + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1 - 1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 2)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \geq 0.95 \end{aligned}$$

$$\overline{P}_{2fa} = \left\{ (1 - \widetilde{p}_{2f})^n + \left(n\widetilde{p}_{2f}(1 - \widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1 - \widetilde{p}_{2f})^{n-2} \right) (1 - \widetilde{p}_{2f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{2f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{2f})^n} \right] \right\}$$





Kavipriya and Sudamani Ramaswamy

$$\begin{aligned}
 & + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \\
 & \div \left\{ 1 + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 & \left. + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\} \leq 0.10
 \end{aligned}$$

Minimizing the sum of risks

The sample size is calculated so as to minimize the sum of the risks and it is presented in Table 5 & 6. Where $\widetilde{AQL}$ is denoted as $\widetilde{p}_{1f}$ and $\widetilde{LQL}$ is denoted as $\widetilde{p}_{2f}$ and the corresponding the probability of acceptance values are $\widetilde{P}_{1fa}$ and $\widetilde{P}_{2fa}$. The mathematical expression to minimize the sum of risk is

$$\begin{aligned}
 \widetilde{\alpha}_f + \widetilde{\beta}_f &= 1 - \widetilde{P}_{1fa} + \widetilde{P}_{2fa} \\
 &= 1 - \left[\left\{ (1-\widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1-\widetilde{p}_{1f})^{n-2} \right) (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1)})}{1-(1-\widetilde{p}_{1f})^n} \right] \right. \right. \\
 &+ \left. \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} \right)^2 (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{1f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{1f})^n)} \right] \right\} \\
 &\div \left\{ 1 + \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1-\widetilde{p}_{1f})^{n-2} \right) (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{1f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} \right)^2 (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{1f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{1f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{1f})^n)} \right] \right\} \right] + \\
 &\left\{ (1-\widetilde{p}_{2f})^n + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\} \\
 &\left\{ 1 + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\}
 \end{aligned}$$

The sum of risks is obtained as interval of fuzzy.

CONCLUSION

In this study a procedure of designing two stage of ChSP-(0, 2) using trapezoidal fuzzy number is presented. Binomial distribution is used to calculate FPA value. FOC Curve values are calculated for the fixed sample size. One can note that fuzzy probability of acceptance is more for $\gamma=0$ than $\gamma=1$ and FOC Curve is closer when $\gamma=1$. For $\gamma=0$, the sample size value is calculated such that it satisfied both the condition of the risks. The optimum value units required in the sample is obtained such that to satisfy both the condition of risks for the given conditions and also minimizes the sum of risks.





REFERENCES

1. C.R. Clark " OC curve for chsp-1 chain sampling plans" , Industrial Quality Control, Vol 17 No 4, pp 10-12 , 1955.
2. H.F. Dodge " Chain sampling inspection plans", Industrial Quality control , Vol 2, pp 10-13 , 1955.
3. D. Dubis and H. Prade "Operations of fuzzy Numbers", International Journal System, Vol 9, pp 613-626 , 1978.
4. Frishman and Fred " An Extended chain sampling plan", Industrial Quality Control, Vol 17 No 1, pp10-12, 1960.
5. E.B Jamkhaneh and B. Sadeghpour-Gildeh, "Chain sampling plan using fuzzy probability theory", Journal of applied sciences, Vol 11 No 24, pp 3830-3838, 2011.
6. J. Jothikumar and C. Raju, " Two stage chain sampling plans ChSP - (0, 2) and ChSP - (1, 2)- part 2, Communication statist-simulation, Vol 25 No 3, pp 817-834 , 1996.
7. C. Kahraman and I. Kaya , "Fuzzy acceptance sampling plans" , In C. kahraman & M Yavuz, (Eds.), Production engineering and management under fuzziness, springer, pp 457-481, 2010.
8. C. Kahraman and I. Kaya , Turanoglu , "Fuzzy acceptance sampling and characteristic curves", International journal of computational intelligence systems, Vol 5 No 1, pp 13-29 , 2012.
9. P. Kavi Priya and A.R. Sudamani Ramaswamy , "A Design of Modified Chain Sampling Plan MChSP-1 using Fuzzy Parameter", Indian Journal of Natural sciences Vol 12 No 68, pp 35036-35044, 2021.
10. P. Kavi Priya and A.R. Sudamani Ramaswamy , "A Design of Two Sided Modified Complete Chain Sampling Plans TSMCChSP-1 using Fuzzy Parameter", Indian Journal of Natural Sciences, Vol 12 No 69, pp 36297-36306, 2021.
11. P. Kavi Priya and A.R. Sudamani Ramaswamy , "A Design of Two Sided Complete Chain Sampling Plans (TSCChSP-1) using Fuzzy Parameter", Advances and Applications in Mathematical sciences, Vol 21 No 3, pp 1417-1430, 2022.
12. P.Kavi Priya and A.R. Sudamani Ramaswamy , "A Design of Special Purpose Double Sampling Plan of Type DSP(0,1) using Fuzzy Parameter", South East Asian Journal of Mathematics and Mathematical sciences, Vol 18 No 2, pp 319-330, 2022.
13. P. Kavi Priya and A.R. Sudamani Ramaswamy, "Design of Repetitive Group Sampling (RGS) Plan using Fuzzy Parameter", Indian Journal of Natural Sciences, Vol 13 No 75, pp 49903-49909 , 2022.
14. P. Kavi Priya and A.R. Sudamani Ramaswamy , "A Design of Chain Sampling Plan ChSP-(0,1) using Fuzzy Parameter" , Vol 17, No 95, pp 110154-110161 , 2026.
15. D.C. Montgomery, "Introduction to statistical quality control", Wiley, New York, USA, 1991.
16. M.N. Narasimha Murthy, "Contributions to the study of special Purpose Sampling Plans", Unpublished Ph.D., Thesis, University of Mysore, Mysore, India , 1994.
17. C. Raju "Contributions to the Study of Chain Sampling Plans", Ph.D Thesis, Bharathiar University, Tamil Nadu, India, 1984.
18. C. Raju and M.N. Narasimha Murthy , "Two stage chain sampling plans ChSP - (0, 2) and ChSP - (1, 2)- part 1", Communication statist-simulation, Vol 25 No 2, pp 557-572, 1996.
19. E.G. Schilling, "Acceptance sampling quality control", Dekker, New York, USA, 1982.
20. K.S. Stephens , " A Class of Cumulative Results Sampling Plans and Their evaluation", an Unpublished Ph.D., thesis, Rutgers- The State University, New Jersey, 1966.
21. K.S. Stephens and H.F. Dodge , "Chain Sampling Inspection Plans ChSP - (0, 2), ChSP - (1, 2)", Technical Report No. N-21, Statistics center Rutgers- The State University, May 1965 a .
22. K.S. Stephens and H.F. Dodge , "Two Stage Chain Sampling Inspection Plans With Different Sample Sizes in the Two Stages, Technical report No. N- 23, Statistics Center, Rutgers- The State University, April 1966 b.
23. K.S. Stephens and H.F. Dodge , "Two Stage Chain Sampling . Inspection Plans with different sample sizes in the two stages", Journal of Quality Technology, Vol. 8, No.4, pp. 209-224 , 1976 b.
24. L.A. Zadeh, "Fuzzy sets", Information and control, Vol 8, pp 338-353, 1965.
25. H.J. Zimmermann, " Fuzzy set theory and its applications" Kluwer academic Publishers, 1991.





Kavipriya and Sudamani Ramaswamy

Table 1: Fuzzy probability of acceptance $n=10$, $k_1=1$ and $k_2=3$

$\check{p}_s = (s, e_2 + s, e_3 + s, e_4 + s)$	$\check{p}_s[\gamma = 0]$	$\check{P}_{as}[\gamma = 0]$	$\check{p}_s[\gamma = 1]$	$\check{P}_{as}[\gamma = 1]$
(0.000,0.001,0.002, 0.003)	[0 .000 0.003]	[NaN 0.9008]	[0.001 0.002]	[0.9626 0.9298]
(0.001,0.002,0.003, 0.004)	[0.001 0.005]	[0.9626 0.8523]	[0.003 0.004]	[0.9008 0.8752]
(0.002,0.003,0.004, 0.005)	[0.002 0.007]	[0.9298 0.8136]	[0.005 0.006]	[0.8523 0.8319]
(0.003,0.004,0.005, 0.006)	[0.003 0.009]	[0.9008 0.7822]	[0.007 0.008]	[0.8136 0.7971]
(0.004,0.005,0.006, 0.007)	[0.004 0.011]	[0.8752 0.7564]	[0.009 0.010]	[0.7822 0.7687]
(0.005,0.006,0.007, 0.008)	[0.005 0.013]	[0.8523 0.7349]	[0.011 0.012]	[0.7564 0.7452]
(0.006,0.007,0.008, 0.009)	[0.006 0.015]	[0.8319 0.7167]	[0.013 0.014]	[0.7349 0.7254]
(0.007, 0.008, 0.009, 0.01)	[0.007 0.017]	[0.8136 0.7012]	[0.015 0.016]	[0.7167 0.7087]
(0.008, 0.009, 0.01, 0.011)	[0.008 0.019]	[0.7971 0.6877]	[0.017 0.018]	[0.7012 0.6942]
(0.009,0.010,0.011, 0.012)	[0.009 0.021]	[0.7822 0.6758]	[0.019 0.020]	[0.6877 0.6816]
(0.010,0.011,0.012, 0.013)	[0.010 0.023]	[0.7687 0.6652]	[0.021 0.022]	[0.6758 0.6704]
(0.011,0.012,0.013, 0.014)	[0.011 0.025]	[0.7564 0.6556]	[0.023 0.024]	[0.6652 0.6603]
(0.012,0.013,0.014, 0.015)	[0.012 0.027]	[0.7452 0.6467]	[0.025 0.027]	[0.6556 0.6511]
(0.013,0.014,0.015, 0.016)	[0.013 0.029]	[0.7349 0.6384]	[0.027 0.028]	[0.6467 0.6425]
(0.014,0.015,0.016, 0.017)	[0.014 0.031]	[0.7254 0.6305]	[0.029 0.030]	[0.6384 0.6344]
(0.015,0.016,0.017, 0.018)	[0.015 0.033]	[0.7167 0.6229]	[0.031 0.032]	[0.6305 0.6267]
(0.016,0.017,0.018, 0.019)	[0.016 0.035]	[0.7087 0.6155]	[0.033 0.034]	[0.6229 0.6192]
(0.017,0.018, 0.019, 0.02)	[0.017 0.037]	[0.7012 0.6082]	[0.035 0.036]	[0.6155 0.6119]
(0.018, 0.019, 0.02, 0.021)	[0.018 0.039]	[0.6942 0.6010]	[0.037 0.038]	[0.6082 0.6046]
(0.019, 0.02, 0.021, 0.022)	[0.019 0.041]	[0.6877 0.5938]	[0.039 0.040]	[0.6010 0.5974]

Table 2: Fuzzy probability of acceptance when k_1 and k_2 values varies

k_1	k_2	$\check{P}_{as}[\gamma = 0]$	$\check{P}_{as}[\gamma = 1]$
1	3	[0.9626 0.8523]	[0.9008 0.8752]
1	4	[0.9540 0.8277]	[0.8814 0.8526]
1	5	[0.9456 0.8060]	[0.8635 0.8323]
2	4	[0.9543 0.8318]	[0.8835 0.8557]
2	5	[0.9460 0.8105]	[0.8659 0.8358]
2	6	[0.9380 0.7916]	[0.8496 0.8177]
3	5	[0.9464 0.8147]	[0.8682 0.8390]
3	7	[0.9306 0.7794]	[0.8372 0.8051]
4	6	[0.9389 0.8002]	[0.8545 0.8246]
4	8	[0.9236 0.7690]	[0.8261 0.7970]
4	9	[0.9163 0.7559]	[0.8134 0.7808]
5	7	[0.9316 0.7878]	[0.8422 0.8119]
5	8	[0.9242 0.7731]	[0.8287 0.7975]
5	10	[0.9099 0.7482]	[0.8044 0.7723]
6	8	[0.9247 0.7771]	[0.8312 0.8008]





Kavipriya and Sudamani Ramaswamy

6	9	[0.9175 0.7639]	[0.8187 0.7877]
6	10	[0.9105 0.7521]	[0.8070 0.7757]
7	9	[0.9181 0.7677]	[0.8212 0.7909]
7	10	[0.9111 0.7559]	[0.8096 0.7789]
8	10	[0.9118 0.7595]	[0.8121 0.7821]
9	11	[0.9057 0.7522]	[0.8038 0.7742]
10	12	[0.8998 0.7457]	[0.7962 0.7670]

Table 3 Fuzzy probability of acceptance when k_1 and k_2 value is fixed

n	$\check{P}_{as}[\gamma = 0]$	$\check{P}_{as}[\gamma = 1]$
50	[0.8530 0.6602]	[0.7196 0.6854]
45	[0.8640 0.6719]	[0.7326 0.6976]
40	[0.8756 0.6852]	[0.7473 0.7116]
35	[0.8880 0.7007]	[0.7641 0.7278]
30	[0.9011 0.7191]	[0.7836 0.7471]
25	[0.9150 0.7417]	[0.8061 0.7701]
20	[0.9299 0.7698]	[0.8325 0.7980]
15	[0.9457 0.8057]	[0.8637 0.8323]
10	[0.9626 0.8523]	[0.9008 0.8752]
5	[0.9807 0.9146]	[0.9455 0.9296]

Table 4 Optimum value of the parameter n, when $\check{P}_{1fa} \geq 0.95$ and $\check{P}_{2fa} \leq 0.10$

$(A\bar{Q}L)$	$(L\bar{Q}L)$	n
(0.001,0.0011,0.0012,0.0013)	(0.320, 0.321, 0.322, 0.323)	10
	(0.340, 0.341, 0.342, 0.343)	10
	(0.340, 0.341, 0.342, 0.343)	8
	(0.340, 0.341, 0.342, 0.343)	5
	(0.280, 0.281, 0.282, 0.283)	10
	(0.290, 0.291, 0.292, 0.293)	10
	(0.290, 0.291, 0.292, 0.293)	9
	(0.300, 0.301, 0.302, 0.303)	8
	(0.310, 0.311, 0.312, 0.313)	7
	(0.320, 0.321, 0.322, 0.323)	6
(0.002,0.0021,0.0022,0.0023)	(0.330,0.331, 0.322, 0.323)	6
	(0.350, 0.351, 0.352, 0.353)	5
	(0.360, 0.361, 0.362, 0.363)	5
	(0.370, 0.371, 0.372, 0.373)	5
	(0.380, 0.381, 0.382, 0.383)	5
	(0.400, 0.401, 0.402, 0.403)	5
	(0.380, 0.381, 0.382, 0.383)	4
	(0.400, 0.401, 0.402, 0.403)	4
	(0.430, 0.431, 0.432, 0.433)	4
	(0.370, 0.371, 0.372, 0.373)	4
(0.003,0.0031,0.0032,0.0033)	(0.380, 0.381, 0.382, 0.383)	4
	(0.390, 0.391, 0.392, 0.393)	4
	(0.400, 0.401, 0.402, 0.403)	4
	(0.400, 0.401, 0.402, 0.403)	4





Kavipriya and Sudamani Ramaswamy

	(0.410, 0.411, 0.412, 0.413)	4
	(0.420, 0.421, 0.422, 0.423)	4
	(0.430, 0.431, 0.432, 0.433)	4

Table 5 Optimum value of the parameter n which minimizes sum of risks for $k_1=1$ and $k_2=3$ When $\tilde{\alpha}_f \cong 0.05$ and $\tilde{\beta}_f \cong 0.10$

n	$\tilde{p}_{1f} [Y = 0]$	$\tilde{P}_{1fa}[Y = 0]$	$\tilde{p}_{2f} [Y = 0]$	$\tilde{P}_{2fa}[Y = 0]$	$\tilde{\alpha}_f + \tilde{\beta}_f$
10	[0.001 0.0013]	[0.9626 0.9523]	[0.320 0.323]	[0.0256 0.0246]	[0.0630 0.0723]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.340 0.343]	[0.0195 0.0187]	[0.0569 0.0664]
8	[0.001 0.0013]	[0.9697 0.9612]	[0.340 0.343]	[0.0406 0.0392]	[0.0709 0.0780]
5	[0.001 0.0013]	[0.9807 0.9751]	[0.340 0.343]	[0.1046 0.1016]	[0.1239 0.1265]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.280 0.283]	[0.0432 0.0416]	[0.0806 0.0893]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.290 0.293]	[0.0380 0.0366]	[0.0754 0.0843]
9	[0.001 0.0013]	[0.9661 0.9567]	[0.290 0.293]	[0.0516 0.0499]	[0.0855 0.0932]
8	[0.001 0.0013]	[0.9697 0.9612]	[0.300 0.303]	[0.0625 0.0605]	[0.0928 0.0993]
7	[0.001 0.0013]	[0.9733 0.9657]	[0.310 0.313]	[0.0763 0.0741]	[0.1030 0.1084]
6	[0.001 0.0013]	[0.9769 0.9704]	[0.320 0.323]	[0.0935 0.0910]	[0.1136 0.1206]
6	[0.001 0.0013]	[0.9769 0.9704]	[0.330 0.323]	[0.0853 0.0830]	[0.1084 0.1126]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.350 0.353]	[0.0941 0.0921]	[0.1316 0.1348]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.360 0.363]	[0.0857 0.0831]	[0.1232 0.1258]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.370 0.373]	[0.0771 0.0746]	[0.1146 0.1173]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.380 0.383]	[0.0689 0.0665]	[0.1064 0.1092]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.400 0.403]	[0.0534 0.0511]	[0.0909 0.0938]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.380 0.383]	[0.0886 0.0846]	[0.1190 0.1193]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.400 0.403]	[0.0619 0.0579]	[0.0923 0.0926]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.430 0.433]	[0.0184 0.0133]	[0.0488 0.0480]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.370 0.373]	[0.1020 0.0979]	[0.1464 0.1464]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.380 0.383]	[0.0886 0.0846]	[0.1330 0.1331]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.390 0.393]	[0.0753 0.0713]	[0.1197 0.1198]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.400 0.403]	[0.0619 0.0579]	[0.1063 0.1064]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.410 0.413]	[0.0482 0.0440]	[0.0926 0.0925]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.420 0.423]	[0.0339 0.0294]	[0.0783 0.0779]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.430 0.433]	[0.0184 0.0133]	[0.0628 0.0618]



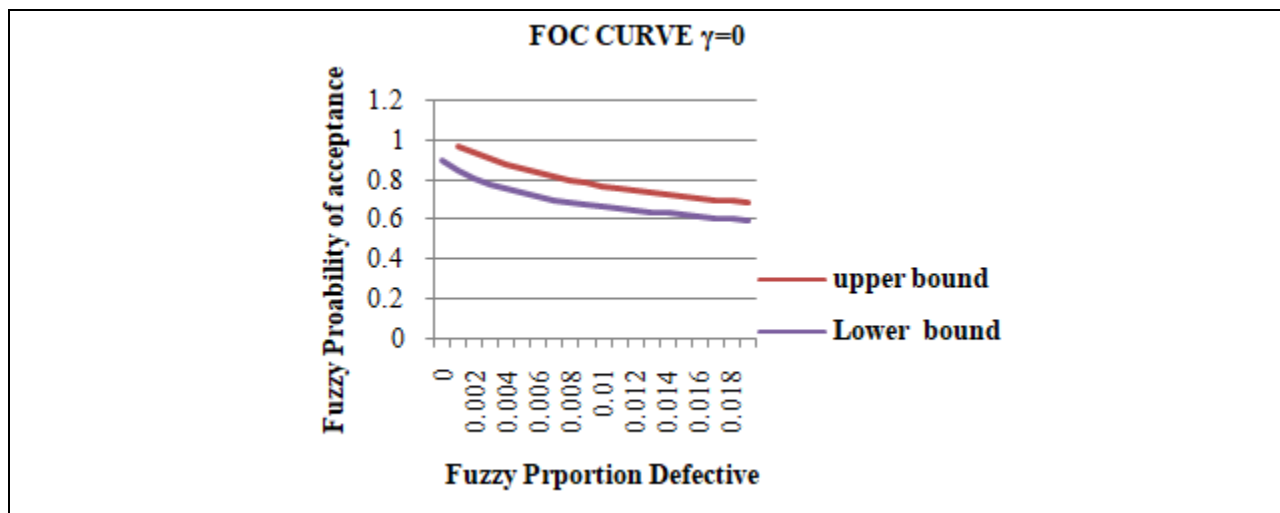
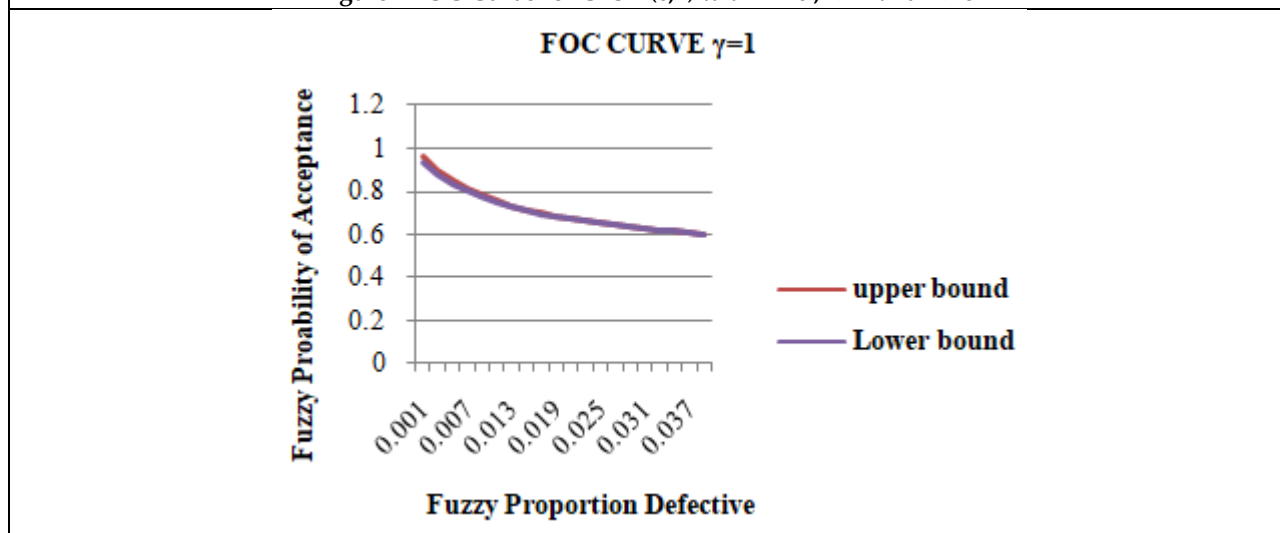


Kavipriya and Sudamani Ramaswamy

Table 6 Optimum value of the parameter n which minimizes sum of risks for $k_1=1$ and $k_2=3$ When $\widetilde{\alpha}_f \cong 0.05$ and $\widetilde{\beta}_f \cong 0.10$

n	$\check{p}_{1f}[Y=1]$	$\check{P}_{1fa}[Y=1]$	$\check{p}_{2f}[Y=1]$	$\check{P}_{2fa}[Y=1]$	$\widetilde{\alpha}_f + \widetilde{\beta}_f$
12	[0.0011 0.0012]	[0.9642 0.9613]	[0.171 0.172]	[0.1054 0.1038]	[0.1412 0.1425]
12	[0.0011 0.0012]	[0.9642 0.9613]	[0.181 0.182]	[0.0911 0.0898]	[0.1269 0.1285]
11	[0.0011 0.0012]	[0.9669 0.9642]	[0.201 0.202]	[0.0847 0.0836]	[0.1178 0.1194]
11	[0.0011 0.0012]	[0.9669 0.9642]	[0.211 0.212]	[0.0738 0.0727]	[0.1069 0.1085]
10	[0.0011 0.0012]	[0.9697 0.9672]	[0.221 0.222]	[0.0823 0.0812]	[0.1126 0.1140]
10	[0.0011 0.0012]	[0.9697 0.9672]	[0.231 0.232]	[0.0723 0.0714]	[0.1026 0.1042]
9	[0.0011 0.0012]	[0.9725 0.9702]	[0.241 0.242]	[0.0836 0.0826]	[0.1111 0.1124]
9	[0.0011 0.0012]	[0.9725 0.9702]	[0.251 0.252]	[0.0742 0.0733]	[0.1017 0.1031]
8	[0.0011 0.0012]	[0.9753 0.9733]	[0.261 0.262]	[0.0890 0.0880]	[0.1137 0.1147]
8	[0.0011 0.0012]	[0.9753 0.9733]	[0.271 0.272]	[0.0798 0.0789]	[0.1045 0.1056]
7	[0.0011 0.0012]	[0.9782 0.9764]	[0.281 0.282]	[0.0993 0.0984]	[0.1211 0.1220]
7	[0.0011 0.0012]	[0.9782 0.9764]	[0.291 0.292]	[0.0901 0.0892]	[0.1119 0.1128]
8	[0.0021 0.0022]	[0.9556 0.9538]	[0.301 0.302]	[0.0570 0.0563]	[0.1014 0.1025]
8	[0.0021 0.0022]	[0.9556 0.9538]	[0.311 0.312]	[0.0508 0.0502]	[0.0952 0.0964]
7	[0.0021 0.0022]	[0.9606 0.9589]	[0.321 0.322]	[0.0665 0.0659]	[0.1059 0.1070]
7	[0.0021 0.0022]	[0.9606 0.9589]	[0.331 0.332]	[0.0600 0.0594]	[0.0994 0.1005]
6	[0.0021 0.0022]	[0.9657 0.09642]	[0.341 0.342]	[0.0819 0.0812]	[0.1162 0.1170]
6	[0.0021 0.0022]	[0.9657 0.09642]	[0.351 0.352]	[0.0747 0.0740]	[0.1090 0.1098]
5	[0.0021 0.0022]	[0.9709 0.9697]	[0.361 0.362]	[0.1065 0.1057]	[0.1356 0.1360]
5	[0.0021 0.0022]	[0.9709 0.9697]	[0.371 0.372]	[0.0985 0.0977]	[0.1276 0.1280]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.381 0.382]	[0.0909 0.0901]	[0.1323 0.1326]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.391 0.392]	[0.0838 0.0831]	[0.1252 0.1256]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.401 0.402]	[0.0771 0.0765]	[0.1185 0.1190]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.431 0.432]	[0.1048 0.1041]	[0.1387 0.1389]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.441 0.442]	[0.0976 0.0969]	[0.1315 0.1317]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.451 0.452]	[0.0908 0.0902]	[0.1247 0.1250]
4	[0.0041 0.0042]	[0.9565 0.9556]	[0.441 0.442]	[0.0976 0.0969]	[0.1408 0.1413]
4	[0.0041 0.0042]	[0.9565 0.9556]	[0.451 0.452]	[0.0908 0.0902]	[0.1343 0.1346]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.531 0.532]	[0.1032 0.1025]	[0.1441 0.1441]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.541 0.542]	[0.0967 0.0961]	[0.1376 0.1377]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.551 0.552]	[0.0905 0.0899]	[0.1314 0.1315]



Figure 1 FOC Curve for ChSP-(0,2) with $n=10$, $k_1=1$ and $k_2=3$ Figure 2 FOC Curve for ChSP-(0,2) with $n=10$, $k_1=1$ and $k_2=3$

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Autoimmune Hypothyroidism Treated with Individualised Homoeopathic Medicines: A Case Series

Vijaykrishna V^{1*}, Munjal Thakar² and Zankhana Desai³

¹Ph.D Scholar, Department of Homoeopathic Materia medica, Parul university, Vadodara, Gujarat and Professor, Department of Homoeopathic Materia Medica, Government Homoeopathic Medical College, Bangalore, Karnataka, India

²Research Supervisor and Professor, Department of Homoeopathic Materia Medica, Ahmedabad Homoeopathic Medical College and Hospital, Ahmedabad, Gujarat, India.

³Professor, Department of Community Medicine, Jawaharlal Nehru Homoeopathic Medical College and Hospital, Parul University, Vadodara Gujarat India

Received: 21 Mar 2026

Revised: 20 Apr 2026

Accepted: 14 Jun 2026

*Address for Correspondence

Vijaykrishna V

Ph. D Scholar,

Department of Homoeopathic Materia medica,

Parul university, Vadodara,

Gujarat and Professor,

Department of Homoeopathic Materia Medica,

Government Homoeopathic Medical College,

Bangalore, Karnataka, India

E.Mail: doc_vijaykrishna@yahoo.co.in



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Autoimmune thyroid disease is rapidly on the rise and is one of the most frequent causes of Hypothyroidism in adults. It is characterised by the formation of antibodies that attack the Thyroid gland resulting in hypothyroidism. Several studies have established that the presence of Anti-thyroid peroxidase (ATPO) and Anti-thyroglobulin (ATG) antibodies are not just associated with thyroid gland damage, but also possibly have a role in systemic inflammation causing extra thyroidal effects including cancer.¹⁾ As thyroid hormones have a key role in the metabolic processes of almost all the tissues in the body, therefore, autoimmune hypothyroidism causes multitude and ambiguous signs and symptoms involving multiple organ systems including a risk of malignancy, and therefore, there is a need to develop effective solutions to treat them. Keeping this in view, a case series of diagnosed autoimmune hypothyroidism treated with individualised Homoeopathic medicines is being reported here. Case summary - 7 diagnosed cases of Autoimmune hypothyroidism were treated with individualised Homoeopathic medicines prescribed after a detailed case taking based on a structured case record proforma. The treatment outcome was assessed based on the ATPO/ ATG titres tested before and after



Vijaykrishna *et al.*,

intervention. The prescribed individualised Homoeopathic medicines were found to have a curative effect in the given cases of Autoimmune hypothyroidism as is evidenced in the reduction in ATPO and ATG titres to normal range, thereby suggesting a good scope of Homoeopathic intervention in the treatment of this condition. Furthermore, large scale clinical trials are necessary to generate more conclusive evidence.

Key words: Case series, Homoeopathy, Autoimmune hypothyroidism, ATPO, Individualised homoeopathic medicines

INTRODUCTION

Autoimmune hypothyroidism falls under the category of primary hypothyroidism and is an organ specific autoimmune disorder which is characterised by infiltration of the thyroid gland by inflammatory cells resulting in the development of auto antibodies to thyroid specific antigens. The two primary thyroid specific antigens are Thyroglobulin and Thyro-peroxidase. The clinical diagnosis of autoimmune hypothyroidism is based on both physical and biochemical abnormalities as well as serological demonstration of autoantibodies to these major Thyroid specific antigens. Autoimmune hypothyroidism has been found to be associated with an exaggerated iodine intake. Radiation exposure, certain viruses such as hepatitis C virus chronic infection, selenium and vitamin D deficiency are some of the environmental risk factors associated with autoimmune hypothyroidism. Stress (both emotional and psychological) has also been identified to be a risk factor for autoimmune hypothyroidism [2]. As per studies, it was found that women are at a higher risk of developing autoimmune hypothyroidism than men. The prevalence of autoimmune hypothyroidism varies from region to region across the globe and was found to be 5.8% in Asia as per a study [3]. As per a cross-sectional, multi-centre, epidemiological study conducted across 8 major cities of India to study the prevalence of hypothyroidism among adult population, it was found that ATPO positivity was very high, with a prevalence of more than 20% in five cities [4].

There is a rise in the prevalence of autoimmune hypothyroidism cases across all age groups, races, genders and regions worldwide. Given the central role of thyroid hormones in systemic metabolism, hypothyroidism is characterized by a wide spectrum of non-specific manifestations affecting multiple organ systems, with potential long-term risks including malignancy. This emphasizes the need to develop effective solutions to treat them. Homoeopathic system is based on a holistic approach and offers a good scope in the treatment of autoimmune hypothyroidism. An exploratory, randomised, placebo controlled, single blind was conducted at Dr. B.R Sur Homoeopathic Medical College, Hospital and Research centre and Institute of Nuclear medicine and Allied sciences, under Defense Research Development Organisation, Ministry of Defense, Timarpur, Delhi on 194 subjects suffering from subclinical hypothyroidism (SCH) with or without autoimmune thyroiditis (AIT). The subjects were divided into 3 major groups – Group A: SCH + AIT (n=38; high TSH with anti TPO ab+), Group B: AIT (n=47; normal TSH with anti TPO ab+), and Group C: SCH (n= 109; only high TSH). These groups were further randomised to two subgroups – verum and control.

Individualised homoeopathic medicine or identical placebo was administered to respective subgroups. Assessment of follow up was done based on changes in serum TSH, serum anti TPO antibody levels and serum FT 4 levels. Homoeopathic remedies were found to have not only brought about a statistically significant decrease in serum TSH and serum anti TPO antibody titres, but also demonstrated a potential to prevent progression to overt hypothyroidism. ($p < 0.006$ and $p < 0.05$) [5]. An open-label, prospective, single-arm trial was conducted on 40 patients suffering from hypothyroidism at the outpatient department of D. N. De Homeopathic Medical College and Hospital, West Bengal, India. The subjects were treated with individualised homoeopathic remedies. Serum TSH and FT 4 were considered as the primary outcomes and Zuleswki's clinical scoring (ZCS) and thyroid symptom



**Vijaykrishna et al.,**

questionnaire (TSQ) as the secondary outcomes, measured at baseline and after 3 months of treatment. Intention-to-treat sample was analysed in the end by paired t-tests. Individualised homoeopathic remedies were found to have promising effects in the treatment of hypothyroidism with a significant reduction in serum TSH and FT 4 levels ($p < 0.001$) [6].

A prospective single-arm clinical study without a control group was conducted in out-patient department (OPD), inpatient department (IPD), thyroid specialty clinic and peripheral health center of Sarada Krishna Homoeopathic medical college (SKHMC) from January 2021 to January 2022, on 30 subjects with elevated thyroid stimulating hormone, anti- microsomal antibody/ anti-thyroid peroxidase antibody, and anti-thyroglobulin antibody. The subjects were administered individualised homoeopathic medicines and followed up every month for a period of 12 months. Treatment outcomes were assessed based on anti-thyroglobulin antibody levels, TSH levels, zulewski's clinical score values of before and after 12 months of treatment. Homoeopathic medicines were found to be effective in the reduction of anti-thyroglobulin-antibody levels. ($p = 0.05$) [7]. This case series of patients diagnosed with autoimmune hypothyroidism and treated with individualised homoeopathic medicines is presented here in accordance with PITCH guidelines, with the aim of further exploring the potential role of homoeopathic intervention in the management of this condition.

MATERIALS AND METHODS

Seven patients diagnosed with Autoimmune hypothyroidism were treated with individualised Homoeopathic medicines. The prime objective of this retrospective case series is to substantiate that Homoeopathy has a curative effect in the treatment of Autoimmune hypothyroidism. All the cases presented here were treated at the out-patient department of Nishika Homoeo Clinic, Bangalore. The cases were diagnosed on the basis of serum ATPO and ATG titres evaluated before treatment. The patients included in this study were those who were not under any other medication at the time of homoeopathic intervention. A detailed history of all the patients was taken as per a structured case record proforma. The cases were analysed according to the principles of Homoeopathy. The individualised homoeopathic medicine was selected based on repertorisation using RADAR 10.0 software and finalised in consultation with the Homoeopathic Materia medica. The medicines were administered in centesimal potency and repeated according to the improvement of the patient. The cases were followed up every month from baseline to 6 months and improvement was assessed based on ATPO and ATG Titres. The individual case profiles are as described below:

Case 1

A 47 year old female, housewife, diagnosed with Autoimmune Hypothyroidism with raised ATG levels, presented with elevated TSH levels since 6 months and increased menstrual cramps before menses since 4 months, with menstrual bleeding characterised by large clots. In the past, she had suffered from COVID in 2020, and was operated for fissure-in-ano. Patient was thermally hot and thirsty and couldn't tolerate hunger. She was short tempered and often quarrelled with family members. She was very picky and choosy by nature, always wanted to be prioritised first and given importance and preferred to buy expensive and branded things. She couldn't bear to be dictated by anyone and often argued with her husband for the same. She would become emotional on seeing or hearing others' sad stories, and was easily moved by sad scenes played on Television too. Respect was of utmost importance to her and she wouldn't take it if anyone spoke rudely to her. She was haughty and would cut off from relationships wherever she felt hurt. Her baseline antibody values were - ATG - 111.2 IU/mL. (Fig 8)

Intervention:

The totality of symptoms was listed and repertorised (Fig 1) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Horrible things, sad stories, affect her profoundly





Vijaykrishna et al.,

- MIND - Exclusive, too
- MIND - Casting off people against her will
- GENERALITIES - Hunger, agg

The remedy that came up in the repertorisation was Platina, and upon consulting the Homoeopathic Materia medica, Platina was found to match the patient's disposition. A single dose of Platina 200C was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up- The case was followed up every month for a period of 6 months. There was a gradual reduction in her ATG levels along with a corresponding reduction in the intensity of her pre-menstrual cramps and clot size. The post-intervention antibody levels were - ATG - 3.6 IU/ ml. (Fig 9) The detailed follow-up is shown in Table 1.

Case 2

A 50 year old female, housekeeper by profession, diagnosed with Autoimmune Hypothyroidism with raised ATPO levels, presented with elevated TSH levels since one year and hair fall and weight gain since two years. Patient also reported that she was experiencing a change of voice in the last 6 months. In the past, she had suffered from recurrent renal calculi. She was married to her maternal uncle until his death 13 years ago, and had 3 children. She had attained menopause one year ago. Patient was thermally chilly and thirsty. She could not tolerate injustice and would confront even higher ups at work. She was a hard worker who did her work sincerely. Patient felt extremely guilty about having gotten her daughter married early as she was being subjected to a lot of harassment by her husband and in-laws. She constantly blamed herself for the same and was deeply saddened by it. Patient was constantly worried as to who will take care of her children, if something were to happen to her. Patient preferred to have piping hot food and drinks, and was highly anxious by nature. Her baseline antibody values were found to be - ATPO - 36.4 IU/mL. (Fig 10)

Intervention:

The totality of symptoms was listed and repertorised (Fig 2) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND - Injustice, cannot support
- MIND - Industrious
- MIND - Anxiety, children about, his
- GENERALITIES - Food and drinks - warm food, desire

Upon consulting the Homoeopathic Materia medica, Arsenicum Album was found to match the patient's disposition. A single dose of Arsenicum album 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up- The case was followed up every month for a period of 6 months. Her ATPO levels were found to gradually reduce to normal range with a corresponding significant reduction in hairfall. She regained her normal voice. The post-intervention antibody levels were - ATPO - 7.1 IU/mL. (Fig 11) The detailed follow-up is shown in Table 1.

Case 3

A 45 year old male, anaesthesiologist by profession, diagnosed with Autoimmune Hypothyroidism with raised ATPO levels, presented with hypothyroidism since 2 years. Patient also had depigmented patches on both elbows, and left ankle since 1 year. In the past, patient had suffered from allergic rhino-bronchitis. Patient was thermally chilly and very thirsty. Patient was extremely fastidious, fault finding and short tempered when others would not listen to him. He was very anxious about his health. Patient had a tendency to hit himself when angry. Patient had a





Vijaykrishna *et al.*,

lot of earning, but was very frugal in his spendings. His baseline antibody values were found to be - ATPO - 51.06 IU/mL. (Fig 12)

Intervention:

The totality of symptoms was listed and repertorised (Fig 3) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Striking himself
- MIND - Fastidious
- MIND - Censorious, critical
- MIND - Avarice
- GENERALITIES - Food and drinks - warm food, desire
- SKIN - Discoloration, white

Upon consulting the Homoeopathic Materia medica, Arsenicum Album was found to match the patient's disposition. A single dose of Arsenicum album 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. The patient's ATPO and ATG levels showed a gradual decline toward normal limits, accompanied by repigmentation of the previously depigmented patches over the elbows and ankle, which was interpreted as being consistent with Hering's law of cure. The post-intervention antibody levels were - ATPO - 27.06 IU/mL. (Fig 13) The detailed follow-up is shown in Table 1.

Case 4

A 42 year old male, software professional, presented with hypothyroidism since a week detected on routine annual health check-up. On further investigations, he was diagnosed to have Autoimmune Hypothyroidism with raised ATPO and ATG levels. In the past, patient had suffered from Typhoid. Patient was thermally hot and thirsty and had hunger intolerance since childhood. Patient was an extrovert who could make connections very quickly. He was lazy at home, but driven at work. He was very intelligent, curious and had an affinity towards learning new things. He was extremely disorganised and least bothered about his personal appearance and was dressed shabbily. He yearned to be recognised as a great achiever. On observation, he was found to be extremely talkative with an element of boasting about himself and making theories about everything. His baseline antibody values were found to be - ATPO > 1300 U/mL, ATG - 500 U/mL. (Fig 14)

Intervention:

The totality of symptoms was listed and repertorised (Fig 4) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Curious
- MIND - Boaster, braggart
- MIND - Indifference apathy, appearance, about personal
- MIND - Theorising
- GENERALITIES - Hunger, agg.

Upon consulting the Homoeopathic Materia medica, Sulphur was found to match the patient's disposition. A single dose of Sulphur 200 c was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in the ATPO, and ATG levels towards normal limits was observed.

The post-intervention antibody levels were - ATPO - 26.5 IU/mL, ATG - 106 IU/mL. (Fig 15, 16) The detailed follow-up is shown in Table 1.





Vijaykrishna *et al.*,

Case 5

A 26year old female, software professional, presented with profound depression with intense suicidal thoughts after the break-up of a relationship which occurred a few months ago. She was diagnosed with autoimmune hypothyroidism and reported that she felt numb completely and just wanted to die. She had considered her partner the most important person in her life and described him as a very lively and enthusiastic person. Patient blamed herself for the break-up constantly as she felt that she didn't match up to her partner's personality. It was observed that throughout the history taking, she kept sighing involuntarily as she narrated her symptoms. Patient was thermally chilly and thirstless. She was a highly emotional person, easily moved to tears and didn't like to be consoled. Her baseline investigation values were found to be - ATPO - 21.5 IU/mL. (Fig 17)

Intervention:

The totality of symptoms was listed and repertorised (Fig 5) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND - Suicidal disposition, thoughts
- MIND - Sighing - involuntarily
- MIND - Consolation, agg.
- MIND - Sadness, love; from disappointed

Upon consulting the Homoeopathic Materia medica, Ignatia was found to match the patient's disposition. A single dose of Ignatia 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in ATPO levels toward the normal range was observed, alongside significant improvement in the patient's mental health, with complete resolution of suicidal ideation. The post-intervention investigation levels were - ATPO - 6.9 IU/mL. (Fig 18) The detailed follow-up is shown in Table 1.

Case 6

A 74 year old female, homemaker, a known case of hypothyroidism, presented with constantly fluctuating thyroid hormone levels in spite of conventional medication. Her physician had to frequently change the dose of eltroxin administered to her. The patient presented with weight loss, reduced interest in occupational activities, and frequent crying spells. The patient reported frequent criticism from her husband despite her efforts to care for him. The patient attributed her husband's behaviour to her infertility, accompanied by persistent self-blame. She described feelings of inadequacy as a wife and perceived her husband's actions as justified. Patient was thermally chilly. She was a duty-oriented person and performed her duties irrespective of the state of her health. She was very fastidious by nature. Physically, emaciation was markedly noticeable. Her baseline investigation values were found to be - ATPO - 295 U/mL. (Fig 19)

Intervention:

The totality of symptoms was listed and repertorised (Fig 6) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Delusion - reproach; he has neglected his duty and deserves
- MIND - Duty too much sense of duty
- GENERALITIES - Emaciation

Upon consulting the Homoeopathic Materia medica, Aurum arsenicum was found to match the patient's disposition. A single dose of Aurum arsenicum 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month. Aurum arsenicum 10M was repeated once more after 3 months when the improvement came to a standstill.





Follow up - The case was followed up every month for a period of 6 months. A progressive normalization of ATPO levels was observed, along with improvement in body weight and restoration of interest in work.

The post-intervention investigation levels were - ATPO - 30.9 IU/mL. (Fig 20) The detailed follow-up is shown in Table 1.

Case 7

A 63 year old female, homemaker, diagnosed with autoimmune hypothyroidism, presented with swelling on the anterior neck and weight loss since few months. Patient was thermally hot and thirsty. She could not tolerate hunger since childhood. The patient reported that her only daughter had been married to a man settled in the USA; however, she later became aware of abusive behaviour by the son-in-law, with her daughter experiencing considerable distress. The patient expressed marked guilt and self-blame, with recurrent thoughts that the marital alliance had not been adequately evaluated by her. By nature, patient was extremely industrious and very fast in all her activities. Neck ultrasonography demonstrated thyroiditis with bilateral thyroid nodules. Her baseline antibody values were found to be - ATPO - 306.69 U/mL. (Fig 21)

Intervention:

The totality of symptoms was listed and repertorised (Fig 7) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND - Industrious
- GENERALITIES - Hunger agg
- GENERALITIES - Emaciation

Upon consulting the Homoeopathic Materia medica, Aurum iodatum was found to match the patient's disposition. A single dose of Aurum iodatum 200 was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in anti-thyroid peroxidase (ATPO) levels toward the normal range was observed, along with an improvement in her body weight and resolution of thyroiditis on neck ultrasonography. The post-intervention antibody levels were - ATPO - 3.50 IU/mL. (Fig 22) The detailed follow-up is shown in Table 1.

RESULTS

Out of the 7 cases chosen for the case series, 5 were females and 2 were males. (Fig 23). A majority of 4 of the subjects were found to be in the 40-50 years age group, 2 subjects were found to be in the 60-70 years age group and only 1 subject was found to be in the 20-30 years age group. (Fig 24). A majority of 3 of the subjects were homemakers, 2 were software professionals, while the others were a housekeeper, and an anaesthesiologist, respectively. (Fig 25). A majority of 5 of the subjects were found to have raised ATPO titres only, whereas 1 subject had both ATPO and ATG titres raised, and 1 subject had only raised ATG titres. A maximum number of 2 cases were prescribed Arsenicum album, and the remaining 5 were prescribed Platina, Sulphur, Ignatia, Aurum arsenicum and Aurum iodatum each respectively. (Fig 26). Maximum number of the 4 cases were prescribed the indicated homoeopathic medicine in 10M potency and the remaining 3 cases were prescribed the medicine in 200C potency. (Fig 27). All of the subjects responded well to the indicated homoeopathic medicines as reflected in a complete reversal of their thyroid antibodies to within normal limits with a corresponding improvement in their presenting complaints.





DISCUSSION

This study has shown that autoimmune hypothyroidism is more prevalent in those between the ages 40 to 50 years. Most of the subjects considered for the study were found to be females which is concurrent with the findings of other studies. Most of the subjects were from the working professional group followed by housewives. Arsenicum album was the remedy which was most indicated, having been prescribed to about 2 subjects. Aurum arsenicum, Aurum iodatum, Ignatia, Sulphur and Platina were prescribed to each of the remaining subjects, respectively. These remedies have demonstrated a good scope in the treatment of autoimmune hypothyroidism as they were found to have brought complete reduction in the ATPO and ATG titres to the normal range. Although formal follow-up was conducted for 6 months, additional follow-up suggested sustained normalization of thyroid function tests and antibody titres, with patients reporting resolution of their presenting complaints. These findings suggest that individualised homeopathic medicines, prescribed on the basis of homeopathic principles, have a positive role in the treatment of Autoimmune hypothyroidism. However, owing to the small number of cases taken up for the study, the results of this study can be considered as exploratory and may serve as the basis of future research studies.

CONCLUSION

This study concludes that homeopathic individualised medicine is effective in reducing the levels of ATPO and ATG in autoimmune hypothyroidism. Further studies on larger populations can be helpful in substantiating the effectiveness of Homoeopathy in treatment of Autoimmune hypothyroidism.

ACKNOWLEDGEMENT

The author expresses sincere gratitude to Dr. Munjal Thakar for his invaluable guidance, encouragement, and continuous support throughout the course of this research. The author also extends thanks to Parul University for providing the necessary academic resources and a conducive research environment. Special appreciation is conveyed to Dr. Samir Gupta, Associate Professor, Department of Practice of Medicine, Jawaharlal Nehru Homoeopathic Medical College, Vadodara, Gujarat, and Dr. G. Swati for their support and assistance in the drafting of this research paper. The author further acknowledges the faculty members, peers, and participants for their cooperation and contributions. Finally, the author is deeply grateful to all the patients for providing written informed consent for the publication of their clinical data.

Conflict of Interest:

No conflict of interest.

REFERENCES

1. Fröhlich E, Wahl R. Thyroid autoimmunity: role of anti-thyroid antibodies in thyroid and extra-thyroidal diseases. *Frontiers in immunology*. 2017 May 9;8:521.
2. Ferrari SM, Ragusa F, Elia G, Paparo SR, Mazzi V, Baldini E, Benvenga S, Antonelli A, Fallahi P. Precision medicine in autoimmune thyroiditis and hypothyroidism *Frontiers in pharmacology*. 2021 Nov 17;12:750380.
3. Hu X, Chen Y, Shen Y, Tian R, Sheng Y, Que H. Global prevalence and epidemiological trends of Hashimoto's thyroiditis in adults: A systematic review and meta-analysis. *Frontiers in public health*. 2022 Oct 13;10:1020709.
4. Unnikrishnan AG, Kalra S, Sahay RK, Bantwal G, John M, Tewari N. Prevalence of hypothyroidism in adults: An epidemiological study in eight cities of India. *Indian journal of endocrinology and metabolism*. 2013 Jul 1;17(4):647-52.





5. Chauhan VK, Manchanda RK, Narang A, Marwaha RK, Arora S, Nagpal L, Verma SK, Sreenivas V. Efficacy of homeopathic intervention in subclinical hypothyroidism with or without autoimmune thyroiditis in children: an exploratory randomized control study. *Homeopathy*. 2014 Oct;103(04):224-31.
6. Ray AS, Ganguly S, Mukherjee SK, Hazra P, Dutta S, Nath A, Koley M, Saha S. Homeopathic Treatment in Hypothyroidism—An Open-Label, Prospective, Single-Arm, Clinical Trial. *Homeopathic Links*. 2021 Sep;34(03):191-
7. Vishnu Priya S, Sathish Kumar V, Aarathy V, Pillai AS. INDIVIDUALIZED HOMOEOPATHIC MEDICINE IN ANTI-THYROGLOBULIN ANTIBODY TITER IN HASHIMOTO THYROIDITIS-A CLINICAL STUDY.

The repertorisation charts with the totality considered for the cases are as below

Fig. 1. Case 1- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - HORRIBLE things, sad stories affect her profoundly	67
2	1234	1	MIND - EXCLUSIVE, too	6
3	1234	1	MIND - CASTING OFF people against her will	1
4	1234	1	GENERALS - HUNGER - agg.	39

	plat.	nat-m.	iod.	calc.	kali-c.	sil.	sulph.	aur.	caust.	phos.
	4/6	3/4	2/6	2/5	2/5	2/5	2/5	2/4	2/4	2/4
1	1	2	3	4	2	2	2	2	2	2
2	1	1	-	1	-	-	-	-	-	-
3	3	-	-	-	-	-	-	-	-	-
4	1	1	3	-	3	3	3	2	2	2

Fig. 2. Case 2- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - INJUSTICE, cannot support	63
3	1234	1	MIND - INDUSTRIOUS	156
4	1234	1	MIND - ANXIETY - children - about his	18
5	1234	1	GENERALS - FOOD and DRINKS - warm food - desire	41

	ars.	cupr.	carc.	ph-ac.	sep.	sulph.	falco-pe.	calc.	med.	aur.
	5/9	5/5	4/7	4/5	4/5	4/5	4/5	4/4	4/4	3/6
1	2	1	2	1	1	1	1	-	1	2
2	1	1	3	1	1	1	2	1	1	1
3	1	1	1	-	2	1	1	1	1	3
4	2	1	1	1	1	2	1	1	-	-
5	3	1	-	2	-	-	-	1	1	-

Fig. 3. Case 3- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - STRIKING - himself	31
2	1234	1	MIND - FASTIDIOUS	73
3	1234	1	MIND - CENSORIOUS	148
4	1234	1	MIND - AVARICE	45
5	1234	1	GENERALS - FOOD and DRINKS - warm food - desire	41
6	1234	1	SKIN - DISCOLORATION - white	18





Vijaykrishna et al.,

	ars.	sil.	lyc.	phos.	sep.	sulph.	nat-m.	plat.	calc.	con.
	6/17	5/7	4/6	4/6	4/6	4/6	4/5	4/5	4/4	4/4
1	1	-	-	2	1	1	-	1	-	1
2	3	1	1	1	1	1	2	1	-	1
3	3	1	1	2	2	3	1	2	1	1
4	4	3	2	1	2	1	1	1	1	1
5	3	1	2	-	-	-	-	-	1	-
6	3	1	-	-	-	-	1	-	1	-

Fig. 4. Case 4- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - CURIOUS	39
2	1234	1	MIND - BOASTER	21
3	1234	1	MIND - INDIFFERENCE - appearance; to his personal	18
4	1234	1	MIND - THEORIZING	40
5	1234	1	GENERALS - HUNGER - agg.	39

	sulph.	verat.	lyc.	aur-s.	aur.	lach.	calc.	hydrog.	puls.	positr.
	5/14	4/6	4/5	4/4	3/5	3/4	3/3	3/3	3/3	3/3
1	1	1	1	1	1	1	1	1	1	1
2	3	2	2	1	-	1	1	1	1	-
3	4	-	-	1	-	-	1	-	-	1
4	3	2	1	1	2	2	-	1	1	1
5	3	1	1	-	2	-	-	-	-	-

Fig. 5. Case 5- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - SUICIDAL disposition - thoughts	62
3	1234	1	MIND - SIGHING - involuntary	4
4	1234	1	MIND - CONSOLATION - agg.	55
5	1234	1	MIND - SADNESS - love; from disappointed	13

	ign.	nat-m.	aur-m-n.	aur.	carc.	hell.	aur-s.	calc-p.	acon.	merc.
	5/13	4/10	4/8	4/8	4/6	4/5	3/5	3/5	3/4	3/4
1	2	2	2	2	2	1	1	1	2	1
2	2	1	2	3	1	1	3	-	1	2
3	3	-	-	-	-	1	-	2	-	-
4	3	4	2	1	2	2	-	2	1	1
5	3	3	2	2	1	-	1	-	-	-

Fig. 6. Case 6- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - DELUSIONS - reproach; he has neglected his duty and deserves	2
2	1234	1	MIND - DUTY - too much sense of duty	38
3	1234	1	GENERALS - EMACIATION	299





Vijaykrishna et al.,

	aur.	calc.	nit-ac.	ars.	kali-c.	lyc.	nat-m.	nat-s.	nux-v.	thuj.
	3/5	2/6	2/6	2/5	2/5	2/4	2/4	2/4	2/4	2/4
1	2	-	-	-	-	-	-	-	-	-
2	1	3	3	2	3	1	1	2	1	2
3	2	3	3	3	2	3	3	2	3	2

Fig. 7. Case 7- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - INDUSTRIOUS	156
3	1234	1	GENERALS - EMACIATION	299
4	1234	1	GENERALS - HUNGER - agg.	39

	aur.	sil.	sulph.	kali-c.	lyc.	nat-m.	merc.	verat.	staph.	iod.
	4/9	4/8	4/8	4/7	4/7	4/7	4/5	4/5	4/4	3/8
1	2	1	1	1	1	2	1	1	1	-
2	3	1	1	1	2	1	1	1	1	2
3	2	3	3	2	3	3	2	2	1	3
4	2	3	3	3	1	1	1	1	1	3

Table 8: Case profiles with Homoeopathic prescription and scoring from baseline to six months of follow- up

Timeline	Case profiles	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Baseline	Symptoms:	Elevated ATG levels. Increased pre-menstrual cramps with discharge of large clots during menses.	Elevated ATPO levels. Hair fall. Weight gain. (86 kgs) Change of voice.	Elevated ATPO levels. Depigmented patches on both elbows and left ankle.	Elevated ATPO and ATG levels. Sulphur 200C – one dose,	Elevated ATPO levels. Profound sadness with suicidal ideation.	Elevated ATPO levels. Weight loss. (45 kgs) Loss of interest in work.	Elevated ATPO levels. Weight loss. (42 kgs) Swelling on anterior Neck
	HI*	Platina 200C – One dose, PL** – twice daily.	Arsenicum album 10M- One dose, PL – twice daily.	Arsenicum album 10M – one dose, PL – twice daily.	PL – twice daily	Ignatia 10M- One dose, PL – twice daily	Aurum arsenic 10M – one dose, PL – twice daily	Aurum iodatum 200C – one dose, twice daily
	ATPO/ ATG level	ATG – 111.2 IU/mL	ATPO – 36.4 IU/mL	ATPO - 51.06 IU/mL	ATPO > 1300 U/mL, ATG - 500 U/mL	ATPO - 21.5 IU/mL	ATPO – 295 U/mL	ATPO – 306.69 U/mL
1 month	Symptoms:	Pre-menstrual cramps	Self - blaming has	Anger has reduced, able to have self-	Generals are good.	Suicidal ideation reduced.	Guilt feeling has come	Self-blaming has





Vijaykrishna et al.,

		better. Size of clots reduced.	reduced. Voice is slightly better. Hair fall is better. Weight has remained same. (86 kgs)	control. No episode of striking himself in anger. Pigmentation is observed in the elbows in the depigmented areas.			down. Interest in work is renewed Weight improved by 2 kgs. (47 kgs)	reduced. Weight improved. Gained 1 kg weight. (43 kgs)
2 months	Symptoms:	Pre-menstrual cramps better. Size of clots reduced.	Self-blaming has reduced. Voice is slightly better. Hair fall is better. Slight loss of weight. (85.5 kgs)	Better self-control when angry. Pigmentation is observed in the elbows in the depigmented areas – better than previous month.	Generally good.	Sadness and crying spells are better. No suicidal thoughts.	Not much of changes. Same as previous. Weight is stable.	Generally happier. Gained weight. Neck swelling has reduced. (43.5 kgs)
	HI	PL – Twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
3 months	Symptoms:	Bearable pre-menstrual cramps. Clots have reduced.	Much happier state of mind. Voice is much better.	Not much of anger. No episodes of striking himself. Pigmentation has started appearing in the ankle area also.	Generally good.	Much better. Able to accept the break-up. Doesn't blame self for it anymore. No suicidal ideation.	Not much of changes. Same as previous. Weight is stable.	Much better. Gained weight. Swelling is better. (44.5 kgs)
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	Aurum arsenicum 10M – one dose, PL twice daily	PL – twice daily
4 months	Symptoms:	No pain before menses.	Voice is back to usual.	No anger. Elbows and ankle	Better.	Back to usual cheerful	Feeling much better and	Much better. Gaining





Vijaykrishna et al.,

		Flow is back to usual.		pigmentation is improving.		self. No more thoughts of past.	more interested in work. Gained weight. (49 kgs)	weight steadily. Swelling better. (46 kgs)
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
5 months	Symptoms:	No pain and no clots. Generally, feeling better.	Voice is back to normal. Overall, better.	Elbows are completely pigmented to usual complexion.	Better	Doing better.	Better. Weight -50 kgs.	Better. Swelling has subsided. Weight – 48 kgs.
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
6 months	Symptoms:	No complaints.	Better	Much better. Pigmentation of ankle is much better.	Better	Better	Weight – 52 kgs.	Better. Weight – 49.5 kgs. Swelling on neck is subsided.
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
	ATPO/ ATG levels	ATG – 3.6 IU/mL	ATPO - 7.1 IU/mL	ATPO - 27.06 IU/mL	ATPO - 26.5 IU/mL, ATG - 106 IU/mL	ATPO - 6.9 IU/mL	ATPO - 30.9 IU/mL	ATPO- 3.50 IU/mL

*HI – Homoeopathic intervention, ** PL – Placebo



Vijaykrishna *et al.*,

Medical Laboratory Report			
Reference: DR.AMRUTHA DIAGNOSTIC CENTRE KASTURINAGAR Sample Collected At: Amrutha Diagnostic Center - Kasthuri Nagar, Amrutha Diagnostic Center - Kasthuri Nagar #74, ground Floor, Kasturinagar, Main Road, Bchannasandra, Bangalore 29, -ka 560001 India Processing Location: Metropolis Healthcare Ltd. #76/10, 15th Floor, Malleshwaram, Bangalore		VID: 230242504175064 Registered On: 03/02/2024 01:12 PM Collected On: 03/02/2024 1:10 PM Reported On: 03/02/2024 04:49 PM	
PID NO: P22723518063962 Age: 46 Year(s) Sex: Female			
Investigation	Observed Value	Unit	Biological Reference Interval
Thyroid Antibodies: TPO and ATG, Serum (Serum, Chemiluminescence)			
Microsomal (TPO) Antibody Titre, Serum	<9.00	IU/mL	< 34.0
Interpretation: 1. Anti-thyroid peroxidase (anti-TPO) antibodies are specific against TPO, which catalyses iodine oxidation & iodination reactions in the thyroid gland. 2. 10-15% of normal individuals & during pregnancy can have raised anti-TPO antibody titres. Anti-TPO antibodies are the most common anti-thyroid autoantibody, present in approximately 90% of Hashimoto's thyroiditis, 75% of Graves' disease and 10-20% of nodular goitre or thyroid carcinoma. Relatives of patients with an autoimmune thyroid disorder (40%-50%) may have elevated serum TPOAb levels. High serum antibodies are found in active phase chronic autoimmune thyroiditis & antibody titer can be used to assess disease activity. Other autoimmune disorders often associated with elevated TPOAb include: Sjogren's syndrome, lupus, rheumatoid arthritis, diabetes mellitus (type1) and pernicious anemia.			
Thyroglobulin Antibody (ATG), Serum	111.20	IU/mL	< 4.11
-- End of Report --			

Figure 1: Case 1 – Baseline thyroid antibody titres

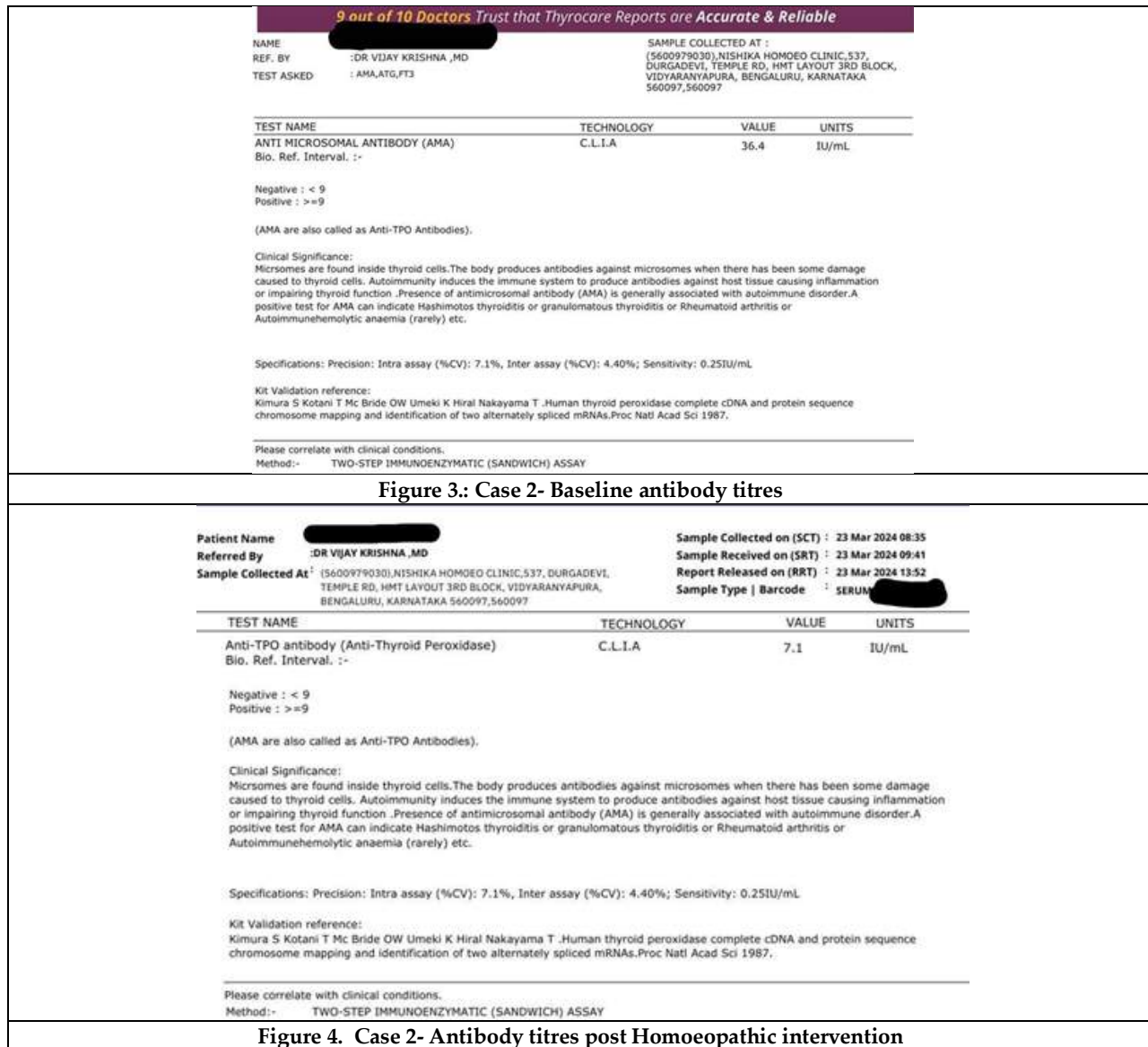
SRI MARUTHI DIAGNOSTIC		Center For Hi-tech Diagnostic Service	
		97439 66134 / 90368 66134. srimaruthidiagnostic134@gmail.com	
NAME : [REDACTED] AGE/SEX : 46 Yrs / Female REFERRED BY : REF CENTER : SRI MARUTHI DIAGNOSTIC CENTRE		REG LAB NO. : 24061328 / 176476 DATE OF RECEIVED : 19-06-2024 at 12:03 PM DATE OF REPORT : 19-06-2024 at 02:36 PM	
TEST PARAMETER	RESULT	REFERENCE RANGE	
HORMONE ASSAYS			
ANTI THYROGLOBULIN ANTIBODY (ANTI Tg)			
ANTI THYROGLOBULIN ANTIBODY (ANTI Tg) CMIA/CLIA	3.60 IU/mL	< 4.11 IU/mL	
CLINICAL NOTE: Anti Tg autoantibody measurements are recommended if Anti TPO autoantibody is negative, but clinical suspicion of Autoimmune thyroid disease is high. Detection of these antibodies in cases of Neonatal hypothyroidism suggests transplacental antibody transfer particularly if there is a maternal history of autoimmune thyroiditis.			

Figure 2. Case 1- Antibody titres post Homoeopathic intervention





Vijaykrishna et al.,





Vijaykrishna et al.,

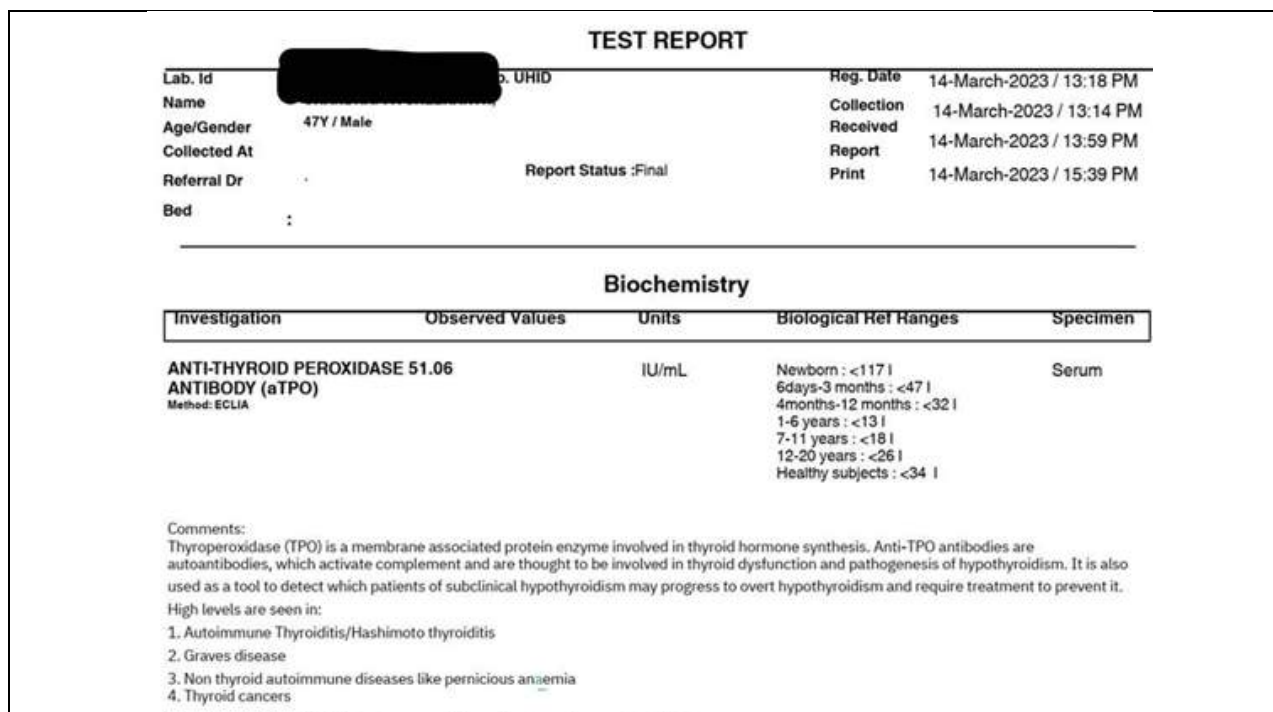


Figure 5.: Case 3- Baseline antibody titres

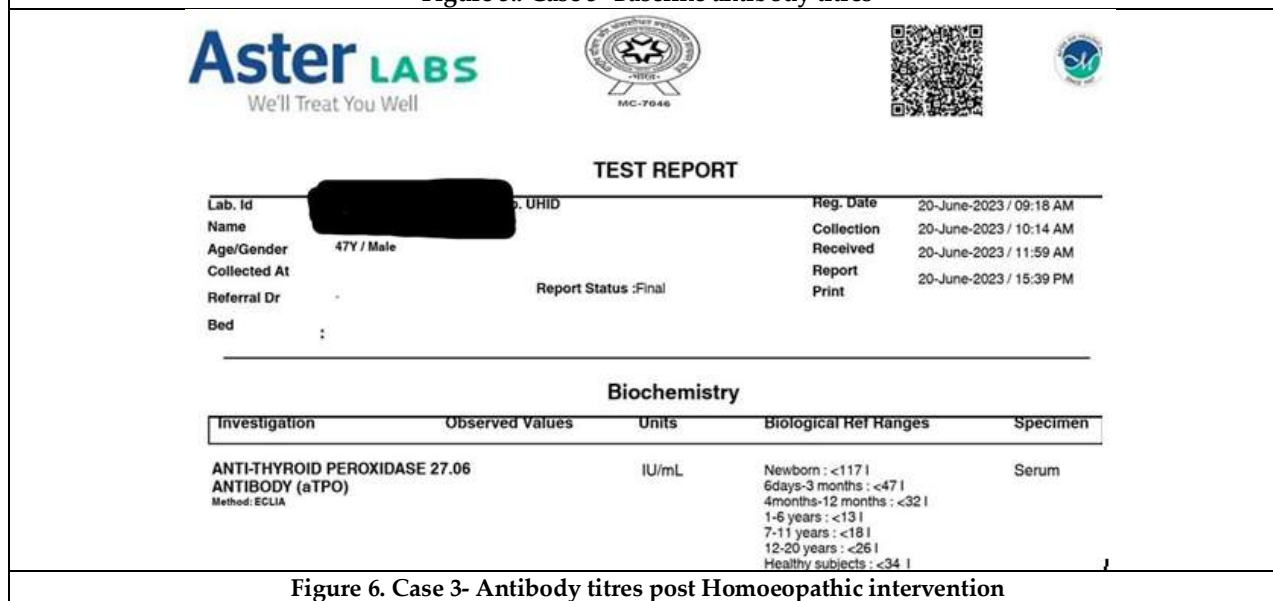


Figure 6. Case 3- Antibody titres post Homoeopathic intervention





TEST REPORT

Neuberg Anand

REFERENCE LABORATORY

Sample Source: Walkin

Sample Received at: No.461, 19MT Layout, 3rd Block, Vidyanagar, Bangalore-560097.

Age: 43 Year(s)

Gender: M

Contact No.:

Registered: 25/11/2023 08:27

Reported: 25/11/2023 15:46

Referring Dr.: DR. COLUMBIA ASIA HOSPITAL

Report Status: Final

HIGHER CHEMISTRY

Test Name	Test Result	Biological Reference Range	Sample
THYROID FUNCTION TESTS (Chemiluminescence)			
TRI IODOETHYRONE (T3)	0.85 ng/ml	0.6 - 1.81 ng/ml	SER
CHEMILUMINESCENCE			
THYROXINE (T4)	4.40 mcg/dl	4.5 - 18.9 mcg/dl Hyperthyroid: 11 - 19.1 mcg/dl Hypothyroid: 0.8 - 5.5 mcg/dl Sick Euthyroid: 1.9 - 13.3 mcg/dl	SER
CHEMILUMINESCENCE			
THYROID STIMULATING HORMONE	21.40 mIU/ml	0.4 - 4.2 mIU/ml	SER
CHEMILUMINESCENCE			
ANTI THYROID ANTIBODIES			
ANTI THYRO PEROXIDASE ANTIBODIES (ANTI TPO)	>1300.0 U/ml	<60 Negative >60 Positive U/ml	SER
CHEMILUMINESCENCE			
ANTIBODY TO THYROGLOBULIN(anti-Tg) (chemiluminescence)	>500.0 U/ml	0-60 U/ml U/ml	SER
CHEMILUMINESCENCE			

Figure 7. Case 4- Baseline antibody titres

TEST REPORT			
Lab. Id	Hosp. URID	Reg. Date	12-May-2024 / 13:18 PM
Name		Collection	12-May-2024 / 13:14 PM
Age/Gender	43Y / Male	Received	12-May-2024 / 13:59 PM
Collected At		Report	12-May-2024 / 15:39 PM
Referral Dr		Print	
Bed			
Report Status: Final			
Biochemistry			
Investigation	Observed Values	Units	Biological Ref Ranges
ANTI-THYROID PEROXIDASE ANTIBODY (aTPO)	26.5	IU/mL	Newborn : <117 I 6days-3 months : <47 I 4months-12 months : <32 I 1-6 years : <13 I 7-11 years : <18 I 12-20 years : <26 I Healthy subjects : <34 I
Method: ECLIA			
			Specimen: Serum

Figure 8: Case 4- Post homoeopathic intervention ATPO titres

TEST REPORT			
Lab. Id	Hosp. URID	Reg. Date	12-May-2024 / 13:18 PM
Name		Collection	12-May-2024 / 13:14 PM
Age/Gender	43Y / Male	Received	12-May-2024 / 13:59 PM
Collected At		Report	12-May-2024 / 15:39 PM
Referral Dr		Print	
Bed			
Report Status: Final			
Biochemistry			
Investigation	Observed Value	Unit	Biological Ref. Interval
ANTI THYROGLOBULIN aTg ANTIBODY	106	IU/mL	Newborn : <134 6days-3 months : <146 4-12 months : <130 1-6 years : <38 7-11 years : <37 12-20 years : <64
Method: ECLIA			
			Specimen: Serum

Figure 9: Case 4- Post homoeopathic intervention ATG titres





Vijaykrishna et al.,

PROCESSED AT :
Thyrocare
 D-37/1, TTC MIDC, Turbhe,
 Navi Mumbai-400 703

 **CAP**
 ACCREDITED
 COLLEGE of AMERICAN PATHOLOGISTS

Thyrocare
honestly yours

Corporate Office : Thyrocare Technologies Limited D-37/3, TTC MIDC, Turbhe, Navi Mumbai - 400703
 ☎ 022 - 3090 0000 / 4125 2525 ☎ 8691866066 ✉ wellness@thyrocare.com 🌐 www.thyrocare.com

REPORT

NAME : [REDACTED]
REF. BY : SELF
TEST ASKED : AMA

SAMPLE COLLECTED AT :
 FLAT NO 402, BLOCK -A, BALAJI PRESTINE
 APARTMENT, WHITEFIELD MAIN ROAD, BESIDES
 GOLDS GYM, WHITEFIELD - 560066

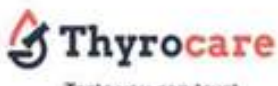
TEST NAME	TECHNOLOGY	VALUE	UNITS
ANTI MICROSOMAL ANTIBODY (AMA) Reference Range : Negative : < 9 Positive : > 9	C.L.I.A	21.5	IU/mL

(AMA are also called as Anti-TPO Antibodies).
Method : FULLY AUTOMATED CHEMI LUMINESCENT IMMUNO ASSAY
Please correlate with clinical conditions.

-- End of report --

Figure 10: Case 5- Baseline antibody titres

PROCESSED AT :
Thyrocare,
 5CA-711, 3rd Floor,
 HRBR 2nd Block,
 Hennur, Bengaluru-560043

 **Thyrocare**
 Tests you can trust

Thyrocare Technologies Limited, D-37/3, TTC MIDC, Turbhe, Navi Mumbai - 400703 ☎ 98706 66333 ✉ wellness@thyrocare.com

9 out of 10 Doctors Trust that Thyrocare Reports are Accurate & Reliable

NAME : [REDACTED]
REF. BY : [REDACTED]
TEST ASKED : AMA

SAMPLE COLLECTED AT :
 (5600979030), NISHIKA HOMEO CLINIC, 537,
 DURGADevi, TEMPLE RD, HMT LAYOUT 3RD BLOCK,
 VIDYARANYAPURA, BENGALURU, KARNATAKA
 560097, 560097

TEST NAME	TECHNOLOGY	VALUE	UNITS
ANTI MICROSOMAL ANTIBODY (AMA) Bio. Ref. Interval. :- Negative : < 9 Positive : >=9 (AMA are also called as Anti-TPO Antibodies). Clinical Significance: Microsomes are found inside thyroid cells. The body produces antibodies against microsomes when there has been some damage caused to thyroid cells. Autoimmunity induces the immune system to produce antibodies against host tissue causing inflammation or impairing thyroid function. Presence of antimicrosomal antibody (AMA) is generally associated with autoimmune disorder. A positive test for AMA can indicate Hashimoto's thyroiditis or granulomatous thyroiditis or Rheumatoid arthritis or Autoimmune hemolytic anaemia (rarely) etc.	C.L.I.A	6.9	IU/mL

Figure 11: Case 5- Post homoeopathic intervention antibody titres





Vijaykrishna et al.,

Neudery
REFERENCE LABORATORIES

Visit Id: R6082298

Cert. No.: SAC - 2734

Sample Source: CGHSAB B'LORE

Sample Collected/Received at: No.461, HMT Layout, 3rd Block, Vidhyaranyapura, Bangalore-560097.

Name: [REDACTED]

Age: 74 Year(s) Gender: F Contact No.: 9886389184

UID: Referring Dr.: DR VIJAY KRISHNA .V

Registered: 02/11/2022 08:13
Reported: 02/11/2022 12:40
Report Status: Final

Test Name	Test Result	Biological Reference Range	Sample
ANTI THYRO PEROXIDASE ANTIBODIES (ANTI TPO) CHEMILUMINESCENCE	295.00 U/ml	<60 Negative >60 Positive U/ml	SER
FREE THYROXINE (FT4) CHEMILUMINESCENCE	1.04 ng/dl	0.89 - 1.76 (Ref Tietz 4th ED) ng/dl	SER
FREE TRI IODOTHYRONINE (FT3) CHEMILUMINESCENCE	2.0 pg/ml	2.3 - 4.2 pg/ml	SER

----- End of HIGHER CHEMISTRY Report -----

Reviewed By: Dr. Prathibha K

Dr. Prathibha K
Biochemist
Reported On: 22/09/2019 12:41
KMC NO.: - 77400

Figure 12: Case 6- Baseline antibody titres

Reference: Dr. JAYALAKSHMI CGHS
Sample Collected At:

VID: 230183000490261

Registered On: 03/05/2023 07:33 AM
Collected On: 03/05/2023 7:36 AM
Reported On: 03/05/2023 12:48 PM

Investigation	Observed Value	Unit	Biological Reference Interval
Microsomal (TPO) Antibody Titre, Serum (Serum, Chemiluminescence)	30.9	IU/mL	< 34.0

Interpretation-

1. Anti-thyroid peroxidase (anti-TPO) antibodies are specific against TPO, which catalyses iodine oxidation & iodination reactions in the thyroid gland.
2. 10-15% of normal individuals & during pregnancy can have raised anti-TPO antibody titres.

Anti-TPO antibodies are the most common anti-thyroid autoantibody, present in approximately 90% of Hashimoto's thyroiditis, 75% of Graves' disease and 10-20% of nodular goitre or thyroid carcinoma. Relatives of patients with an autoimmune thyroid disorder (40%-50%) may have elevated serum TPOAb levels. High serum antibodies are found in active phase chronic autoimmune thyroiditis & antibody titer can be used to assess disease activity. Other autoimmune disorders often associated with elevated TPOAb include: Sjogren's syndrome, lupus, rheumatoid arthritis, diabetes mellitus (type1) and pernicious anemia.

Figure 13: Case 6- Post homoeopathic intervention antibody titres





Vijaykrishna et al.,

R.V. [Redacted] Name [Redacted] Ref. [Redacted] Corporate : METRO POLIS (GOKULA)		Reg. Date : 03/08/2022 11:17 Age / Sex : 63 Year(s) / Female
TEST REPORT		Referred In Sample
Biochemistry		
Test Name	Result(s)	Biological Reference Interval
ANTI THYRO PEROXIDASE ANTIBODIES (Anti TPO) / MICROSOMAL (Chemiluminescence)	306.69 IU/ml	< 5.61 IU/mL
End Of Report		03/08/2022
Verified By Scientific Officer - NRS	Your paragraph text Dr. RaviKumar H N MD DCP PATHOLOGIST	

Figure 14: Case 7- Baseline antibody titres

No.21, NTI Layout, Vidyaranyapura, Bangalore - 97, Ph: 080 23649780			
Name	[Redacted]	Ref By	DR. VIJAYAKRISHNA V
Age/Sex	64 Year(s)/Female	Reg Date	05/02/2023 17:00
Lab. No	[Redacted]	Reported on	05/02/2023 18:25

Test Name	Observed Values	Reference Range	Page 1 of 1
SEROLOGY REPORT			
Anti Thyroperoxidase Antibody (Anti TPO)	3.50 IU/mL	<5.61	
----- End of Report -----			
 Mrs. Lekshmi Bijoy Medical Bio-Chemist			

Figure 15: Case 7- Post homoeopathic intervention antibody titres

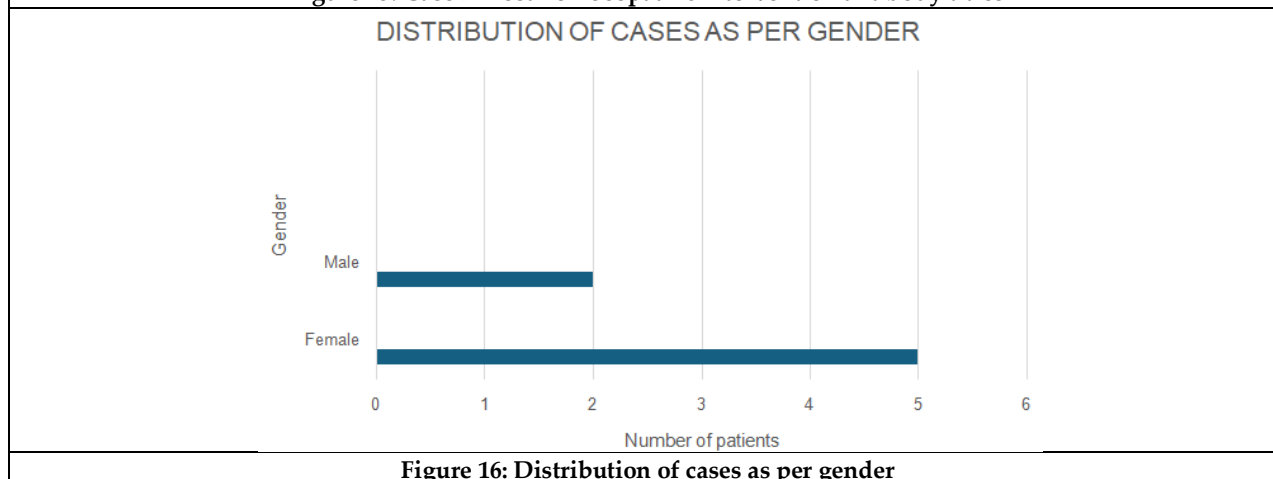


Figure 16: Distribution of cases as per gender





DISTRIBUTION OF CASES AS PER AGE

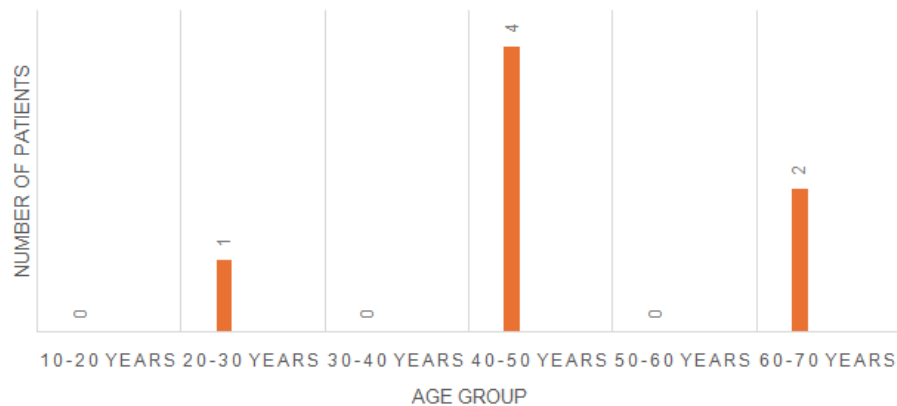


Figure 17: Distribution of cases as per age

DISTRIBUTION OF CASES AS PER OCCUPATION

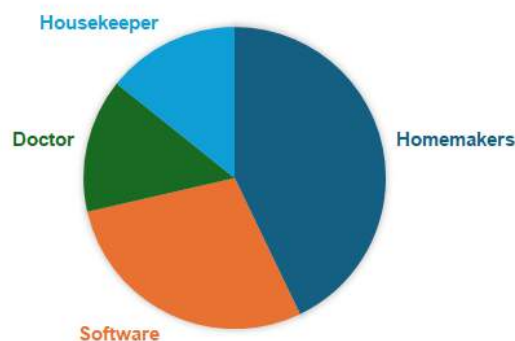


Figure 18: Distribution of cases as per occupation

DISTRIBUTION OF CASES AS PER MEDICINE PRESCRIBED

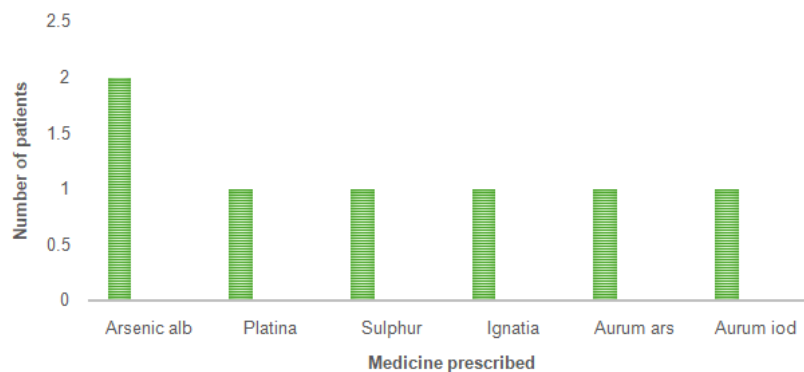
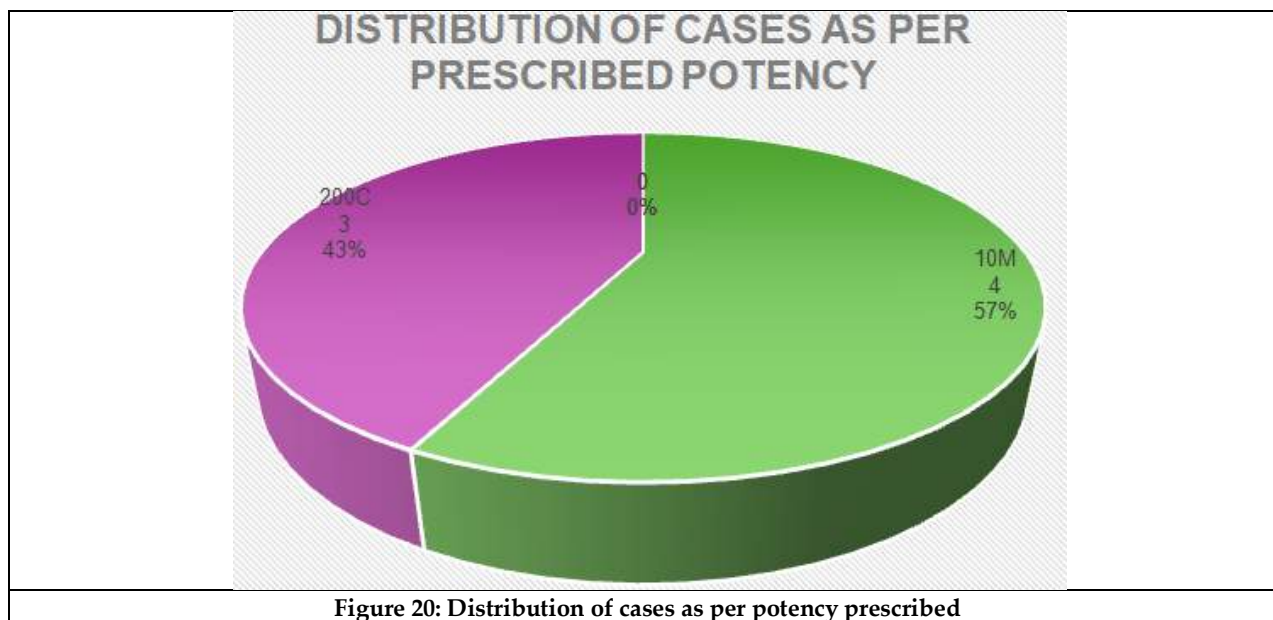


Figure 19: Distribution of cases as per Medicine prescribed





Vijaykrishna et al.,



Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.





RESEARCH ARTICLE

Neutrosophic Subalgebras of Several types in UP – Algebras

T. Radha^{1*} and P. Gomathi Sundari²

¹Assistant Professor, Department of Mathematics, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, (Affiliated to Anna University, Chennai), Tamil Nadu, India.

²Assistant Professor, Department of Mathematics, Rajah Serfoji Government College, Thanjavur, (Affiliated to Bharathidasan University, Tiruchirappalli), Tamil Nadu, India.

Received: 12 Mar 2026

Revised: 10 Apr 2026

Accepted: 10 Jun 2026

*Address for Correspondence

T. Radha

Assistant Professor,
Department of Mathematics,
Dhanalakshmi Srinivasan Engineering College (Autonomous),
Perambalur, (Affiliated to Anna University, Chennai),
Tamil Nadu, India.



This is an Open Access Journal / article distributed under the terms of the **Creative Commons Attribution License** (CC BY-NC-ND 3.0) which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. All rights reserved.

ABSTRACT

Characterizations of an $(\in, \in)$ -neutrosophic subalgebra and an $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are provided. Given special sets, so called neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets, conditions for the neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets to be subalgebras are discussed. Conditions for a neutrosophic set to be a $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are considered.

Keywords: Neutrosophic set, neutrosophic $\in$ -subset, neutrosophic q -subset, neutrosophic $\in \vee q$ -subset, $(\in, \in)$ -neutrosophic subalgebra, $(\in, q)$ -neutrosophic subalgebra, $(q, \in)$ -neutrosophic subalgebra, $(q, \in)$ -neutrosophic subalgebra, $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra, $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra.

2020 Mathematics Subject Classification. 06F35, 03G25, 03B52.

INTRODUCTION

The Sheffer operation, also known as the Sheffer stroke or NAND operator was first introduced by H. M. Sheffer [2]. This operation holds significance because it can be used on its own, without any other logical operators, to construct a logical system. This means that any axiom of a logical system can be restated using only the Sheffer operation. Because of this property, it becomes easier to control certain properties of the newly constructed logical system.





Radha and Gomathi Sundari

Additionally, it's worth noting that the axioms of Boolean algebra, which is the algebraic counterpart of classical propositional calculus, can be expressed solely using the Sheffer operation. This highlights the fundamental nature and versatility of the Sheffer operation in logical and algebraic systems. In this paper, characterizations of an $(\in, \in)$ -neutrosophic subalgebra and an $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are provided. Given special sets, so called neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets, conditions for the neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets to be subalgebras are discussed. Conditions for a neutrosophic set to be a $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are considered

Preliminaries

Definition 2.1: [2] Let $H = \langle H, | \rangle$ be a groupoid. The operation $|$ is said to be a Sheffer stroke operation if it satisfies the following conditions:

$$(S1) \ x|y = y|x$$

$$(S2) \ (x|x)|(x|y) = x$$

$$(S3) \ x|((y|z)|(y|z)) = ((x|y)|(x|y))|z$$

$$(S4) \ (x|((x|x)|(y|y))|(x|((x|x)|(y|y)))) = x.$$

Definition 2.2: [1] A Sheffer stroke Hilbert algebra is a structure $\langle H, | \rangle$ of type (2), in which H is a non-empty set and $|$ is a Sheffer stroke operation on H such that the following identities are satisfied for all $x, y, z \in H$:

$$1. \left(\left(\left((z|z) \right) \right) \right) \left| \left(\left(\left((z|z) \right) \right) \right) \right) = x| (x),$$

$$2. \text{If } x|(y|y) = y|(x|x) = x|(x|x) \text{ then } x = y.$$

Proposition 2.3:[1] Let $\langle A, | \rangle$ be a Sheffer stroke Hilbert algebra. Then the binary relation $x \leq y$ if and only if $(x|(y|y)) = 1$ is a partial order on A .

Definition 2.4: A nonempty subset G of a Sheffer stroke Hilbert algebra of X is called a subalgebra of X if $(x|(y|y))|(x|(y|y)) \in G$ for all $x, y \in G$. A neutrosophic set in X is a structure of the form $A = \{ \langle x, A_T(x), A_I(x), A_F(x) \rangle : x \in X \}$, where $A_T : X \rightarrow [0, 1]$ is a truth membership function, $A_I : X \rightarrow [0, 1]$ is an indeterminate membership function, and $A_F : X \rightarrow [0, 1]$ is a false membership function. For the sake of simplicity, we use the symbol $A = (A_T, A_I, A_F)$ for the neutrosophic set $A = \{ \langle x, A_T(x), A_I(x), A_F(x) \rangle : x \in X \}$.

Neutrosophic subalgebras of several types

Given a neutrosophic set $A = (A_T, A_I, A_F)$ in a set X , $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$, we consider the following sets:

$$T_{\in}(A, \alpha) = \{x \in X : A_T(x) \geq \alpha\},$$

$$I_{\in}(A, \beta) = \{x \in X : A_I(x) \geq \beta\},$$

$$F_{\in}(A, \gamma) = \{x \in X : A_F(x) \leq \gamma\},$$

$$T_q(A, \alpha) = \{x \in X : A_T(x) + \alpha > 1\},$$

$$I_q(A, \beta) = \{x \in X : A_I(x) + \beta > 1\},$$

$$F_q(A, \gamma) = \{x \in X : A_F(x) + \gamma < 1\},$$

$$T_{\in \vee q}(A, \alpha) = \{x \in X : A_T(x) \geq \alpha \text{ or } A_T(x) + \alpha > 1\},$$

$$I_{\in \vee q}(A, \beta) = \{x \in X : A_I(x) \geq \beta \text{ or } A_I(x) + \beta > 1\},$$

$$F_{\in \vee q}(A, \gamma) = \{x \in X : A_F(x) \leq \gamma \text{ or } A_F(x) + \gamma < 1\}.$$

We say $U_{\in}(A, \alpha)$, $I_{\in}(A, \beta)$ and $F_{\in}(A, \gamma)$ are neutrosophic $\in$ -subsets of X , and $U_q(A, \alpha)$, $I_q(A, \beta)$ and $F_q(A, \gamma)$ are neutrosophic q -subsets of X and $U_{\in \vee q}(A, \alpha)$, $I_{\in \vee q}(A, \beta)$ and $F_{\in \vee q}(A, \gamma)$ are neutrosophic $\in \vee q$ -subsets of X . For $\Phi \in \{\in, q, \in \vee q\}$, the element of $T_{\Phi}(A, \alpha)$ (resp. $I_{\Phi}(A, \beta)$, $F_{\Phi}(A, \gamma)$) is called a neutrosophic T_{Φ} -point (resp. neutrosophic I_{Φ} -point, neutrosophic F_{Φ} -point) with value α (resp. β , γ). It is clear that

$$T_{\in \vee q}(A, \alpha) = T_{\in}(A, \alpha) \cup T_q(A, \alpha),$$

$$I_{\in \vee q}(A, \beta) = I_{\in}(A, \beta) \cup I_q(A, \beta),$$





Radha and Gomathi Sundari

$$F_{\in \vee q}(A, \gamma) = F_{\in}(A, \gamma) \cup F_q(A, \gamma).$$

Definition 3.1: Given $\Phi, \Psi \in \{\in, q, q \in \vee q\}$, a neutrosophic set $A = (A_T, A_I, A_F)$ in a UP-algebra X is called an (Φ, Ψ) -neutrosophic subalgebra of X if the following assertions are valid:

$$\begin{aligned} x \in T_{\Phi}(A, \alpha_x), y \in T_{\Phi}(A, \alpha_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in T_{\Psi}(A, \alpha_x \wedge \alpha_y), \\ x \in I_{\Phi}(A, \beta_x), y \in I_{\Phi}(A, \beta_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in I_{\Psi}(A, \beta_x \wedge \beta_y), \\ x \in F_{\Phi}(A, \gamma_x), y \in F_{\Phi}(A, \gamma_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in F_{\Psi}(A, \gamma_x \vee \gamma_y), \end{aligned} \quad (3.1)$$

for all $x, y \in X, \alpha_x, \alpha_y, \beta_x, \beta_y \in (0, 1]$ and $\gamma_x, \gamma_y \in [0, 1)$.

Theorem 3.2: A neutrosophic set $A = (A_T, A_I, A_F)$ of X is an $(\in, \in)$ -neutrosophic subalgebra of X if and only if

$$(\forall x, y \in X)(A_T((x|(y|y))|(x|(y|y))) \geq A_T(x) \wedge A_T(y) \wedge A_I((x|(y|y))|(x|(y|y))) \geq A_I(x) \wedge A_I(y) \wedge A_F((x|(y|y))|(x|(y|y))) \leq A_F(x) \vee A_F(y)) \quad (3.2)$$

Theorem 3.3: If $A = (A_T, A_I, A_F)$ is an $(\in, \in)$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha), I_{q_{k_T}}(A, \beta)$ and $F_{q_{k_T}}(A, \gamma)$ are subalgebras of X for all $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$ whenever they are nonempty.

Proof: Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $A_T(x) + \alpha + k_T > 1$ and $A_T(y) + \alpha + k_T > 1$.

It follows that $A_T((x|(y|y))|(x|(y|y))) + \alpha + k_T \geq (A_T(x) \wedge A_T(y)) + \alpha + k_T = (A_T(x) + \alpha + k_T) \wedge (A_T(y) + \alpha + k_T) > 1$ and so that $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. Hence $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . Similarly, we can prove that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Now let $x, y \in F_{q_{k_F}}(A, \gamma)$. Then $A_F(x) + \gamma + k_F < 1$ and $A_F(y) + \gamma + k_F < 1$, which imply that $A_F((x|(y|y))|(x|(y|y))) + \gamma + k_F \leq (A_F(x) \vee A_F(y)) + \gamma + k_F = (A_F(x) + \gamma + k_F) \vee (A_F(y) + \gamma + k_F) < 1$. Hence $(x|(y|y))|(x|(y|y)) \in F_{q_{k_T}}(A, \gamma)$ and $F_{q_{k_T}}(A, \gamma)$ is a subalgebra of X .

Theorem 3.4: If $A = (A_T, A_I, A_F)$ is a $(q_{(k_T, k_I, k_F)}, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha), I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1], \beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$ whenever they are nonempty.

Proof: Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $(x|(y|y))|(x|(y|y)) \in T_{\in \vee q_{k_T}}(A, \alpha)$, and so $(x|(y|y))|(x|(y|y)) \in T_{\in}(A, \alpha)$ or $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. If $(x|(y|y))|(x|(y|y)) \in T_{\in}(A, \alpha)$, then $A_T((x|(y|y))|(x|(y|y))) \geq \alpha > 1 - \alpha$ since $\alpha > \frac{1-k_T}{2}$. Hence $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. Therefore $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . Similarly, we prove that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Let $x, y \in F_{q_{k_F}}(A, \gamma)$. Then $(x|(y|y))|(x|(y|y)) \in F_{\in \vee q}(A, \gamma)$, and so $(x|(y|y))|(x|(y|y)) \in F_{\in}(A, \gamma)$ or $(x|(y|y))|(x|(y|y)) \in F_{q_{k_F}}(A, \gamma)$. If $(x|(y|y))|(x|(y|y)) \in F_{\in}(A, \gamma)$, then $A_F((x|(y|y))|(x|(y|y))) \leq \gamma < 1 - \gamma$ since $\gamma \in [0, \frac{1-k_F}{2})$. Hence $(x|(y|y))|(x|(y|y)) \in F_{q_{k_F}}(A, \gamma)$, and therefore $F_{q_{k_F}}(A, \gamma)$ is a subalgebra of X .

Theorem 3.5: A neutrosophic set $A = (A_T, A_I, A_F)$ of X is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X if and only if

$$\begin{aligned} (\forall x, y \in X) \left(A_T((x|(y|y))|(x|(y|y))) \geq \Lambda \left\{ A_T(x) \wedge A_T(y), \frac{1-k_T}{2} \right\} \wedge A_I((x|(y|y))|(x|(y|y))) \right. \\ \left. \geq \Lambda \left\{ A_I(x) \wedge A_I(y), \frac{1-k_I}{2} \right\} \wedge A_F((x|(y|y))|(x|(y|y))) \leq \vee \left\{ A_F(x) \vee A_F(y), \frac{1-k_F}{2} \right\} \right) \end{aligned} \quad (3.3)$$

Proof: Suppose that $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X and let $x, y \in X$. If $A_T(x) \wedge A_T(y) < \frac{1-k_T}{2}$, then we have $A_T((x|(y|y))|(x|(y|y))) \geq A_T(x) \wedge A_T(y)$. Suppose that $A_T((x|(y|y))|(x|(y|y))) < A_T(x) \wedge A_T(y)$ and choose α_t such that $A_T((x|(y|y))|(x|(y|y))) < \alpha_t < A_T(x) \wedge A_T(y)$. Then $x \in T_{\in}(A, \alpha_t)$ and $y \in T_{\in}(A, \alpha_t)$ but $(x|(y|y))|(x|(y|y)) \notin T_{\in}(A, \alpha_t)$. Also $A_T((x|(y|y))|(x|(y|y))) + \alpha_t < 1 - k_T$, that is, $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha_t)$. Thus $(x|(y|y))|(x|(y|y)) \notin T_{\in \vee q_{k_T}}(A, \alpha_t)$, a contradiction. Therefore





Radha and Gomathi Sundari

$A_T((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ whenever $A_T(x) \wedge A_T(y) < \frac{1-k_T}{2}$. Now suppose that $A_T(x) \wedge A_T(y) \geq \frac{1-k_T}{2}$. Then $x \in T_{\in} \left(A, \frac{1-k_T}{2} \right)$ and $y \in T_{\in} \left(A, \frac{1-k_T}{2} \right)$, which imply that $(x | (y | y)) | (x | (y | y)) \in T_{\in \vee k_T} \left(A, \frac{1-k_T}{2} \right)$. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \frac{1-k_T}{2}$. Otherwise, $A_T((x | (y | y)) | (x | (y | y))) + \frac{1-k_T}{2} < \frac{1-k_T}{2} + \frac{1-k_T}{2} = 1 - k_T$, a contradiction. Consequently, $A_T((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_I(x), A_I(y), \frac{1-k_I}{2} \right\}$ holds for all $x, y \in X$. Suppose that $A_F(x) \vee A_F(y) > \frac{1-k_F}{2}$. If $A_F((x | (y | y)) | (x | (y | y))) > A_F(x) \vee A_F(y) = \gamma_s$, then $x, y \in F_{\in}(A, \gamma_s)$, not $(x | (y | y)) | (x | (y | y)) \notin F_{\in}(A, \gamma)$ and $A_F((x | (y | y)) | (x | (y | y))) + \gamma > 2\gamma > 1 - k_F$, that is, $(x | (y | y)) | (x | (y | y)) \notin F_{q_{k_F}}(A, \gamma)$, a contradiction.

Hence $A_F((x | (y | y)) | (x | (y | y))) \leq \wedge \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ whenever $A_F(x) \vee A_F(y) > \frac{1-k_F}{2}$. Now, assume that $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$. Then $x, y \in F_{\in} \left(A, \frac{1-k_F}{2} \right)$ and so $(x | (y | y)) | (x | (y | y)) \in F_{\in \vee q_{k_T}} \left(A, \frac{1-k_F}{2} \right)$. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \frac{1-k_F}{2}$ or $A_F((x | (y | y)) | (x | (y | y))) + \frac{1-k_F}{2} < 1 - k_F$. If $A_F((x | (y | y)) | (x | (y | y))) > \frac{1-k_F}{2}$, then $A_F((x | (y | y)) | (x | (y | y))) + \frac{1-k_F}{2} > \frac{1-k_F}{2} + \frac{1-k_F}{2} = 1 - k_F$, a contradiction. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \frac{1-k_F}{2}$, and so $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ whenever $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$. Therefore $A_F((x | (y | y)) | (x | (y | y))) \leq \wedge \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ for all $x, y \in X$. Conversely, let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X which satisfies the condition (3.3). Let $x, y \in X$ and $\alpha_x, \alpha_y, \beta_x, \beta_y, \gamma_x, \gamma_y \in [0, 1]$. If $x \in T_{\in}(A, \alpha_x)$ and $y \in T_{\in}(A, \alpha_y)$, then $A_T(x) \geq \alpha_x$ and $A_T(y) \geq \alpha_y$. If $A_T((x | (y | y)) | (x | (y | y))) < \alpha_x \wedge \alpha_y$, then $A_T(x) \wedge A_T(y) \geq \frac{1-k_T}{2}$. Otherwise, we have $A_T((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} = A_T(x) \wedge A_T(y) \geq \alpha_x \wedge \alpha_y$, a contradiction. It follows that $A_T((x | (y | y)) | (x | (y | y))) + \alpha_x \wedge \alpha_y > 2A_T((x | (y | y)) | (x | (y | y))) \geq 2 \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} = 1 - k_T$ and so that $(x | (y | y)) | (x | (y | y)) \in T_{q_{k_T}}(A, \alpha_x \wedge \alpha_y) \subseteq T_{\in \vee q_{k_T}}(A, \alpha_x \wedge \alpha_y)$. Similarly, if $x \in I_{\in}(A, \beta_x)$ and $y \in I_{\in}(A, \beta_y)$, then $(x | (y | y)) | (x | (y | y)) \in I_{\in \vee q_{k_I}}(A, \beta_x \wedge \beta_y)$. Now, let $x \in F_{\in}(A, \gamma_x)$ and $y \in F_{\in}(A, \gamma_y)$. Then $A_F(x) \leq \gamma_x$ and $A_F(y) \leq \gamma_y$. If $A_F((x | (y | y)) | (x | (y | y))) > \gamma_x \vee \gamma_y$, then $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$ because if not, then $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} \leq A_F(x) \vee A_F(y) \leq \gamma_x \vee \gamma_y$; which is a contradiction.

Hence $A_F((x | (y | y)) | (x | (y | y))) + \gamma_x \vee \gamma_y < 2A_F((x | (y | y)) | (x | (y | y))) \leq 2 \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} = 1 - k_F$; and so $(x | (y | y)) | (x | (y | y)) \in F_{q_{k_F}}(A, \gamma_x \vee \gamma_y) \subseteq F_{\in \vee q_{k_F}}(A, \gamma_x \vee \gamma_y)$. Therefore $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Theorem 3.6: If $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha)$, $I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$ whenever they are nonempty.

Proof: Assume that $T_{q_{k_T}}(A, \alpha)$, $I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are nonempty for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$. Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $A_T(x) + \alpha + \frac{1-k_T}{2} > 1$ and $A_T(y) + \alpha + \frac{1-k_T}{2} > 1 - k_T$. It follows from Theorem 3.5 that $A_T((x | (y | y)) | (x | (y | y))) + \alpha + \frac{1-k_T}{2} \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} + \alpha = \wedge \left\{ A_T(x) + \alpha, A_T(y) + \alpha, \frac{1-k_T}{2} + \alpha \right\} > 1 - k_T$; that is, $(x | (y | y)) | (x | (y | y)) \in T_{q_{k_T}}(A, \alpha)$. Hence $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . By the similar way, we can induce that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Now, let $x, y \in F_{q_{k_F}}(A, \gamma)$. Then $A_F(x) + \gamma + \frac{1-k_F}{2} < 1 - k_F$ and $A_F(y) + \gamma + \frac{1-k_F}{2} < 1 - k_F$. Using Theorem 3.5, we have $A_F((x | (y | y)) | (x | (y | y))) + \gamma + \frac{1-k_F}{2} \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} + \gamma = \vee \left\{ A_F(x) + \gamma, A_F(y) + \gamma, \frac{1-k_F}{2} + \gamma \right\} < 1 - k_F$; and so $(x | (y | y)) | (x | (y | y)) \in F_{q_{k_F}}(A, \gamma)$. Therefore $F_{q_{k_F}}(A, \gamma)$ is a subalgebra of X .





Radha and Gomathi Sundari

Theorem 3.7: A neutrosophic set $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X if and only if the subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$ whenever they are nonempty.

Proof: Let $A = (A_T, A_I, A_F)$ be an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . For any $x, y \in X$, let $\alpha \in (0, \frac{1-k_T}{2}]$ be such that $x, y \in T_\in(A, \alpha)$. Then $A_T(x) \geq \alpha$ and $A_T(y) \geq \alpha$. It follows from 3.4 that $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha \wedge \frac{1-k_T}{2} = \alpha$ and so that $(x | (y | y)) | (x | (y | y)) \in T_\in(A, \alpha)$. Hence $T_\in(A, \alpha)$ is a subalgebra of X . By the similar way, we can induce that $I_\in(A, \beta)$ is a subalgebra of X for all $\beta \in (0, \frac{1-k_I}{2}]$. Now, let $\gamma \in [\frac{1-k_F}{2}, 1)$ be such that $x, y \in F_\in(A, \gamma)$. Then $A_F(x) \leq \gamma$ and $A_F(y) \leq \gamma$. It follows from 3.4 that $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma \vee \frac{1-k_F}{2} = \gamma$ and so that $(x | (y | y)) | (x | (y | y)) \in F_\in(A, \gamma)$. Hence $F_\in(A, \gamma)$ is a subalgebra of X . Conversely, let $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$ be such that $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X . If there exist $a, b \in X$ such that $A_T((a | (b | b)) | (a | (b | b))) < \alpha \wedge \{A_T(a), A_T(b), \frac{1-k_T}{2}\}$, then we can take $\alpha \in (0, 1)$ such that $A_T((a | (b | b)) | (a | (b | b))) < \alpha < \{A_T(a), A_T(b), \frac{1-k_T}{2}\}$. Thus $a, b \in T_\in(A, \alpha)$ and $\alpha < \frac{1-k_T}{2}$, and so $(a | (b | b)) | (a | (b | b)) \in T_\in(A, \alpha)$. But, the left inequality in induces $(a | (b | b)) | (a | (b | b)) \notin T_\in(A, \alpha)$, a contradiction. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for all $x, y \in X$. Similarly, we can show that $A_I((x | (y | y)) | (x | (y | y))) \geq \{A_I(x), A_I(y), \frac{1-k_I}{2}\}$ for all $x, y \in X$. Now suppose that $A_F((a | (b | b)) | (a | (b | b))) > \gamma \vee \{A_F(a), A_F(b), \frac{1-k_F}{2}\}$ for some $a, b \in X$. Then there exists $\gamma \in (0, 1)$ such that $A_F((a | (b | b)) | (a | (b | b))) > \gamma > \{A_F(a), A_F(b), \frac{1-k_F}{2}\}$. It follows that $\gamma \in (\frac{1-k_F}{2}, 1)$ and $a, b \in F_\in(A, \gamma)$. Since $F_\in(A, \gamma)$ is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in F_\in(A, \gamma)$ and so $A_F((a | (b | b)) | (a | (b | b))) \leq \gamma$. This is a contradiction, and thus $A_F((x | (y | y)) | (x | (y | y))) \leq \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for all $x, y \in X$. Hence $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Using Theorems 3.6 and 3.7, we have the following corollary.

Corollary 3.8: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_{\in \vee q_{k_T}}(A, \alpha)$, $I_{\in \vee q_{k_T}}(A, \beta)$ and $F_{\in \vee q_{k_T}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$, then the subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.9: Given a neutrosophic set $A = (A_T, A_I, A_F)$ of X , the nonempty subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ of X are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$ if and only if

$$(\forall x, y \in X) \left(A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y) \wedge A_I((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \right. \\ \left. \geq A_I(x) \wedge A_I(y) \wedge A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_T}{2} \leq A_F(x) \vee A_F(y) \right) \quad (3.4)$$

Proof: Assume that the nonempty subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ of X are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$. Suppose that there are $a, b \in X$ such that $A_T((a | (b | b)) | (a | (b | b))) \vee \frac{1-k_T}{2} < A_T(a) \wedge A_T(b) = \alpha$. Then $\alpha \in (\frac{1-k_T}{2}, 1]$ and $a, b \in T_\in(A, \alpha)$. Since $T_\in(A, \alpha)$ is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in T_\in(A, \alpha)$, that is, $A_T((a | (b | b)) | (a | (b | b))) \geq \alpha$, a contradiction. Thus $A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y)$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_I}{2} \geq A_I(x) \wedge A_I(y)$ holds for all $x, y \in X$. Now, if $A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_F}{2} > A_F(x) \vee A_F(y)$ for some $x, y \in X$, then $x, y \in F_\in(A, \gamma)$ and $\gamma \in [0, \frac{1-k_F}{2})$ where $\gamma = A_F(x) \vee A_F(y)$. But, $(x | (y | y)) | (x | (y | y)) \notin F_\in(A, \gamma)$, a contradiction. Hence $A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_F}{2} \leq A_F(x) \vee A_F(y)$ for all $x, y \in X$. Conversely, let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X satisfying the condition (3.4). Let $x, y, a, b \in X$ and $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ be such that $x, y \in T_\in(A, \alpha)$ and $a, b \in I_\in(A, \beta)$. Then $A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y) \geq \alpha > \frac{1-k_T}{2}$, $A_I((a | (b | b)) | (a | (b | b))) \vee \frac{1-k_I}{2} \geq A_I(a) \wedge$





Radha and Gomathi Sundari

$A_I(b) \geq \beta > \frac{1-k_I}{2}$. It follows that $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha$ and $A_I((a | (b | b)) | (a | (b | b))) \geq \beta$, that is, $(x | (y | y)) | (x | (y | y)) \in T_\epsilon(A, \alpha)$ and $(a | (b | b)) | (a | (b | b)) \in I_\epsilon(A, \beta)$. Now, let $x, y \in X$ and $\gamma \in [0, \frac{1-k_F}{2})$ be such that $x, y \in F_\epsilon(A, \gamma)$. Then $A_F((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_F}{2} \leq A_F(x) \vee A_F(y) \leq \gamma < \frac{1-k_F}{2}$ and so $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma$, that is, $(x | (y | y)) | (x | (y | y)) \in F_\epsilon(A, \gamma)$.

Theorem 3.10: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$, then $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ neutrosophic subalgebra of X .

Proof: Let $T_{\epsilon \vee q}(A, \alpha)$ be a subalgebra of X and $A_T((x | (y | y)) | (x | (y | y))) < \alpha \leq \bigwedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for some $x, y \in X$. Then there exists $\alpha \in (0, \frac{1-k_T}{2}]$ such that $A_T((x | (y | y)) | (x | (y | y))) < \alpha \leq \bigwedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$. It follows that $x, y \in T_\epsilon(A, \alpha) \subseteq T_{\epsilon \vee q}(A, \alpha)$, and so that $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha$ or $A_T((x | (y | y)) | (x | (y | y))) + \alpha > 1$, a contradiction, and so $A_T((x | (y | y)) | (x | (y | y))) \geq \bigwedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \geq \bigwedge \{A_I(x), A_I(y), \frac{1-k_I}{2}\}$ holds for all $x, y \in X$. Now let $F_{\epsilon \vee q}(A, \gamma)$ be a subalgebra of X and assume that $A_F((x | (y | y)) | (x | (y | y))) > \bigvee \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for some $x, y \in X$. Then

$$A_F((x | (y | y)) | (x | (y | y))) > \gamma \geq \bigvee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \quad (3.5)$$

for some $\gamma \in [\frac{1-k_F}{2}, 1)$, which implies that $x, y \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Thus $(x | (y | y)) | (x | (y | y)) \in F_{\epsilon \vee q}(A, \gamma)$. From (3.5), $(x | (y | y)) | (x | (y | y)) \notin F_\epsilon(A, \gamma)$ and $A_F((x | (y | y)) | (x | (y | y))) + \gamma > \epsilon \geq 1$, that is, $(x | (y | y)) | (x | (y | y)) \notin F_q(A, \gamma)$, a contradiction, and hence $A_F((x | (y | y)) | (x | (y | y))) \leq \bigvee \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for all $x, y \in X$. By Theorem 3.5, $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Theorem 3.11: If $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Proof: Assume that $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are nonempty for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Let $x, y \in T_{\epsilon \vee q}(A, \alpha)$. Then $x \in T_\epsilon(A, \alpha)$ or $x \in T_q(A, \alpha)$, and $y \in T_\epsilon(A, \alpha)$ or $y \in T_q(A, \alpha)$. Hence we have the following four cases:

- $x \in T_\epsilon(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$,
- $x \in T_\epsilon(A, \alpha)$ and $y \in T_q(A, \alpha)$,
- $x \in T_q(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$,
- $x \in T_q(A, \alpha)$ and $y \in T_q(A, \alpha)$.

The first case implies that $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. For the second case, $y \in T_q(A, \alpha)$ induces $A_T(y) > 1 - \alpha \geq \alpha$, that is, $y \in T_\epsilon(A, \alpha)$. Thus $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Similarly, the third case implies $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. The last case induces $A_T(x) > 1 - \alpha \geq \alpha$ and $A_T(y) > 1 - \alpha \geq \alpha$, that is, $x \in T_\epsilon(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$. Hence $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Therefore $T_{\epsilon \vee q}(A, \alpha)$ is a subalgebra of X for all $\alpha \in (0, \frac{1-k_T}{2}]$.

By the similar way, we show that $I_{\epsilon \vee q}(A, \beta)$ is a subalgebra of X for all $\beta \in (0, \frac{1-k_I}{2}]$. Let $x, y \in F_{\epsilon \vee q}(A, \gamma)$. Then $A_F(x) \leq \gamma$ or $A_F(x) + \gamma < 1$, and $A_F(y) \leq \gamma$ or $A_F(y) + \gamma < 1$. If $A_F(x) \leq \gamma$ and $A_F(y) \leq \gamma$, then $A_F((x | (y | y)) | (x | (y | y))) \leq \bigvee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \leq \bigvee \{\gamma, \frac{1-k_F}{2}\} = \gamma$ by Theorem 3.5, and so $(x | (y | y)) | (x | (y | y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. If $A_F(x) \leq \gamma$ and $A_F(y) + \gamma < 1$, then $A_F((x | (y | y)) | (x | (y | y))) \leq \bigvee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \leq$





Radha and Gomathi Sundari

$\forall \left\{ \gamma, 1 - \gamma, \frac{1-k_F}{2} \right\} = \gamma$ by Theorem 3.5. Thus $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Similarly, if $A_F(x) + \gamma < 1$ and $A_F(y) \leq \gamma$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Finally, assume that $A_F(x) + \gamma < 1$ and $A_F(y) + \gamma < 1$. Then $A_F((x \mid (y \mid y)) \mid (x \mid (y \mid y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} \leq \vee \left\{ 1 - \gamma, \frac{1-k_F}{2} \right\} = \frac{1-k_F}{2} < \gamma$. Hence $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Consequently, $F_{\epsilon \vee q}(A, \gamma)$ is a subalgebra of X for all $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.12: If $A = (A_T, A_I, A_F)$ is an $(q, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Proof: Assume that $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are nonempty for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Let $x, y \in T_{\epsilon \vee q}(A, \alpha)$. Then $x \in T_\epsilon(A, \alpha)$ or $x \in T_q(A, \alpha)$. and $y \in T_\epsilon(A, \alpha)$ or $y \in T_q(A, \alpha)$. If $x \in T_q(A, \alpha)$ and $y \in T_q(A, \alpha)$, then obviously $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. Suppose that $x \in T_\epsilon(A, \alpha)$ and $y \in T_q(A, \alpha)$. Then $A_T(x) + \alpha \geq 2\alpha > 1$, that is, $x \in T_q(A, \alpha)$. It follows that $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. Similarly, if $x \in T_q(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. The proof for $I_{\epsilon \vee q}(A, \beta)$ is similar. Now, let $x, y \in F_{\epsilon \vee q}(A, \gamma)$. Then $x \in F_\epsilon(A, \gamma)$ or $x \in F_q(A, \gamma)$, and $y \in F_\epsilon(A, \gamma)$ or $y \in F_q(A, \gamma)$. If $x \in F_\epsilon(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$, then clearly $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. If $x \in F_\epsilon(A, \gamma)$ and $y \in F_q(A, \gamma)$, then $A_F(x) + \gamma \leq 2\gamma < 1$, that is, $x \in F_q(A, \gamma)$. It follows that $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Similarly, if $x \in F_q(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Finally, assume that $x \in F_q(A, \gamma)$ and $y \in F_q(A, \gamma)$. Then $A_F(x) + \gamma \leq 2\gamma < 1$ and $A_F(y) + \gamma \leq 2\gamma < 1$, that is, $x \in F_\epsilon(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$. Therefore $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Consequently, $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.13: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_q(A, \alpha)$, $I_q(A, \beta)$ and $F_q(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in (0, \frac{1-k_F}{2}]$, then

$$\begin{aligned} x \in T_\epsilon(A, \alpha_x), y \in T_\epsilon(A, \alpha_y) &\Rightarrow ((y) \mid ((y))) \in T_q(A, \alpha_x \wedge \alpha_y), \\ x \in I_\epsilon(A, \beta_x), y \in I_\epsilon(A, \beta_y) &\Rightarrow ((y) \mid ((y))) \in I_q(A, \beta_x \wedge \beta_y), \quad 3.6 \\ x \in F_\epsilon(A, \gamma_x), y \in F_\epsilon(A, \gamma_y) &\Rightarrow (x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_q(A, \gamma_x \vee \gamma_y), \quad \text{For all } x, y \in X, \alpha_x, \alpha_y \in (\frac{1-k_T}{2}, 1], \beta_x, \beta_y \in (\frac{1-k_I}{2}, 1] \text{ and } \gamma_x, \gamma_y \in [0, \frac{1-k_F}{2}] \end{aligned}$$

Proof. Let $x, y, a, b, u, v \in X$, let $\alpha_x, \alpha_y \in (\frac{1-k_T}{2}, 1]$, $\beta_a, \beta_b \in (\frac{1-k_I}{2}, 1]$ and $\gamma_u, \gamma_v \in (0, \frac{1-k_F}{2})$ be such that $x \in T_\epsilon(A, \alpha_x)$, $y \in T_\epsilon(A, \alpha_y)$, $a \in I_\epsilon(A, \beta_a)$, $b \in I_\epsilon(A, \beta_b)$, $u \in F_\epsilon(A, \gamma_u)$ and $v \in F_\epsilon(A, \gamma_v)$. Then $A_T(x) \geq \alpha_x > 1 - \alpha_x$, $A_T(y) \geq \alpha_y > 1 - \alpha_y$, $A_I(a) \geq \beta_a > 1 - \beta_a$, $A_I(b) \geq \beta_b > 1 - \beta_b$, $A_F(u) \leq \gamma_u < 1 - \gamma_u$ and $A_F(v) \leq \gamma_v < 1 - \gamma_v$. It follows that $x, y \in T_q(A, \alpha_x \wedge \alpha_y)$, $a, b \in I_q(A, \beta_a \wedge \beta_b)$ and $u, v \in F_q(A, \gamma_u \vee \gamma_v)$. Since $\alpha_x \wedge \alpha_y \in (\frac{1-k_T}{2}, 1]$, $\beta_a \wedge \beta_b \in (\frac{1-k_I}{2}, 1]$ and $\gamma_u \vee \gamma_v \in (0, \frac{1-k_F}{2})$, we have $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_q(A, \alpha_x \wedge \alpha_y)$, $(a \mid (b \mid b)) \mid (a \mid (b \mid b)) \in I_q(A, \beta_a \wedge \beta_b)$ and $(u \mid (v \mid v)) \mid (u \mid (v \mid v)) \in F_q(A, \gamma_u \vee \gamma_v)$.

Given a subset S of X , consider a neutrosophic set $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ in X defined by

$$A_S(x) = \{(1, 1, 1) \text{ if } x \in S, (0, 0, 1) \text{ otherwise}\} \text{ That is,}$$

$$A_{S_T}(x) = \{1 \text{ if } x \in S, 0 \text{ otherwise}\}, A_{S_I}(x) = \{1 \text{ if } x \in S, 0 \text{ otherwise}\}, A_{S_F}(x) = \{0 \text{ if } x \in S, 1 \text{ otherwise}\},$$

Theorem 3.14: A nonempty subset S of X is a subalgebra of X if and only if the neutrosophic set $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Proof: Let S be a subalgebra of X . Then the subsets $T_\epsilon(A_S, \alpha)$, $I_\epsilon(A_S, \beta)$ and $F_\epsilon(A_S, \gamma)$ are obviously subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Hence $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . Conversely, assume that $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . Let $x, y \in S$. Then





Radha and Gomathi Sundari

$$A_{S_T}((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_{S_T}(x), A_{S_T}(y), \frac{1-k_T}{2} \right\} = 1 \wedge \frac{1-k_T}{2} = \frac{1-k_T}{2}, A_{S_I}((x | (y | y)) | (x | (y | y))) \geq \\ \wedge \left\{ A_{S_I}(x), A_{S_I}(y), \frac{1-k_I}{2} \right\} = 1 \wedge \frac{1-k_I}{2} = \frac{1-k_I}{2}, A_{S_F}((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_{S_F}(x), A_{S_F}(y), \frac{1-k_F}{2} \right\} = 1 \vee \frac{1-k_F}{2} = \\ \frac{1-k_F}{2},$$

which imply that $A_{S_T}((x | (y | y)) | (x | (y | y))) = 1$, $A_{S_I}((x | (y | y)) | (x | (y | y))) = 1$ and $A_{S_F}((x | (y | y)) | (x | (y | y))) = 0$. Hence $(x | (y | y)) | (x | (y | y)) \in S$, and so S is a subalgebra of X .

Theorem 3.15: Let S be a subalgebra of X . For every $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$, there exists an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra $A = (A_T, A_I, A_F)$ of X such that $T_\in(A, \alpha) = S$, $I_\in(A, \beta) = S$ and $F_\in(A, \gamma) = S$.

Proof: Let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X defined by

$$A_S(x) = \{(\alpha, \beta, \gamma) \text{ if } x \in S (0,0,1) \text{ otherwise}$$

that is,

$A_{S_T}(x) = \{\alpha \text{ if } x \in S 0 \text{ otherwise}, A_{S_I}(x) = \{\beta \text{ if } x \in S 0 \text{ otherwise}, A_{S_F}(x) = \{0 \text{ if } x \in S \gamma \text{ otherwise}$, Obviously, $T_\in(A, \alpha) = S$, $I_\in(A, \beta) = S$ and $F_\in(A, \gamma) = S$. Suppose that $A_T((a | (b | b)) | (a | (b | b))) < \wedge \left\{ A_T(a), A_T(b), \frac{1-k_T}{2} \right\}$ for some $a, b \in X$. Since $Im(A_T) = 2$, it follows that $\left\{ A_T(a), A_T(b), \frac{1-k_T}{2} \right\} = \alpha$ and $A_T((a | (b | b)) | (a | (b | b))) = 0$. Hence $A_T(a) = \alpha = A_T(b)$, and so $a, b \in S$. Since S is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in S$. Thus $A_T((a | (b | b)) | (a | (b | b))) = \alpha$, a contradiction. Therefore $A_T((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ for all $x, y \in X$. Similarly, we can verify that $A_I((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_I(x), A_I(y), \frac{1-k_I}{2} \right\}$ for all $x, y \in X$. Assume that there exist $a, b \in X$ such that $A_F((a | (b | b)) | (a | (b | b))) > \vee \left\{ A_F(a), A_F(b), \frac{1-k_F}{2} \right\}$. Then $A_F((a | (b | b)) | (a | (b | b))) = 1$ and $\vee \left\{ A_F(a), A_F(b), \frac{1-k_F}{2} \right\} = \gamma$ since $Im(A_F) = 2$. It follows that $A_F(a) = \gamma = A_F(b)$ and so that $a, b \in S$. Hence $(a | (b | b)) | (a | (b | b)) \in S$, and so $A_F((a | (b | b)) | (a | (b | b))) = \gamma$, which is a contradiction. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ for all $x, y \in X$. Therefore $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

REFERENCES

1. T. Oner, T. Katican and A. Borumand Saeid, Relation between Sheffer Stroke and Hilbert Algebras. Categories and General Algebraic Structures with Applications 2021, 14(1), pp. 245-268.
2. H. M. Sheffer, A set of five independent postulates for Boolean algebras, with application to logical constants, Transactions of the American Mathematical Society, 14(4) (1913), 481-488.
3. F. Smarandache, A Unifying Field in Logics: Neutrosophic Logic. Neutrosophy, Neutrosophic Set, Neutrosophic Probability, American Reserch Press, Rehoboth, NM. (1999).
4. F. Smarandache, Neutrosophic set-a generalization of the intuitionistic fuzzy set, Int. J. Pure Appl. Math., 24(3) (2005), 287-297.

Disclaimer / Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of IJONS and/or the editor(s). IJONS and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

