The Biobrio ISSN : 2393-9508 e-ISSN: 2582-4902
An International Quarterly Journal of Life Sciences
Website: www.thebiobrio.in SJIF 2025:8.37
12 (1&2): 1270-1275, 2025

Ecological Role, Behavioral Adaptations, and Invasive Potential of *Solenopsis geminata*: A Comprehensive Review

Seema Kumari & Arun Kumar*
University Department of Zoology, B.N. Mandal University, Madhepura, Bihar, India

Received : 03rd January, 2025 ; Accepted : 03rd February, 2025
DOI:- https://doi.org/10.5281/zenodo.15228249

ABSTRACT

Solenopsis geminata, the tropical fire ant, is an aggressive and ecologically significant species native to Central and South America but now widespread in tropical and subtropical regions worldwide. This review synthesizes existing knowledge and presents novel insights into the species' ecological roles, behavioral adaptations, and invasive potential. Notable for its polymorphic worker caste, intricate mound-building, and aggressive foraging strategies, *S. geminata* demonstrates remarkable ecological plasticity, thriving in both disturbed and natural habitats. Its ability to dominate through interspecific competition, efficient foraging, and complex chemical communication underscores its invasive success. We explore its impact on plant communities through intense seed predation, its nesting behavior, and adaptive strategies such as temporal foraging patterns and flexible reproductive systems. These traits enable *S. geminata* to rapidly expand and alter ecosystems, often at the expense of native biodiversity. The article also highlights the importance of understanding these behavioral mechanisms in developing effective management strategies for controlling this invasive species. Insights into its ecological and behavioral flexibility provide a model for studying invasive social insects and their interactions with changing environments.

Key Words - *Solenopsis geminata*, tropical fire ant, invasive species, behavioral plasticity, seed predation, ecological dominance, chemical communication, habitat adaptation

***Corresponding author :** prf.arunkumar@gmail.com

INTRODUCTION

The order *Hymenoptera* comprises one of the most diverse and ecologically significant groups of insects, with over 100,000 described species and many more yet to be discovered. This order encompasses a wide range of ecological roles, with species that may be free-living, phytophagous (plant-feeding), predatory, parasitic on other insects (entomophagous), or highly social in nature. Among its most notable representatives are wasps, bees, and ants—many of which exhibit polymorphism and eusocial behavior. These social hymenopterans demonstrate extraordinary behavioral diversity and biological organization, characterized by complex nest architecture, a caste-based division of labor, and intricate communication systems largely mediated by chemical signals such as pheromones.

A key factor in the ecological success of hymenopterans, particularly ants, is their remarkable behavioral plasticity, which enables them to thrive across nearly every terrestrial habitat. This adaptability is often linked to specific genetic mechanisms, including those governing foraging behavior. The ant family *Formicidae* alone includes over 13,000 described species and is estimated to contribute up to 20% of terrestrial animal biomass in certain ecosystems. Their evolutionary success is closely tied to their obligate eusociality, wherein colony members perform specialized roles for the collective benefit rather than individual gain. This is most clearly exemplified in their foraging behavior, a complex, colony-level process involving decision-making strategies that include site selection, evaluation of resource quality, and optimization of foraging routes based on the spatial relationship between nests and food sources. These behaviors reflect advanced problem-solving abilities and often resemble shortest-path algorithms in nature.

Within this diverse group, the tropical fire ant, *Solenopsis geminata* (Fabricius, 1804), emerges as a model species for studying ecological adaptability and behavioral sophistication. Belonging to the subfamily Myrmicinae, *S. geminata* is among the most ecologically versatile ants. Although originally native to Central and South America, it has successfully invaded tropical and subtropical regions across the globe, establishing dominant populations in both disturbed and natural habitats. Its invasive success is attributed to a combination of aggressive foraging behavior, a highly organized caste system, and efficient use of chemical communication for trail formation, resource recruitment, and colony defense.

Despite the extensive documentation of *S. geminata*'s spread and impact, relatively few studies provide a comprehensive synthesis of its ecological roles and behavioral mechanisms underpinning its dominance. As such, further investigation into its foraging strategies, colony structure, and adaptability to diverse environmental conditions can offer valuable insights into both ant ecology and broader themes in collective behavior and social organization among insects.

Morphological and Colony Structure

Solenopsis geminata, commonly known as the tropical fire ant, exhibits pronounced worker polymorphism, which plays a crucial role in the functional efficiency and ecological flexibility of its colonies. The worker ants are broadly divided into three morphological categories based on their size and assigned duties—minor, medium, and major workers (the latter often referred to as soldiers). This variation in physical form facilitates a division of labor, where each subcaste is adapted to carry out specific tasks vital for colony maintenance and survival.

Minor workers, being the smallest, primarily undertake responsibilities within the nest, such as tending to the brood, maintaining nest structure, and foraging over short distances. Medium workers serve as generalists, engaging in both nest-based and external duties, including trail marking and resource collection. The major workers, by contrast, are significantly larger and equipped with oversized heads and powerful mandibles. These traits are essential for grinding hard seeds—a key component of the species' diet—and for providing defensive support, especially in encounters with predators or rival colonies.

Reproductive females, or queens, are winged during mating seasons and are noticeably larger than the workers. During nuptial flights, they pair with males in mid-air, after which mated queens descend to establish new colonies. This can occur through independent colony founding (ICF), where a single queen initiates a nest and nurtures the first cohort of workers. Additionally, *S. geminata* can reproduce through budding, a strategy where a queen accompanied by a group of workers migrates from the original nest to create a satellite colony nearby. This method is especially prevalent in polygyne colonies (those containing multiple queens), enabling swift expansion and aiding in the species' ability to invade and dominate new environments.

The combination of worker caste polymorphism and flexible colony reproduction strategies equips *Solenopsis geminata* with remarkable adaptability. These characteristics enable the species to efficiently exploit a diverse array of habitats, thereby contributing to its widespread success both within its native range and in areas where it has been introduced.

Colony size: Colonies vary from a few thousand to over 100,000 individuals, with some supercolonial tendencies observed in invasive populations. Both monogyne (single-queen) and polygyne (multi-queen) systems exist, with polygyne colonies showing higher invasion success due to cooperative brood care and reduced intraspecific aggression.

Habitat Preference and Nesting Behavior

The tropical fire ant, *Solenopsis geminata*, shows a strong tendency to inhabit open and human-altered environments, a characteristic that plays a significant role in its ecological success both within its native range and in areas it has invaded. Colonies are frequently found in agricultural fields, roadside margins, urban fringes, and construction zones—landscapes where vegetation is sparse and human activity has modified the natural terrain. Such disturbed areas offer ideal conditions for nesting, including exposed soil, minimal plant cover, and easy access to human-related food sources, all of which favor colony establishment and proliferation.

The nesting structure of *S. geminata* is both characteristic and well-suited to these disturbed habitats. Colonies typically build a single dome-shaped mound, composed of finely textured soil, that stands out visibly above the ground. These mounds often feature multiple entry points, enabling efficient movement of workers in and out of the nest, promoting better foraging coordination and ventilation. Due to their prominent visibility, these mounds are often used as reliable indicators of infestation, especially in farmlands and residential areas.

Data from recent fieldwork conducted in Bihar, India (2023–2024), have added valuable information about the nest depth and structure of this species in subtropical conditions. During the dry months, nests were typically found to reach depths of 45 to 60 centimeters, but during the monsoon, nest construction extended beyond 70 centimeters. This increase in depth during wetter periods is likely a moisture-regulation strategy, allowing the ants to maintain favorable microclimatic conditions—especially temperature and humidity—critical for colony health and brood development.

Within the soil, *S. geminata* nests comprise vertically arranged chambers, which are linked by narrow tunnels. These chambers are frequently built near plant root systems or decomposing organic matter, which not only provide physical reinforcement to the nest but also contribute to thermal insulation and moisture retention. This close association with roots and debris may indicate opportunistic behavior, where the ants utilize naturally occurring spaces in the soil created by decayed roots or other organisms. The habitat and nesting choices of *Solenopsis geminata* illustrate its remarkable behavioral flexibility and ecological resilience. Its capacity to exploit anthropogenically disturbed environments, along with adaptable nesting strategies, underpins its competitive advantage and widespread success in diverse ecosystems.

Foraging Strategies and Diet

Solenopsis geminata workers exhibit a highly coordinated foraging strategy characterized by the use of trail pheromones and efficient recruitment behavior, enabling rapid mobilization of foragers to profitable food sources. Recent field observations have uncovered a previously undocumented temporal pattern in their activity: colonies show a marked preference for foraging during early morning and twilight hours. This behavior appears to be closely aligned with environmental factors—specifically, elevated humidity levels and lower temperatures during these periods help mitigate the risk of desiccation, enhancing forager efficiency. Additionally, reduced visibility and predator activity during these twilight windows likely lower the threat of predation, suggesting that this time-specific foraging pattern is an adaptive response to both physiological and ecological pressures.

Diet: *Solenopsis geminata* has a highly omnivorous diet, consuming a diverse array of food items such as seeds, small arthropods, nectar, and honeydew, showcasing remarkable trophic adaptability. This dietary flexibility enables the species to flourish across a variety of environments, including disturbed sites, farmlands, and natural ecosystems. By feeding on seeds, the ants tap into readily available or seasonally abundant plant resources, while hunting small arthropods supplies vital proteins necessary for colony development and brood rearing. Their intake of nectar and honeydew—often sourced through mutualistic relationships with sap-feeding insects like aphids—provides a consistent source of carbohydrates, particularly when other food sources are limited. This ability to utilize multiple food types reduces direct competition with more specialized species and significantly contributes to *S. geminata's* ecological dominance and success as an invasive species..

Seed predation role: Field trials conducted in dry deciduous forests have revealed that *Solenopsis geminata*, a species of fire ant, plays a significant role in seed predation. These ants, known for their aggressive foraging behavior and adaptability, were observed to actively collect and remove seeds from the forest floor. Their activities were particularly notable in experimental plots where researchers measured the extent of seed removal over time. The findings point to the ants' strong influence on seed dynamics, with implications for the broader ecological community.

One of the most striking results from these trials was the rapid rate at which *S. geminata* removed grass seeds. Within just 24 hours, removal rates reached as high as 85% in some plots. This exceptionally high rate of seed removal indicates that fire ants are highly efficient and opportunistic seed predators. Their activity can drastically reduce the number of seeds available for germination, thereby limiting the potential for new plant growth and regeneration in the area.

The implications of such intense seed predation extend to the structure and composition of the plant community. By disproportionately removing certain types of seeds—particularly those of grasses—*S. geminata* can alter which species successfully establish and persist over time. This selective pressure may lead to shifts in species dominance, potentially reducing plant diversity and favoring species whose seeds are less attractive or accessible to ants. Over the long term, this can result in changes to forest composition and function, highlighting the ants' role as ecosystem engineers.

Aggression and Competitive Dominance

Solenopsis geminata is renowned for its intense aggressiveness and formidable competitive strength, characteristics that have played a central role in its dominance across both native and non-native habitats. This species engages in frequent conflicts with other ants—whether indigenous or invasive—competing fiercely for limited resources such as food and nesting territories. Its superiority in such interactions stems from a powerful mix of overwhelming numbers, rapid mobilization, and potent stinging capability.

Observations from bait station trials conducted in urban Madhepura, Bihar (2023–2024) provide compelling evidence of its competitive advantage. Using sugar- and protein-rich baits, researchers recorded behavioral interactions between *S. geminata* and co-occurring species, specifically *Monomorium pharaonis* and *Paratrechina longicornis*. In approximately 76% of observed encounters, *S. geminata* emerged victorious within just 30 minutes, showcasing its ability to detect, colonize, and dominate foraging sites with remarkable speed and efficiency.

The fire ants' success was primarily driven by their coordinated swarming tactics and aggressive confrontations. Territorial disputes often escalated into physical altercations, with *S. geminata* workers inflicting serious damage—sometimes lethally—on rival species. The major caste, known for its enlarged head and powerful mandibles, played a central role in subduing opponents, while minors and mediums acted in supportive roles, reinforcing the front lines and ensuring bait control. Their venomous sting, used liberally during skirmishes, proved especially effective in incapacitating or deterring smaller, less robust ant species.

This strategy—combining high worker density, tactical aggression, and chemical defense mechanisms—enables *S. geminata* to claim and defend resource-rich areas effectively. As a result, native species or those less suited for direct confrontation are often excluded or displaced, leading to shifts in local ant community composition and potentially reducing overall species diversity.

In ecosystems where human activity or environmental disturbance has already weakened native ant populations, the aggressive nature and expansive foraging behavior of *S. geminata* allow it to gain a foothold and expand rapidly. This aggressive dominance, reinforced by its ecological adaptability and high reproductive output, positions *S. geminata* as one of the most disruptive and invasive ant species in tropical and subtropical regions worldwide.

Reproductive Behavior and Seasonal Activity

The reproductive behavior and seasonal activity patterns of *Solenopsis geminata* are closely tied to environmental cues, particularly the onset of the monsoon season. Nuptial flights—when winged males and virgin queens take to the air to mate—typically occur at the beginning of the monsoon rains. This timing is ecologically significant, as the increased soil moisture following rainfall creates favorable conditions for colony establishment. The synchronized emergence and mating of reproductive individuals during this period enhance the likelihood of successful mating and dispersal, ensuring the propagation of the species.

Following mating, *S. geminata* queens exhibit a reproductive strategy known as claustral founding. In this process, the queen seals herself inside a chamber and relies on her internal energy reserves to raise the first brood without foraging. This rapid founding phase is highly efficient in *S. geminata*, with the first generation of workers typically emerging within 20 to 25 days post-mating. These early workers take over foraging and colony maintenance, allowing the queen to focus solely on reproduction from that point onward. This swift transition from solitary founding to a functioning colony is critical for survival, especially in competitive or predator-rich environments.

Seasonal activity patterns of *S. geminata* colonies also show strong correlation with climatic conditions. The colonies are most active during the early monsoon and post-monsoon periods, when environmental conditions are optimal. Specifically, peak activity is observed when temperatures range between 27°C and 32°C, and relative humidity exceeds 65%. These conditions not only support higher metabolic rates and mobility in ants but also promote greater availability of food resources such as seeds and small invertebrates. During drier or cooler periods, activity tends to decline, indicating that S. geminata colonies are highly responsive to seasonal changes.

Chemical Ecology and Defense

Venom alkaloids, primarily solenopsins, serve both predatory and defensive functions. Preliminary chemical analyses from Madhepura populations suggest a slightly different alkaloid profile than that documented in Central American populations—possibly a regional adaptation or the result of genetic drift.

Implications for Management and Conservation

While *S. geminata* contributes to seed dispersal and nutrient cycling in its native range, its invasive populations often disrupt native arthropod diversity, pollination networks, and even soil processes. Management strategies should prioritize habitat restoration and early detection in high-risk zones, especially in biodiversity-rich tropical areas.

CONCLUSION

Solenopsis geminata epitomizes the ecological paradox of many invasive species—serving important roles in its native ecosystems while becoming ecologically disruptive elsewhere. Its success is anchored in an array of adaptive traits: polymorphic castes, flexible reproductive systems, aggressive interspecific behavior, and a pronounced ability to thrive in human-disturbed habitats. This review underscores its influence as a potent ecological engineer—capable of reshaping plant communities through intense seed predation and displacing native arthropods via sheer numerical and chemical dominance. Field data from subtropical India further illuminate its seasonal activity, deep nesting adaptations, and emerging chemical variation across regions. These observations highlight its behavioral plasticity and adaptability to diverse climates—traits that contribute to its global invasiveness. As *S. geminata* continues to expand into biodiversity hotspots, its management becomes both an ecological and conservation priority. Restoration of native habitats, early detection protocols, and community engagement are vital. Simultaneously, the species offers a valuable model for understanding the dynamics of invasive social insects under environmental stressors such as climate change and urban expansion. Ultimately, managing *S. geminata* demands an integrated approach—bridging behavioral ecology, chemical signaling, landscape management, and public awareness. Doing so will not only safeguard native biodiversity but also advance our understanding of how complex social organisms adapt and persist in a rapidly changing world.

REFERENCES

Cohen, P., & Privman, E. 2019. Speciation and hybridization in invasive fire ants. BMC *Evolutionary Biology*, 19: 111.

Imirzian, N., Zhang, Y., Kurze, C., Loreto, R. G., Chen, D. Z., & Hughes, D. P. 2019. Automated tracking and analysis of ant trajectories shows variation in forager exploration. *Scientific Reports,* 9: 13246.

Lai, L.-C., & Chao, T.-Y. 2021. Random choice of the tropical fire ant in the enclosed space. *Taiwania*, 66(1): 73–78.

Lee, H. S., Lee, I. H., & Lyu, D. P. 2008. A concerned pest of invasion in Korea, fire ant, *Solenopsis geminata* (Fabricius) (Hymenoptera: Formicidae). *Korean Journal of Applied Entomology*, 47: 107–110.

Norasmah, B., Abu Hassan, A., Che Salmah, M. R., Nurita, A. T., & Nur Aida, H. 2006. Daily foraging pattern and proteinaceous food preferences of *Solenopsis geminata* (Fabricius) (Hymenoptera: Formicidae). Tropical Biomedicine, 23(2): 134–139.

Ouellette, G.D., Drummond, F.A., Choate, B. and Groden, E., 2010. Ant diversity and distribution in Acadia National Park, Maine. *Environmental entomology*, 39(5): pp.1447-1456.

Seema Kumari & Arun Kumar. 2020. Study on foraging behavioral pattern in *Solenopsis geminata. Biospectra.* 15(1): 79-82

Stuble, K. L., Kirkman, L. K., & Carroll, C. R. 2009. Patterns of abundance of fire ants and native ants in a native ecosystem. *Ecological Entomology*, 34: 520–526.

Vander Meer, R. K., & Lofgren, C. S. 1988. Chemical communication in the fire ant Solenopsis invicta (Hymenoptera: Formicidae). *Journal of Chemical Ecology*, 14:1915–1932.

Way, M. J., & Heong, K. L. 2009. Significance of the tropical fire ant Solenopsis geminata (Hymenoptera: Formicidae) as part of the natural enemy complex responsible for successful biological control of many tropical irrigated rice pests. *Bulletin of Entomological Research,* 99(5): 503–512.

Way, M. J., Heong, K. L., & Javier, G. 2002. The role of ants, especially the fire ant, Solenopsis geminata (Hymenoptera: Formicidae), in the biological control of tropical upland rice pests. *Bulletin of Entomological Research*, 92(5):431–437.

***