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Behavioural Adaptations to Environmental Stress in Spiders of the Semi-arid Habitat

Ruchi Singh
Department of Zoology
Dayalbagh Educational Institute
Agra, Uttar Pradesh, India

Sant Prakash
Department of Zoology
Dayalbagh Educational Institute
Agra, Uttar Pradesh, India

Alka Prakash
Department of Zoology
Dayalbagh Educational Institute
Agra, Uttar Pradesh, India

Abstract- Spiders are ecological highly significant and exhibit diverse behavioural adaptations enabling survival in the stressful semi-arid environments by their strategies of hunting, web building, dispersal, defence mechanisms, community behaviour and parental care. The current study presents the behavioural characteristics of spiders in the semi-arid region of Agra, Uttar Pradesh, India. Predation was by active hunting as well as web-based. Diversity in web types such as orb web, funnel web, sheet web, irregular web, and community web were recorded. Community web-building in *Cyrtophora* enhanced prey capture efficiency. Camouflage, mimicry, territorial behaviour and ballooning dispersal were also observed as key adaptive strategies. Parental care, particularly among Salticidae and Pholcidae, reflected significant reproductive involvement. The study demonstrates that spiders of the semi-arid Agra region exhibit considerable behavioural plasticity and ecological resilience, enabling them to cope with temperature extremes, resource variability, and habitat heterogeneity. These findings highlight the adaptive significance of spider behaviour in maintaining ecological stability within semi-arid ecosystems towards the survival of the species in the onslaught of the climate change.

Keywords- *Semi-arid habitat, Spider behaviour, Parental care, Web types and Web construction.*

I. INTRODUCTION

The Agra region, which lies in the southwest of Uttar Pradesh between latitudes 26°44′N and 27°55′N and longitudes 77°26′E and 78°32′E, is classified as a semi-arid habitat. It is a component of northern India's upper Gangetic Plains. In addition to residual soils made up of rock fragments, pebbles, boulders, and sand, the soil composition is primarily alluvial. The region's climate is clearly periodic, with significant daily temperature fluctuations, a high saturation deficit, and comparatively little to moderate precipitation. According to the average annual temperature is roughly 23.65°C, and the average annual precipitation is roughly 760.4 mm (Singh and Islam, 2010).

Spiders are arachnids, which are members of the order Araneae and class Arachnida. In the world, 53,714 species are listed in the World Spider Catalog, Version 27. More than 1600 species of spiders from 11 families have been identified in India thus far, with 65 of these species found in the semi-arid regions of central India (Anjali & Prakash, 2019; Raghu & Kumar, 2022; Singh *et al*., 2024). Even though spiders are known to play a significant role in semi-arid ecosystems, there is very scant region-specific research that focuses on how spiders adapt to environmental stress in the semi-arid conditions.

Behavioural adaptations in spiders may include temporal shifts in activity patterns, microhabitat selection such as burrow construction or utilization of shaded refugio; modification of web architecture to withstand desiccation; wind stress, and energy-conserving strategies during prey scarcity. Burrowing species, particularly within families, often construct silk-lined retreats that buffer extreme temperature fluctuations and reduce water loss. Orb-weaving species may alter web orientation, height, and rebuilding frequency in response to environmental conditions. Behavioural flexibility affects predator avoidance, dispersion techniques (including ballooning), and reproductive time in addition to thermoregulatory and hydric strategies. These adaptations demonstrate the ecological importance of spiders in environments that are prone to stress. Therefore, this study records the adaptive pattern behaviour that spider colonies display in Agra's semi-arid habitat and aims to improve our understanding of spider survival strategies under environmental stress and advance our ecological understanding of the relationship to the climatic variables.

II. MATERIALS AND METHODS

The visual searching sampling approach was used to observe the various behaviours of spiders. A Samsung Galaxy M52 camera was used to take the spider photos and videos. The Agra region (U.P.), which is located on the border of the State of Rajasthan, served as the focused sampling area for the behavior study (Fig. 1). The keys and catalogs of Sebastian and Peter 2009, Tikader 1987, Pocock 1900, and Platnick 2013 were used to identify the spiders.

Fig. 1. Satellite map of Sampling sites (Agra, Uttar Pradesh)
(Source: Google Earth Pro)

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III. RESULT AND DISCUSSION

Following behaviour patterns emerge during the course of our study:

A. Hunting and Feeding behaviour

Spiders are predominantly carnivorous predators exhibiting diverse hunting strategies that vary according to species and habitat (Foelix, 2011; Anjali and Prakash, 2019). Some species actively hunt prey using agility and vision, while others adopt sit-and-wait tactics. After capture, spiders inject venom through their chelicerae to paralyze or kill prey and initiate extra-oral digestion. They mainly feed on insects, contributing significantly to natural pest control. In the present work, we observed this type of behaviour in the group of salticids spiders which feed on the insects i.e. *Menemerus bivittatus* feeding on housefly (fig. 2). Our finding supports the results of Nyffeler & Birkhofer, 2017.

Web-building spiders construct various web types, including sheet webs and irregular cobwebs to trap prey (fig. 3). Orb-weaving Garden spiders (Araneidae) produce geometrically structured silk webs with adhesive threads that effectively entangle insects (fig. 4) (Wise, 1993; Blackledge *et al*., 2009).

Fig. 2. *Menemerus bivittatus feeding on housefly*

Fig. 3. Insect trapped in the sheet web

Fig. 4. Ant trapped in the orb web

B. Dispersal and Migration behaviour

Spiders employ diverse dispersal strategies to colonize new habitats. One of the most common methods is ballooning, in which spiders release silk threads that catch air currents and transport them over considerable distances (Foelix, 2011; Bell *et al*., 2005). In the present work, we observed this Neoscona spiders often disperse by releasing silk threads into the air, allowing wind currents to carry them to new locations (fig. 5). Mass migration events, where large numbers of spiders move simultaneously, and are often triggered by environmental factors such as seasonal shifts, habitat disturbance, or resource scarcity (Bonte *et al*., 2003; Foelix, 2011).

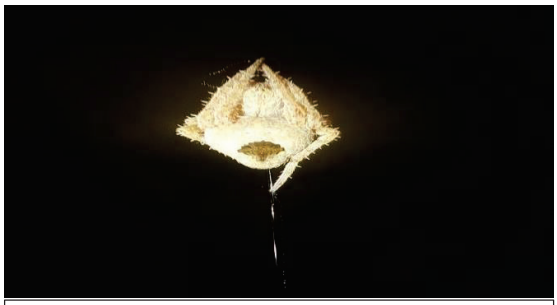

Fig. 5. *Neoscona* sp. migrating through ballooning

C. Mimic behaviour

Spiders have amazing mimicking behaviours, especially ant mimicry (*myrmecomorphy*), in which their bodies, colors, and movements are remarkably similar to those of ants. However, upon close inspection, they may be distinguished from real ants by their eight legs. These spiders frequently lift their front legs to mimic ant antennae in order to intensify the illusion during possible dangers. Myrmarachne sp. (fig. 6), a species renowned for its realistic ant-like look and activity was found to exhibiting similar type of mimicry (Cushing, 1997; Ceccarelli, 2008).

Fig. 6. *Myrmarachne sp.* ant mimic spider

D. Territoriality and Defense

Spiders frequently act in a territorial manner, especially when protecting their webs, hiding places, or breeding grounds. Threat displays, web vibrations, or direct physical battle are some of the ways they may react to invaders (Foelix, 2011; Wise, 1993). Furthermore, spiders have a variety of defense strategies that help them survive against predators, such as mimicry, camouflage, and poisonous attacks. Species of *Cyclosa* were observed decorating their orb webs with debris and prey remains, effectively concealing themselves within the web structure (fig. 7). Similarly, *Misumena vatia* (crab spiders) (Family: Thomisidae) documented during the study exhibited body color matching with flowers and foliage, making them nearly indistinguishable from their background (fig. 8). These field observations highlight the ecological

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significance of defensive and concealment strategies in ensuring survival under environmental stress conditions.

Fig. 7. *Cyclosa* sp. camouflaging itself with the environment

Fig. 8. *Misumena vatia* camouflaging itself with the garden environment

E. Social behaviour

Some spider species engage in communal web-building activity, when several individuals work together to create expansive, interconnected webs that can concurrently capture a variety of prey. Large-scale communal webs were seen in Agra's semi-arid areas during the current investigation. It was discovered that several insects were caught securely in dense web connections and then eaten by various spider groups. Species such as *Cyrtophora* sp. (Fig. 9) were observed producing notably enormous and dense web structures, occasionally spanning entire trees or walls. Initially, newly spun silk appeared nearly translucent; however, over time, the webs became brown or grey due to the buildup of trapped insects and dust particles. *Cyrtophora* species exhibited a pronounced inclination towards communal web formation. Communal webs were frequently noted in arid ecosystems characterized by prickly flora, including berry shrubs and date palm trees, situated at intervals of roughly 200 meters. While communal web creation was absent from highly woody areas, similar patterns were also observed in marshy places. These findings imply that in order to improve prey capture effectiveness and survival in particular ecological conditions, spiders have evolved adaptive social and cooperative behaviours.

Fig. 9. Community web of *Cyrtophora sp*

F. Parental care

Spider species exhibit parental care, which may be performed by either males or females depending on the species. In the present study, females were primarily observed protecting and guarding their offspring. Parental investment was recorded in several families, particularly Salticidae, Araneidae, and Pholcidae. In Salticidae (jumping spiders), females construct a silken retreat sac after fertilization and deposit their eggs within it (fig. 10). The female remains inside the retreat guarding the egg sac until spiderlings emerge. After hatching, both the mother and spiderlings exit the retreat, and the juveniles begin searching for food and shelter independently. In *Cyrtophora* species, egg sacs are attached within the inner region of the web, where spiderlings hatch and initially feed within the protected web environment (fig. 11, 12). Similarly, females of the family Pholcidae were observed carrying their egg sacs with them, providing continuous protection (fig. 13, 14). Spiders generally place egg sacs in secure microhabitats that ensure adequate ventilation, shelter, and optimal humidity and temperature conditions. During field observations, egg sacs were found in wall crevices and beneath tree bark (fig. 15, 16). These behaviours indicate adaptive reproductive strategies that enhance offspring survival in variable environmental conditions.

Fig. 11. *Cyrtophora citricola with egg* sac

Fig. 12. Spiderlings hatching out from egg sac of *cyrtophora citricola*

Fig. 13. *Crossopriza lyoni with egg sac*

Fig. 14. Spiderlings hatching out from egg sac of *crossopriza lyoni*

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Fig. 15. Spider sac on the tree bark

Fig. 16. Eggs inside the web silk sheet

Fig. 10. Eggs preserved in web silk

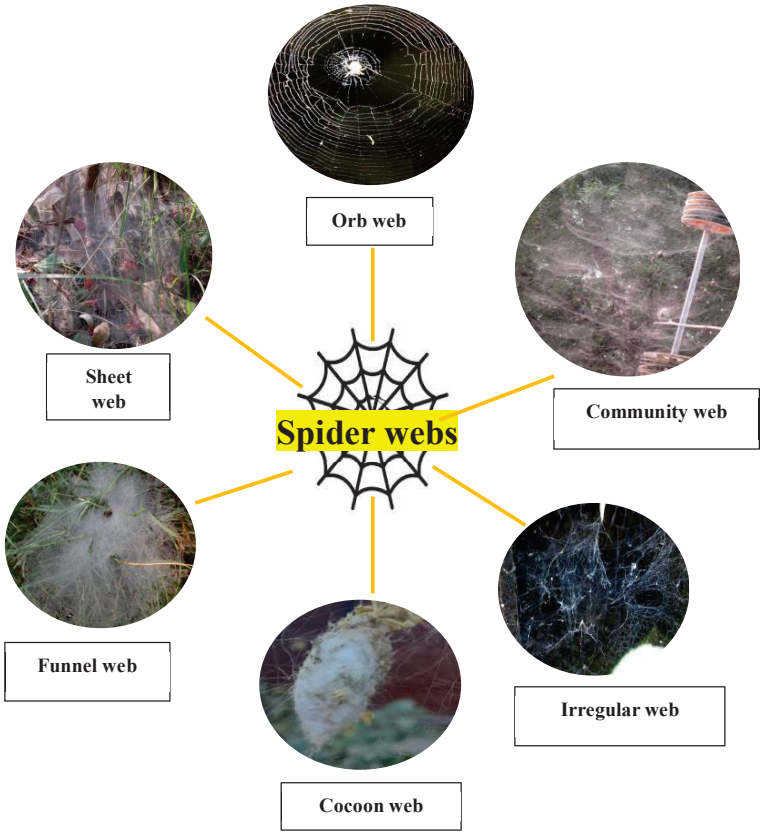

Fig. 17. Types of Webs

G. Web construction behaviour

Web building is one of the characteristic and well-recognized behaviours of spiders. They possess specialized silk glands and spinnerets located at the posterior end of the abdomen, through which silk is extruded and manipulated into precise geometric structures (Foelix, 2011). Webs serve multiple functions, including prey capture, shelter, reproduction, and dispersal. The architecture of a web varies among species and is largely influenced by hunting strategy and environmental conditions (Wise, 1993). Based on structural organization, a number of web types were identified during the current survey in Agra's semi-arid ecosystem (Fig. 17). Members of the Araneidae and Tetragnathidae families frequently built orb webs. Agelenidae were found to have funnel-shaped webs, whilst Lycosidae were found to have ground-associated sheet or retreat structures. Collective web formation was demonstrated by Cyrtophora sp. Pholcidae often produced irregular and sheet webs. Salticidae, Gnaphosidae, and Araneidae were found to have cocoon-like or retreat-like silk constructions that served as shelter and protection for eggs. The structural diversity of spider webs and their adaptive importance in semi-arid environments are highlighted by these changes.

H. Silk production

Spider silk is a multifunctional biological material used for web construction, egg sac formation, prey wrapping, dispersal, and as a safety dragline during predator escape (Foelix, 2011). Spiderlings commonly disperse through ballooning behavior, in which they climb to an elevated position, raise their abdomen, and release one or more silk threads that catch air currents and facilitate aerial transport (Zschokke, 2003). Spider silk has attracted a lot of scientific interest lately because of its remarkable mechanical qualities, which include great tensile strength, flexibility, and biocompatibility. Its potential uses in tissue scaffolding, biomedical engineering, advanced material science, and sutures have been emphasized by these features (Vollrath & Knight, 2001).

IV. CONCLUSION

The present study demonstrates the spiders exceptional behavioral diversity and adaptability in their semi-arid habitat in Agra. Spiders were seen using a variety of hunting techniques, such as web-based prey capture and aggressive predation, exhibiting adaptability in their foraging behavior in response to changing environmental conditions. Their evolutionary responses to environmental stress and predation

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pressure are further demonstrated by defensive adaptations such web decoration, territoriality, mimicry, and camouflage.

Dispersal mechanisms, particularly ballooning and active movement, facilitate colonization of new microhabitats, ensuring population persistence in fragmented and resource-limited landscapes. Communal web-building behavior observed in genera such *Cyrtophora* reflects cooperative strategies that enhance prey capture efficiency and survival. Additionally, parental care behaviours recorded in families such as Salticidae, Pholcidae, and Araneidae indicate significant reproductive investment aimed at improving offspring survival in semi-arid conditions. The structural diversity of webs—including orb, funnel, sheet, irregular, and communal forms—demonstrates ecological specialization linked to habitat structure and prey availability. The multifunctional use of silk for web construction, egg protection, dispersal, and predator avoidance further emphasizes its critical role in spider survival and ecological success.

Overall, the findings suggest that spiders in the semi-arid region of Agra exhibit a wide range of behavioral and ecological adaptations that enable them to withstand environmental stress, optimize resource utilization, and maintain ecological balance. These adaptive strategies underscore the importance of spiders as resilient and ecologically significant components of semi-arid ecosystems.

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