Journal of Applied Life Sciences International

Volume 27, Issue 5, Page 1-9, 2024; Article no.JALSI.121760
ISSN: 2394-1103

Spiders as Natural Pest Controllers: Insights into Their Distribution, Diversity, and Ecological Impact in Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jalsi/2024/v27i5655

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/121760

Review Article

Received: 20/06/2024
Accepted: 22/08/2024
Published: 29/08/2024

ABSTRACT

Spiders, crucial for controlling agricultural pests, offer an eco-friendly alternative to chemical pesticides. They inhabit diverse environments, with their distribution influenced by climatic and abiotic factors. Spiders are a highly diverse group, ranking seventh in global animal diversity, and

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Cite as: *M.P, Sugumaran, Natarajan K, Porkodi G, Gayathry G, Jayakumar J, Kalaichelvi K, Suganya K, Akila S, and Sindhuja M. 2024. "Spiders As Natural Pest Controllers: Insights into Their Distribution, Diversity, and Ecological Impact in Agriculture". Journal of Applied Life Sciences International 27 (5):1-9. https://doi.org/10.9734/jalsi/2024/v27i5655.*

play essential roles in ecosystems as both predators and prey. In India, spiders are notably abundant in rice, sugarcane, and cotton fields, where they contribute to pest management. Recent studies have identified several new spider species, highlighting their significant but underrecognized role in natural pest control. This review underscores the need for more research on spiders for their positive utilization as effective biological control agents in various ecosystems.

Keywords: Biodiversity; biocontrol; predatory potential; cultivation practices on spider; shannon diversity index.

1. INTRODUCTION

It is estimated that planet Earth contains nearly 30 to 40 million species of flora and fauna and quite a few million under each of them are yet to be identified. In the 70 percent geographical area surveyed so far, 47,000 species of plants and 89,451 species of animal have been described by the Botanical Survey of India, Kolkata. Biodiversity in natural habitats represents an important pool of species and genetic material of potential use to human society [1]. India has a rich diversity with a vast majority of the species harboured in the four hot spots *viz.*, the Western Ghats and Srilanka, Eastern Himalayas, Indo-Burma region, Sundalands.

Biological diversity can be defined as the variety of life forms Molecular, Organismic, Population, Species and Ecosystem levels [2]. Over the years, further refinement of the term biological diversity has been made [3].

India has an immense biological diversity which is about 7% of the world's flora and 6.5% of the fauna spread in the 10 biogeographic areas and it is one of the 12 countries identified as mega centers of biological diversity [4]. The Zoological Survey of India and Forest Survey of India in their estimation of faunal diversity have accounted for 82,616 animal species in India including 1685 species of spiders.

Spiders date-back to 350 million years ago [5] are one of the most successful groups under phylum Arthropoda which comprises more than 7,50,000 known species. At present, more than 30,000 species of spiders under 3000 genera and 105 families have been recognized all over the world.

They are important predatory organisms in all ecosystems that they inhabit, with a high prey-finding ability and capacity to consume a greater number of prey than any other predator. They are the only class of arthropods that are entirely predaceous [6]. Though their prey consists mainly of insects they also consume some unusual prey such as small mice, bats, fish, crabs, frogs, lizards, snakes and scorpions and are themselves food to many birds and wasps. Thus, spiders help maintain the biotic balance of nature. This is especially true in the tropics where spiders are particularly abundant. Despite their importance, the role of spiders in the management of the pest populations has only been lately recognized, and scant attention has been paid to them as pest control agents in India. Studies on spiders, made so far are limited to the investigation of the species composition and their seasonal occurrence in the field.

Losses in crop production due to pests causing famines in the affected area. The use of various pesticides and insecticides for pest control has serious ecological consequences and poses threats to human health. The current focus is to find safer ways of pest control, especially the use of natural enemies. In this respect spiders have a great scope in the category of predators. This review deals with spider's distribution, diversity, and their predatory potential.

2. DISTRIBUTION AND HABITAT

Spiders can live just about anywhere and that is why there is such diversification out there. They are ranked seventh when it comes to the most diversified living creatures in the world. The only place without spiders is Antarctica.Though spiders are found in a variety of environments, most species require strictly defined conditions. Climatic and other abiotic conditions (temperature, humidity, wind and light intensity) are among the most critical factors that determine the habitat preference of spiders, apart from plant community characteristics. Rushton et al. [7] found the site moisture and management regimes to be the most important variables influencing the distribution of grassland spiders.

Majority of the spider species living on the terrestrial ecosystem. Spider exist under varied

climatic condition. Spiders are both spatially and vertically distributed. The distribution pattern is determined more by environmental factors and prey availability than by inter-specific competition.

Spiders disperse by walking on the ground or by using silk thread bridges between plants as well as by ballooning through the atmosphere from place to place on silken threads [8]. Juvenile and newly hatched spiderlings disperse by balooning. A newly-hatched spider throws out a tiny line of silk on which it floats away on breezes or updrifts, sometimes as far as 200 miles from land, alighting on the super-structure of ships at sea, or rising to 2,000 feet above the earth [9].

3. BIODIVERSITY OF SPIDERS

Spiders play many important roles in the ecosystem as predators and source of food as prey for other animals. They have attracted the attention of naturalists from early times [10] and later in India [11], and enormous amount of literature has been accumulated. Diversity of a species is defined as the measurable property of any collection of organisms containing more than one species. The pattern of diversity in a community is high when individuals of various species are thoroughly mingled so that several species are usually present in a small area [12]. A rich diversity of spiders is also important in the sense that a single spider species may not be very efficient in controlling a precise pest, but greater biodiversity increases the potentiality of finding a particular species and controlling it in a given ecosystem.

4. SPIDER DIVERSITY AT THE GLOBAL LEVEL

The 30,000 species of spiders identified so far are well distributed among different habitat types. Dondale [13] recorded that 12,000 species of spiders approximately occur in the world out of which only one-fourth of the total fauna has been recorded. Platnick [14] launched “World Spider Catalogue” a website and described the spiders with a total of 110 families representing 3,618 genera and 39,112 species. The goblin spider (Oonopidae) under genus *Gamasomorpha* currently contains 56 species with a wide distribution found in the United States of America, Panama, South America, China, Africa, Indonesia and Australia [15].

Species diversity in spiders differs for different ecosystems and habitats. Merwe-m-van-der et al*.* [16] surveyed five different habitats *viz.,* indigenous grasslands, open (without undergrowth). and dense (with undergrowth), indigenous forests, exotic pine *(Pinus albus)* plantations, and an ecotone of mature pine indigenous forest and concluded that pine plantations had the lowest spider diversity while grasslands exhibited highest spider diversity.

Spider diversity in india: Rice crop ecosystems support more species and numbers than other ecosystems. A survey of spiders in rice fields of Coimbatore, Pudukottai and Tanjore districts of Tamil Nadu indicated 73 species under 13 families [17]. Among other crop systems, sugarcane and cotton crops were reported to support a diverse population of spiders. Easwaramoorthy et al*.* [18] recorded 57 species of spiders belonging to 13 families from sugarcane fields in South India.

The genus *Conothele* of the trapdoor family *Ctenizidae* is reported for the first time from India with the description of two new species *Conothele varvarti* from Similipal Tiger Reserve in Orissa, eastern India and *C. vali* from Tawang district in Arunachal Pradesh, Northeastern India [19]. Two new species of the genus *Diplothele* (Araneae: Barychelidae) from Orissa were reported by Siliwal et al*.,* [19]. A new Brush-footed trapdoor spider (Araneae: Barychelidae) *Sipalolasma arthrapophysis* (Gravely) was recorded from Andhra Pradesh by Javed et al*.,* [20]. From the survey conducted, in the different forests ecosystems of Western Ghats of Tamil Nadu in Nilgris, Coimbatore, Erode, Virudhunagar and Tirunelveli districts to collect the adult spiders and study them taxonomically. Fifty-six species of spider collections were made [21].

Siliwal et al*.,* [19] discovered a new species *Tigidia sahyadri* from Uttara Kannada District, Karnataka. Two new trapdoor spider species of the genus *Scalidognathus* (Araneae: Idiopidae) from South Western Ghats of India are reported by Sanap and Mirza (2011). Marusik et al*.,* [22] observed a new species, *Amaurobius koponeni* (Araneae: Amaurobiidae) from Himachal Pradesh based on a male specimen.

Two new species of the spiders, *Oxyopes kobaenis* sp. nov., *Oxyopes boriensis* sp. nov. from Oxyopidae family are described from central India from Koha and Bori meadows, Goa by

Bodkhe and Vankhede [23]. Gupta and Pawar [24] attempted to survey spider species inhabiting the rice ecosystem. Rajendran (1987) reported five species from Tamil Nadu while Nirmala [25] reported 13 genera falling under eight families. In Tamil Nadu, Nirmala [25] surveyed rice pockets in the western region of the state and gathered 18 species of spiders from different kinds of rice ecosystems namely, well-irrigated and direct-sown rice. Ganesh Kumar [26] surveyed spiders occurring in the rice fields of Aliyarnagar, Coimbatore and Karaikal. After this no concerted attempt has been made to investigate the rest of the regions of Tamil Nadu including the major eastern coastal belt. During the last 20 years, several studies on spider fauna in forest ecosystems and plantation crops have been published all over the world. Although a large number of studies exist, the significance of spiders as natural control agents in the forest agroecosystem is still largely unknown. From the study conducted in horticultural ecosystems especially in vegetable crops, fruit crops, and flower crops, eighteen species under eleven families were collected and identified i.e., Salticidae: *Plexippus paykulli, P. chandraseharani, P. petersi, Telamonia dimidiata; Oxyopidae: Oxyopes birmanicus, O. salticus, O. shweta; Sparassidae: Palystes castaneus, Olios milleti; Hersilidae: Hersilia sp., H. savignyi; Araneidae: Neoscona rumpfi; Erisidae: Steogodyphus sarasinorum; Lycosidae: Pardosa pseudoannulata; Theraphosidae: Poecilotheria striata; Thomisidae: Oxytate virens; Philodromidae: Philodromus sp; Pisauridae: Dolomedes tenebrosus*. Shannon diversity index was maximum (1.18) in vegetables during April to July and minimum diversity was observed during May (1.04) in flowering crops [27]. From a survey, a total of 1039 spider individuals covering 50 species belonging to 17 families were collected. Maximum number of individuals were collected from dry deciduous forest and from that 12 number of species was recorded from the family araneidae [28].

Natural enemies of spiders: Though spiders are voracious predators by nature, they themselves are prey for many larger animals and birds. The spider wasp (Pompilidae) and mud dabbers (Sphecidae) are known to be the arch hunters of spiders (Toft and Rees, 1998). Arachnids like harvestmen, pseudo scorpions and mites have also been reported to prey occasionally on spiders [8]. Other animals like toads, fish, lizards, geckoes, birds and monkeys also feed on spiders [8].

Effect of cultivation practices on spiders: The influence of different agricultural practices (such as edge crop, zero tillage sowing and low input of fertilizers) on the density and diversity of spider populations of small wheat fields present in close vicinity were compared in experiments conducted from 2007-2009.Agroecosystems are ephemeral habitats and existence of spiders depends upon the growing season of annual crops. Bishop and Riechert [29] reported that crop cultivation destroyed vegetational complexity and significantly reduced the local spider community. On the other hand, vegetational complexity, particularly involving weeds, has been associated with increased spider populations in any ecosystem [30]. Thomas and Jepson [31] opined that agricultural operations caused large population depletions of Linyphiid spiders in grass and cereal fields. Crop harvesting has a greater negative impact on spider populations than any other agricultural practice by way of physical injury and egg sac destruction (Gertsch and Riechert, 1976; Hatley and Macmahon, 1980), Bishop, [32]. Cutting operations in grass fields for silage production were reported to reduce spider populations by 56 to 96 percent [31]. Next to harvesting, tillage was mainly responsible for the mortality of spider populations in agricultural ecosystems Apart from the harvest and tillage practices and other agricultural practices like herbicide and pesticide application, weeding, over-grazing, flood irrigation, over fertilization, and trash burning affect the spider species. Biology studies with *Peucetia virridana* and *Micrommata virescens* showed that both species took more than 350 days to complete their life cycles. *Heteropoda venetoria* and *Oxyopes javanus* took more than 250 days to complete their life cycle. *Agelena kariansholensis* took 381 days and *Olios hampsoni* took 345 days to complete their life cycles. 30% of *Peucetia virridana* and more than 20% of *Heteropoda venatoria* and *Micrommata virescens* and 7% of *Oxyopes javanus* developed into adults in captivity [33].

Anthropogenic effect on spider diversity: "The abundance and number of spider species is negatively affected by the impact of many human land uses, such as habitat fragmentation, fire and pesticides." Human activities create unfavourable atmosphere for spider sustenance by destruction of natural vegetation. Human recreational and pedestrian activities affect the structure and composition of spiders. These generate the small, moderate and long- term effect of the spider species.

Predatory potential: Spiders are the dominant insectivores in terrestrial ecosystem and exhibit a very diverse range of foraging behaviours. Experimental evidences suggest that spiders are generalist predators. Spiders as predators of *lepidopterous* larvae on apples in Canada are reported by Dondale [13]. Turnbull [34] pointed out that *Linyphia triangularis* consumed a wide range of species of prey and its prey preference varied from place to place depending upon density of particular species at a particular time and place.

Spiders not only prey upon the larvae and adults of the pest insects, but also cause indirect mortality by disturbing effect. Marc and Canard [35] also reported that spiders are polyphagous predators. Stealing of prey from other spiders also is an alternative foraging strategy observed among various web spinners [36].

As arachnids in general and spiders in particular are effective predators of insects they could be employed in many biocontrol programmes (Savory, 1977). Mansour et al*.* [37] suggested that larval populations of the apple pest *Spodoptera litroalis* did not increase at pest level on trees occupied by spiders whereas significant damage was observed on trees from which they had been removed. These workers further reported that spiders' activity (Predation and disturbance) was responsible for a 98% reduction in larval densities.

Though insects constitute about seventy per cent o(total food intake of spiders they are al so reported to feed on a wide range of other animals (Nyffeler and Benz, 1981), Mc Cormick and Polis, [38]. The spider, *Peucetia viridans* Hentz was observed preying on bees (Raju, 1997) whereas the spider *Lycosa carmichaeli* Gravely was found to predate on smaller and juveniles of the common spider frog, *Rana cyanophlyctis* Schn [39].

Both web spiders and hunters kill their prey by injecting venom into the body of its victim. Spider venom is neurotoxic and is made of proteins and low molecular weight compounds [40]. The amount of venom injected varies with different species and is also based on the size of prey. Spiders also exhibit cannibalism (preying on weaker members of their own species) [41]. This cannibalism is not confined to younger spiders, but it is true of adults. In general, they tend to concentrate on insect prey and to a lesser degree on other spiders [42]. It is believed that spiders turn cannibalistic only when prey is deficient, as observed in the Giant crab spider, *Heteropoda venetoria.*

Walker and Rypstra (2003) investigated the effects of hunger and predation risk on feeding behaviour of wolf spider, *Pardosa milvina* (Hentz). Gonzalez et al*.,* (2009) reported a predation by adult females of *Misumenops pallidus* (Araneae: Thomisidae) on insect pests of soybean cultures in Buenos Aires Province from Argentina. Nelson and Jackson (2009) carried out the prey classification by an araneophagic ant-like jumping spider in Western Kenya. Pekar and Lubin [43] observed prey and predatory behaviour of two Plesiomorphic Zodariid species, *Lachesana insensibilis* (Jocque) and *Pax islamita* (Simon) from Israel. The role of spiders in regulation of insect pests has been studied in the rice ecosystem from Aduthurai, Tamil Nadu by Jayakumar and Sankari (2010).

Vetter [44] recorded scavenging by spiders and its relationship to pest management of the brown recluse spider from California. Pekar et al*.* [43] presented a prey race drives differentiation of biotypes in ant-eating spiders of the genus *Zodarian* from Iberian Peninsula. The potential of predatory spider, *Argiope anasuja* (Thorell) as a biocontrol agent of winter vegetable pest, *Phyllotreta cruciferae* has been discussed by Shunmugavelu and Ganesan [45].

The prey selection behaviour of nocturnal web-building spider, *Eriophora edax* (Araneae: Araneidae) among Lepidoptera is reported by Meraz et al*.,* (2012). Karthikeyani and Kannan [46] observed the feeding efficacy of huntsman spider, *Heteropoda venatoria* on *Nilaparvata lugens,* the brown plant hopper, the common pest on rice plants *Oryza sativa.* The *Zodarian cesari* species (Araneae: Zodariidae) as specialised ant eating predators in four citrus groves (Monzo et al*.,* 2013) Dippenaar-Schoeman et al*.,* (2013) discussed five agrobiont spider species that might play an important role as natural control agents on crop pests in South Africa. The described species are *Ostearius melanopygius, Pardosa crassipalpis, Cheiracanthium furculatum, Heliophanus pistaciae* and *Misumenops rubrodecoratus*. It was observed that *Raft Spider Dolomedes fimbriatus* diving into the water along with the egg sac but after the formation of the egg sac, the forays into water were not so common. Just before hatching, a loose web at the edge of the

aquarium was constructed. The spiderlings which hatched out remained for two days in the web before dispersing. Dispersal was by ballooning as in the case of other species [47].

Spiders in biocontrol: Use of spiders as biocontrol agents has been assessed by different researchers as they feed on wide range of pest like leafhoppers, thrips, aphids, caterpillars etc. Spiders are most dominant predators in many habitats, upto 550 individuals per square meter have been found in cereals. They are strictly carnivorous and a true predators emphasizes its use as biocontrol agent. The can capture 6000 individuals prey during whole of their life time. Riechert SE,Lockley T [48]. Arachnids in general and spiders in particular are effective predators of insects they could be employed in many bio-control programmes (Savory, 1977).

Biocontrol in agricultural ecosystem: Spiders have been extensively reported to play an important role in suppressing pest population in agricultural ecosystem. Bhathal and Dhaliwal (1990) studied the feeding efficiency of six predators of whitebacked planthopper and reported that *Salticus scenicus* (Clerck) was found to be the most efficient predator consuming 4.95 nymphs per day. In cotton, the lynx spiders *(Oxyopes salticus)* were found to be the most abundant spider predators [49,50]. Lynx spiders are cursorial hunters and are generally considered to be diurnal predators (Gertsch, 1949; Whitcomb et al*.,* 1963; Young and Lockely, 1985). Similarly, in pigeon peas, *Thomisus shivajiensis* Tikader (Thomisidae) and *Clubiona abboti* Kochi· (Clubionidae) were found to be the predominant predators of the blue butterfly, *Lampides boetleus* [51].

Apart from agricultural crops, spiders also serve as efficient biocontrol agents m horticultural crops. Three species of Lycosids *viz., Lycosa birmaniea* Gravely, *Lyeosa ehaperi* Simon and *L. himalayensis* Gravely were commonly found associated in the control of hemipterous insects on brinjal, okra and tomato [52]. *Araneus* sp. and *Marpissa* sp. along with *Heteropoda* sp., *Phidippus* sp. and *Oxyopes pandae* Tikader predated upon the nymphs of citrus Psylla, *Diaphorina eitrikuw* [53]. Though all species of spiders are predatory in nature, the potential use of spiders in biological control in agricultural ecosystems seems to be feasible only for the members of families Thomisidae, Araneidae, Lycosidae, Oxyopidae, Eresidae, Clubionidae and Hersilidae [54].

5. CONCLUSION

Spiders play a vital role in agricultural ecosystems by naturally controlling pest populations, offering a sustainable and eco-friendly alternative to chemical pesticides. Their widespread distribution and diversity across various habitats underscore their adaptability and importance in maintaining ecological balance. In India, spiders contribute significantly to pest management in crops like rice, sugarcane, and cotton. Despite their potential, much remains to be explored about their effectiveness and application in pest control. Continued research into spider biodiversity and their ecological roles will enhance our understanding and utilization of these natural predators, promoting healthier, more sustainable agricultural practices.

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1. ChatGPT was used for editing this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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