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Role of spiders in agriculture and horticulture ecosystem

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Abstract

Spiders are carnivorous arthropods, consume a large number of preys and do not damage plants. They have unique habitat and they live in almost all the environments. Spiders serve as buffers that limit the initial exponential growth of prey populations. The predatory spiders are classified into five major groups based on their foraging style. Prey searching ability, wide host range, ease in multiplication and polyphagous in nature make them as a potential predator in biological pest suppression. Species abundance of spider communities in agricultural and horticultural ecosystem can be as high as in undisturbed natural ecosystem. About 19 species in rice ecosystem, 13 species in maize, 16 species in soybean, 18 species in oil seeds, 21 species in cotton, 57 species in sugarcane, 13 species in vegetables, 11 species in fruit crops and 26 species in coconut were recorded. The use of biopesticides, botanicals and organic manure will enhance the spider population in different ecosystems. This contribution deals with mass production, importance in pest management and conservation of spiders.

Key words: Araneae, Arachinidae, arachinids, biological pest suppression, carnivorous arthropods, predatory spiders, prey populations.

Introduction

Spiders belong to order Araneae, class Arachinidae and are members of phylum Arthropoda, the largest assemblage of animal with jointed legs and hard exoskeleton. They are the largest group of arachinids comprising more than 30,000 species distributed over 60 families over worldwide. They have unique habitat and they live in almost all the environments. They are the most abundant predator of insects of terrestrial ecosystem and consume large number of preys without damaging the plants. Under favourable conditions, they can reach maximal densities of up to 1000 individuals m^{-2} approximately. The population densities and species abundance of spider communities in cultivated fields can be as high as in natural ecosystem [1,2]. The potential attributes like number of insects killed per unit time, good searching ability (especially hunting spiders), wide host range, adaptation under conditions of food limitation, low metabolic rate, energy conservation mechanism and polyphagous nature makes them as a model predator [3]. This contribution deals with classification, mass rearing, predatory potential, conservation and augmentation of spiders (Table 1).

Mass Rearing of Spiders

There are three different methods followed for multiplication of predatory spiders based on its habitat.

Mass multiplication of hunting spiders: Egg-sacs of hunting spiders are placed into beehive-like, closed breeding boxes. The inner structure was covered with a removable material which provides the spiders with a large surface within a relatively small volume, in order to decrease cannibalism. There are holes on one side of the box, where changeable tubes containing fruit fly (*Drosophila melanogaster*) culture are connected to the box. The inner side of the box is coated with teflon, or a teflon-like material that spiders are unable to climb so that they cannot get into these tubes. From hatching to egg-laying, spiders feed on fruit flies emerging from the tubes. At the bottom of the box there are larvae of flour-beetles (*Tenebrio molitor)*, which continuously clean up the dead fruit flies, preventing underlay from mildewing. The maintenance of the breeding means the regular change of tubes containing old cultures to fresh ones. Simultaneously hatched spiders become mature and breed at the same time and attach their egg-sacs to the inner structure of the box. Egg-sacs are removed from the box together with the carrier surface and they are kept on low temperature to postpone hatching until application. Egg sacs are applied in greenhouses. From each egg-sac, 50-70 spiderlings emerged. Spiderlings distribute evenly on the plants and suppress or eradicate populations of small-sized arthropods. Since hunting spiders do not spin a web for capturing prey, they do not pollute the plants with detectable quantity of silk [5].

Mass multiplication of ground dwelling spider: Rearing of ground dwelling spiders (Micryphantids and Linyphiids) is comparatively easier than others. A wide mouthed jar covered with a net is commonly used for rearing. The net held in place with several rubber hands or a lid can be used with punched air holes. One to two inch of soil or sand layer is formed in the bottom of the jar for providing a good substratum to the spiders. A broken flower pot or a piece of bark is provided to create a conducive microclimate for the spiders. Spiders effectively use mud pot/bark for its sheltering. Egg cocoons are collected from the bottom and the sand layer is replaced with the help of removable paper towel. In the process of culturing, water should be supplied in small plastic cups. If the spiders are very small in size, the plastic cups must be filled with small rock pills, so that spider dose doesn't drown. Mostly the ground nesting spiders are delicate and weak and they should not be picked up by fingers as they will often lose legs in the process. If dropped, the abdomen usually bursts and spider dies. Chilling them in a refrigerator prior to handling may be helpful. While rearing young ones, they should be provided

Table 1. Classification of predatory spiders: The spiders are classified based on their foraging style [4].

Classification of predatory spiders	Important families	Species (Common name)
Tarantulas	Theraphosidae	*Aphonopelma chalcodes* (typical tarantulas)
Primitive hunters and weavers	Scytodidae	*Scytodes* sp. (spitting spiders)
Small hunters	Thomisidae	*Misumenops asperatus* (crab spiders)
	Salticidae	*Metacyrba* sp. (jumping spiders)
Large hunters	Pisauridae	*Dolomedes tenebrosus* (nursery web spiders)
	Lycosidae	*Lycosa ceratiola* (wolf spiders)
	Sparassidae	*Heteropoda venatoria* (giant grab spiders)
Web weavers	Filistatidae	*Filistata hibernalis* (snare weavers)
	Araneidae	*Argiope aurantia* (orb weavers)
	Agelenidae	*Agelenôpsis pennsyvanica* (funnel web weavers)
	Linyphiidae	*Florinda coccinea* (black tailed red sheet weaver)

with rooms for establishing burrows. If they are left together, they will also eat each other (i.e. cannibalistic behaviour).

Mass multiplication of rice spiders: Barrior and Litsinger [6] reported the mass multiplication of the common rice spiders. The adult male and female spiders of each of the common rice spiders were collected from rice fields, border habitats, and fallows, and held in cylindrical plastic containers (15.4 cm x 36 cm) or Mylar film provided with a 35-45 day–old rice plant as a substrate. Some twigs or small bamboo sticks were also added to serve additional substrate. Egg masses and cocoons were cut from the foliage, kept separately by species in 1 cm x 6 cm glass vials provided with moist cotton at the bottom and capped with dry cotton.

Egg cocoons laid on inside the Mylar films were collected and placed individually in glass vials or in 1.5 mm x 9 mm plastic Petri dishes. Similar provisions were made in this set-up to avoid drying and desiccation of the eggs. Spiderlings that emerged were individually isolated using a camel hair brush in 7.6 cm x 12.8 cm plastic vials provided inside with freshly cut stems or leaves of rice, partly dried straw or small twigs of any plant available and a nylon mesh window on top. Each mesh was secured by either a tape or rubber band on the mouth of the vial. The vegetation served as substrate for clinging and walking. After first moult, in which almost all stored food (yolk) had been utilized, the spiderlings were fed with a variety of diets: first – instar nymphs of Cicadellids and Delphacids, Collembola, Drosophila flies, Hydrellia adults and Chironomids. The food, except Collembola, was partially crushed to help spiderlings feed. Drinking water was provided inside the cell in the form of an inverted film tube filled with water, the lid of which was picked with pin no. 3 to allow water to ooze out slowly and wet the layer of cotton on its floor. After two or three moults, each immature of the Tetragnathid, (*Tetragnatha* spp.) was again transferred to a bigger cylindrical cage (12 in x 15 in) with two mesh windows and a top vent. Similarly, longer branches of sticks were placed inside each chamber along with a hanging cotton ball wet with water. In addition, plastic vial provided with water as described above was placed on the floor of the rearing cell. It provided an additional source of drinking water as well as cooling the spider.

The larger cage provided more space for the *Tetragnatha* to construct a web. A similar rearing methodology was used in *Argiope, Araneus* and *Neoscona*. The rest – the lycosids, oxyopids, etc. – were reared in smaller cells or tubes (2 in x 5 in). The bottom end of each rearing cell plugged with a cotton ball rested on the floor of a rectangular or circular pan lined with wet paper towel. Cut rice stems or leaves and some dry straws were placed inside the tube as additional substrate for the spider. The top end had a nylon mesh secured by rubber bands. As the spiders grew, more and more food had to be added. A diverse diet was continuously provided to the spiders to attain success in moulting and to reach the adult stage.

Predatory Spiders in Agriculture Ecosystem

Cereals and millets: Cereals constitute the staple food of the people of Asia. The damage caused by the insects lead to lesser yield and loss in quality in these crops. In rice, more than 100 insect species are associated at one stage or the other and 20 of these are pests of major economic importance [7]. The spider fauna found in the rice ecosystem effectively reduces the populations of *Nephotettix virescens, Sogatella furcifera, Nilaparvatha lugens* [8], *Scirphophaga incertulas, Mythimina separata* and *Cnaphalocrosis medinalis* [9]. About 19 species of spiders grouped under 15 genera belonging to 10 families were recorded in rice ecosystem. Spider species such as *Lycosa pseudoannulata* Boeset. Str., *Paradosa sumatrana* Thorell (Lycosidae), *Clubiona nr. drossodes* Cambridge (Clubionidae), *Oxyopes javanus* Thorell (Oxyopidae). *Runcinia nr. albostriata* Boesat. Str (Thomisidae) and *Neoscona theisi* Walckner were observed in the rice nursery. Among them *L. pseudoannulata, N. theisi* and *O. javanus* were abundant.

The spider species observed in field bund, irrigation channel and fallow land of rice ecosystem were *C. nr. drassodes* (Clubionidae), *L. pseudoannulata, P. sumatrana, Hippasa* sp. (Lycosidae), *O. javanus,* (Oxyopidae), *Bianor nr. anagulosus* Karsh, *B. hotingchieechi* Schenkel (Salticidae), *Tetragnantha mandibulata* Walknear and *T. maxillosia* Thorell (Tetragnathidae). The predatory potential studies of *Paradosa* sp., *Tetragnatha* sp. and *Oxyopes* sp. indicated that they were effective against lepidopteran pest complex of rice [10]. The sap feeders like *N. lugens, S. furcifera* and *N. virescens* were effectively checked by *L. pseudoannulata, T. javana* and *O. javanus* [11]. Sigsgaard et al. [12] reported that a spider species *Afypena formosa* (Linyphiidae) was found effective against rice BPH under field conditions.

The *Erigone* sp., *Oedothrox* sp. (Micryphantidae), *Paradosa* sp., *P. agrestis, P. amentata* (Lycosidae) were predaceous on the harmful cereal aphids like *Rhaphalosiphum padi* and *Sitobium avenae* [13]. Maize crop was attacked by about 130 insect species; among this half a dozen are of economic importance. About 13 species of spiders belong to 7 families were evaluated against maize borer *Chilo partellus* [14, 15]. *Cheiracanthium* sp. seemed to be effective spider among all. The other important spider species recorded in maize ecosystem were *Clubiona* sp. Clubionidae, *Drassodes sp.* Gnaphosidae, *Heteropoda* sp. Heteropodidae, *Lycosa* sp. Lycosidae, *Oxyopes pandae*

Oxyopidae, *Oxyopes sp.* Oxyopida. *Uloborus* sp. (Uloboridae), *Theridion* sp. and *Theridola* sp. (Theridiidae) were recorded in sorghum, which checks the population of tetranychid mite *Oligonychus indicus* [16]. *Dictyna arundinacea* was effective against cereal aphid *Sitobium avenae, Rhapalosiphum padi* and various Dipterans in wheat ecosystem [17].

Pulses: Pulses are an important source of protein. Among the different pulse crops red gram and soyabean are the commonly cultivated crops. About 17 pests belonging to the families Lepidoptera, Diptera, Hemiptera, Coleoptera and Isoptera were recorded [18]. The predominant spiders found in redgram ecosystem were *Thomisus shivajiensis* (Thomisidae), *Clubiona abbotti* (Cluionidae) and *Hippasa haryanesis*, which were effective against Lycaenid butterfly *Lampides boeticus* [19]. They also control the population of *H. armigera, Clavigrella* sp. and moderately feed on *Melanagromyza obtuse* [20]. Among the pulses soybean holds the maximum spider density [21,22]. In soybean 16 species of spiders were recorded. Among these *Reduviolus roseipennis, Tropionalis capsiformis* and *Hoplistoscelis deceptirus* were the important predators of eggs and larvae of soybean semilooper *Pseudoplusia includens* and *H. armigera* [23]. The other effective species against these pests found in soybean ecosystem were *Peucetia viridanus* and *Ozyopes saltius*. Faleiro et al. [24] found that spiders effectively check the sucking pests on cowpea.

Oilseeds: The important oil seed crops in order of importance are groundnut, linseed, rape seed and mustard, sunflower, safflower, castor, sesame etc. There are 18 species of predatory spiders belonging to 16 genera in 7 families commonly observed under oil yielding crops [25]. *Lycosa* sp. and *Theridid* sp. play a prominent role in decreasing the pest complex in groundnut ecosystem [26]. In groundnut *O. saltius*, *P. pauxilla* and *Misumenops* sp. occupied 85.8 to 97.7% of overall population of spiders and effectively controlled the population of sesame capsule borer *Antigastra catalunalis* and *Acherontia styx* [27].

Fibre crops: The cotton ecosystem includes a wide variety of arthropods throughout the world. More than 1326 species of insects have been reported attacking cotton in the world. In India, 162 species have been recorded among which only 15 species are considered potential threat to the crop. In cotton ecosystem 21 species of spiders grouped under 16 genera belonging to eight families were reported [28] (Table 2). The spider fauna present in cotton ecosystem are classified by Dhulia and Yadav [29].

The predatory potential of 4 species of spiders *viz., P. viridiana, Araneus minuta*, *O. javanus* and *N. theisi* against cotton sucking pests indicated that they effectively check the population of leaf hoppers, aphids and whiteflies. They were also effective against *Spodoptera litura* and *H. armigera*. The predatory potential of *P. viridanum* was maximum on sucking pests of cotton [30]. Nyffeler et al. [31] reported that spiders effectively check the population of cotton flea hoppers in Texas, USA.

Sugar crops: Sugarcane is grown throughout the subtropical and tropical parts of South and South East Asia. As many as 200 species of insect pests have been reported to cause damage to the sugarcane crop. In sugar cane ecosystem, 57 species of predatory spiders belonging to 13 families were reported in Southern Peninsular India [32]. Most dominant sp. are *Hippasa greenvalliae* (Lycosidae) and *Crytophora cicatorosa* (Araneidae). *H. greenvalliae* existed throughout the crop period and was seen abundantly up to 180 days and *C. cicatrosa* was seen from 100 days after transplanting up to 240 days [33]. These were effective against leaf hopper and borers [34]. The spider species *Plexippus paykull* and *Misumenops bivittatus* (Thomisidae) were found prey on pyrilla leaf hopper [35]. The potential predator spider sp. found in sugar beet ecosystem is *Theridion impressum* (Theridiidae), which exponentially reduced the aphid population (*Myzus persicae*) [36].

Table 2. Different species of spiders recorded on hybrid cotton.

Group / Family	Species
Hunting spiders	
Oxyopidae	*Oxyopes ratane*
Clubionidae	*Clubioa* sp., *Castianeira* sp.
Salticidae	*Plexippus* sp.
Lycosidae	*Hippasa* sp.
Web building spiders	
Araneidae	*Neoscona theisi, Neoscona* sp.
Uloboridae	*Uloborus khasiensis*
Argiopidae	*Argiope puchella*
Ambushing spiders	
Thomisidae	*Thomisus* sp., *T. cherapunjeus T.projectus*
Miscellaneous spiders	
Heteropodidae	*Olios* sp.

Predatory Spiders in Horticultural Ecosystem

Vegetables: The vegetable crops belonging to the families of Solanaceae, Cucurbitaceae, Brassicaceae and Liliaceae recorded 13 spiders belonging to 8 families [37]. *O. papauanus* was abundantly present in cabbage fields and effectively feeds on cabbage aphids and other pests [38]. Two salticid spiders were effective against brinjal brown leaf hopper population in the field. In watermelon *Clubiona japonicola* is a potential spider in this ecosystem [39]. In edible aroids spiders were found effective on sucking pests such as *Aphis gossypii* and *Tetranychus* sp. [40].

Fruit crops: Fruit crops are attacked by insects, mites and nematodes. Insects eat away or bore into leaves, flowers, buds, fruits and roots. *Araneus singhagadensis, Cheiracanthium danieli* and *Stegodlyphus sarasinorum* were the abundant predatory spiders noticed among the 11 spider sp. recorded in mango ecosystem on mealy bugs [41]. The spiders belonging to the families of Theridiidae, Anyphenenidae and Dictynidae constituted 72–92% among the 68 species recorded in apple [42]. They were effective against mite pests and *S. littoralis* [43]. These spiders caused 98% reduction in *S. littoralis* larval densities which was the result from predation (64%) and larval abandonment of branches occupied by spiders [44]. In grapevine 27 species belonging to 14 families were recorded. The important species were *C. inclusum, T. dilutum, T. melanurum, Trachelas paceficus* and *Hololena dedra* [45]. These spiders were harmful to the grapevine leaf hopper *Erythroneura variabilis*.

Plantation crops: Coconut (*Cocus nucifera* L.) is a majestic perennial palm. It is grown extensively in numerous islands and also in the humid coastal tracts of tropical countries. In coconut 26 species of spiders belonging to 6 families were commonly observed [46]. The *Rhene indicus* and *Cheiracanthium* sp. were effective against coconut black-headed caterpillar *Opisina arenosella*.

Flower crops: Various species of thrips, leafhoppers, scale insects, mealy bugs, caterpillars, cutworms and chaffer beetles attack the common flower crops including rose, jasmine, chrysanthemum etc.[47]. The important predatory spiders found in Jasmine ecosystem were *Phidippus punjabensis, Salticus* sp., *Cheiracanthium* sp., *Paradosa* sp. and *Theridion* sp. They were effective against larvae of *Nausinoe geometralis* [48]. In rose the predominant species effective against insect pest was *Cyclosa conica* [49].

Conservation and augmentation of predatory spiders: Conservation is the most frequently used biological control tactic in IPM and is defined as the actions to preserve and increase natural enemies by environmental manipulation. The main disruptive effects under agricultural and horticultural ecosystem to predatory spiders are due to the application of pesticides/ chemicals and cultivation strategies/mechanical disturbance. Careful choice of insecticides might also restrict the adverse effects of chemical application on the spider fauna. Spiders, for instance do not appear to be as susceptible to endosulfan [50], dieldrin [51], methyl parathion [52] and carbamates and pyridaphenthion [53] as they are to other insecticides. Limiting the spraying program to mid day when the spiders are in active and in sheltered locations, is one of the best ways to conserve spider numbers and diversities in agro-ecosystem. Abamectin, betacyfluthrin [54] and thiomethoxam [55] were found to be less harmful. There was no significant fluctuation in the population of predatory spider recorded with the application of fungicides [56].

Botanicals and biopesticides were not harmful to the spider population in the field. Use of botanicals namely neem oil, neem seed kernel extract, neem seed biters, chinaberry oil and custard apple oil almost conserved the natural spider population [57]. Mishra and Mishra [58] evaluated different pesticides including *Bacillus thuringiensis* on bhendi and found out that the spray schedule consisting of Biotox + Malathion + Biotox (in 20 days interval) was found to be less (0.3 plant) harmful to the spiders.

Rao et al. [59] studied the impact of chemical fertilizers and organic compounds against the development of coccinellids and spiders in groundnut. Application of FYM, neem cake and vermicompost resulted with lesser number of spiders/plant but in case of chemical fertilizers (NPK) it is more. This is due to lesser pest incidence in organic farming vice versa. Neem-coated urea (1:5) at the rate of 100 kg/ha significantly enhanced the spider population and reduction in the GLH population. Azolla @ 1.5 kg/m^2 along with N 30 kg/ha increased spider population, especially *L. pseudoannulata,* as well as use of coir waste ash @ 150 kg/ha encouraged the spider population [60].

The planting and harvesting procedures utilized in agricultural systems are perhaps even more distruptive to spider communities than use of pesticides. At least once in each year, both the habitat and beneficial fauna are destroyed. Aside from the obvious problem with loss of egg sacs and the general suppression of spider numbers, habitat structure is lost, and this is a major determinant of spider community diversity [61]. So spiders can be effectively used in perennial agricultural system as orchards and citrus grooves, where habitat structure, microclimate and beneficial fauna are least distrupted. The back–yard garden is another habitat in which spider control of insect pest might be applied. If small plots are bound by hedge rows, abandoned fields and other natural habitats, the deleterious fauna each year can be offset by recolonization from adjacent habitats.

Spider emigration is generally associated with three phenomena (a) unfavorable thermal environment (e.g. temperature, humidity), (b) low prey availability and (c) disturbance. Among these, the third factor in agro-ecosystem plays a major role. So it is necessary to manipulate the cultivation strategies to avoid the spider emigration from one field to other.

Mangan and Byers [62] reported that minimum tillage will conserve the spider population. Rajendran [63] reported that the aquatic weed, *Pistia straitoides,* in rice ecosystem harboured more spider and spiderlings of *Oxyopes* sp. and *Paradosa pseudoannulata*. This weed provided favourable microclimate for the multiplication of spiders. Prey numbers and local thermal environments can be enhanced by planting beneficial weeds and annual flowers as regular intervals and by maintaining compost heaps in the garden. Maintaining compost heaps in agro- ecosystem is followed in USA and Australia to increase the detrivores (allochthonous inputs) population which will serve as an off season food for the spiders. Folis and Hord [64] reported that allochthonous inputs from detrivores food chain may also subsidize spider population densities, permitting them to have greater cascading effects on crop production.

Maintaining ground cover crops in orchard e.g. introduction of desirable legume species into old fields improved the spider fauna [65]. They also reported that a diverse spider population survived and activated during the establishment phase of minimum tillage pasture improvement. Further, the importance of ground cover on spider conservation revealed by Costello and Daane [66] and experimentally proved the increase in spider density is related to the addition of cover crops in turn it reduces the pest density. However they have indicated the limitations in the use of ground cover for the pest management.

Between–row mulching provides shelter for spiders and improves the foraging behaviour. Chinese are using straw bundles to provide such shelter for spiders [67]. The bundles are initially laid down in areas where spiders are numerous and are subsequently transported from field to field as needed to implement control. Overall, by manipulating the cultural strategies, indirectly it provides structural complexity i.e. refugia with increased humidity.

Augmentation: Introduction of egg sacs of spiders along with Drosophila flies were the main sources in augmenting the spider population under field condition. Spider egg sacs can be kept in low temperature to postpone the hatching period. So it is easy to augment the spider population in field. But before going to release the spiders in particular locality there should be thorough knowledge about the territory size, personal space, website construction and its influence in spider's predation.

Future thrust: A quantitative analysis of the capacity of spiders to suppress insect pests, including the spatial distribution of major species of spiders and pests, should be carried out in the field on a large scale, so that spiders can be successfully used as biological control agents. Ecological and biological characteristics of spiders need to be understood. Findings are necessary, to solve the cannibalistic behaviour of spiders in rearing. Developing a new molecular insecticide compounds are needed for better colonization of spiders in field. Interpreting and analyzing the climatic factors affecting the spider population in the field and their predation efficiency are needed. Identification of specific diets or artificial diets preferred by spiders through molecular studies (i.e. using PCR, ELISA and monoclonal antibody technologies) should be done. Improving the web site success potential mechanism involved in web–building spiders is needed. Advanced study in spider taxonomy is needed to identify new species of spiders. Some of the new species of spiders identified in India and Bangladesh are all effective in field condition.

Conclusions

In recent years, utilisation of spiders in biological control is getting more importance as the spiders are having much character suitable for a successful predator. Steady progress has been made for the past few years and from that scientists were removed the major obstacles in spider study, namely mass multiplication, conservation, taxonomy, reproduction, communication and other branches. However, still spiders are not fully utilized in pest management in most of the countries. In USA, Australia and China, spiders are effectively used in biocontrol programme. In China alone, particularly Hubei province, the use of chemical pesticides was reduced by 70-90% on behalf of spiders in the field. The study effort on the challenges in developing spiders as successful biocontrol agents will hopefully extend the economically viable, environmentally sound and socially accepted pest management for the future generations.

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