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ROLE OF SPIDERS IN REGULATING INSECT PESTS IN THE AGRICULTURAL ECOSYSTEM – AN OVERVIEW

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ABSTRACT

Large numbers of a wide range of spider species inhabit agricultural fields. Their presence limits the habitats open to insect pests. Spiders threaten insect pests with various foraging strategies. As well as consuming large numbers of insect pests as prey, they have the trait of killing all insects living in their territory. For this reason, spiders are a favorable biological control agent in the agricultural ecosystem and can be successfully used to check pest population in the field.

KEYWORDS: Spiders, Biological Control, Agro-Ecosystem, Predators.

INTRODUCTION

For many decades, insecticides have been widely used to control agricultural pests. However, the continuous use of a wide range of pesticides has caused many side effects, including loss of biodiversity, the problem of secondary pests, insecticide resistance, residual toxicity, the resurgence of insect pests, and environmental pollution. Recently, many efforts have been made to combine various non-chemical control methods with insecticides in systems of Integrated Pest Management (IPM). One such effort is the use of natural enemies, like spiders to combat pest population. Many uses of parasitic and predatory natural enemies to control agricultural pests have been reported (Van den Bosch et al. 1982).

Spiders belong to the class Arachnida, subclass Araneae and order Arachnid. A diverse group of spiders may be effective in biological control because they differ in hunting strategies, habitat preference and activity periods. Spiders exhibit both functional and numerical responses to prey densities. By virtue of these density dependent responses, as well as polyphagy, spider populations in agrosystems are stable. As an ideal biocontrol agent, spiders show tolerance and sometimes even
resistance against pesticides in agricultural field. For some time, spiders were considered important predators which help to regulate the population densities of insect pests (Pickett et al. 1946, Dondale 1956, Kajak et al. 1968, Fox and Dondale 1972, Tanaka 1989). In particular, spider communities in areas with a temperate climate achieve equilibrium in the control of agricultural pests (Riechert 1981). In spite of this, they have not usually been treated as an important biological control agent, because there is so little information on the ecological role of spiders in pest control (Turnbull 1973, Riechert and Lockley 1984). However, research has shown that spiders in rice fields can play an important role as predators in reducing the densities of planthoppers and leafhoppers (Hamamura 1969, Sasaba et al. 1973, Gavarra and Raros 1973, Samal and Misra 1975, Kobayashi 1977, Chiu 1979, Holt et al. 1987, Tanaka 1989). As one of the unique part of biocontrol, spiders can be effectively used in both perennial horticulture and field crops.

They are carnivorous arthropods and are classified into 40,000 species, and are found all over the world in almost every kind of habitat. They mainly prey on insects, although they may also feed on various other kinds of prey. The population densities and species abundance of spider communities in agricultural fields can be as high as in natural ecosystems (Turnbull 1973, Tanaka 1989, Riechert 1981).

**Spider: an excellent predator in agricultural ecosystem**

Herbivore populations are not limited by competition for food. This idea is supported by the observation that green plants are abundant (Hairston et al. 1960). Therefore, it is theorized that herbivores must be limited by predation. However, in many agricultural ecosystems limited physical and chemical disruptions have led to local extirpation of predators (Maloney et al., 2003). Herbivores, released from control by predators, sometimes become abundant to the point of severely damaging crop plants (Maloney et al., 2003). If a predator could be established that would feed upon these herbivores, their numbers might be lowered. Spiders may be such a predator (Sunderland, 1999). Although the spiders (Araneae) are a diverse arachnid order consisting of more than 3500 species in North America (Young and Edwards, 1990), and are obligate predators, and many feed upon herbivorous pest insects. The orb-web weavers Araneidae and Tetragnathidae feed upon Diptera, Homoptera (leafhoppers) and Orthoptera, especially grasshoppers. The smaller, sheet-web weavers such as Linyphiidae, Dictynidae and Theridiidae capture Diptera, Hemiptera,
and Homoptera (especially aphids and leafhoppers), as well as weevils in the family Curculionidae. The funnel-web weavers (Agelenidae, Atypidae, Ctenizidae, and Eresidae) prey upon Orthoptera, Coleoptera and Lepidoptera (Riechert and Bishop, 1990; Nyffeler et al., 1994a). Hunting spiders (Lycosidae, Oxyopidae, Themisidae and Salticidae) frequently capture Orthoptera, Homoptera, Hemiptera, Lepidoptera, Thysanoptera, Diptera, Coleoptera and Hymenoptera (Riechert and Bishop, 1990; Young and Edwards, 1990; Nyffeler et al., 1994).

**Spiders can reduce and stabilize the pest densities**

For effectively and economically control an insect pest, a predator must be capable of not only reducing pest densities to levels below an economic threshold, but also to stabilize those pest densities overtime (Maloney et al., 2003). If the pest population is not stable, the predator may drive the prey to local extinction, and then die off itself, thus allowing for the potential of an unchecked secondary outbreak in the absence of this predator (Morin, 1999; Pedigo, 2001). Spiders may be capable of fulfilling both pest reduction and pest stabilization requirements. Spiders can lower insect densities, as well as stabilize population, by virtue of their top down effects, wasteful killing, prey specialization, functional responses, numerical responses, and obligate predatory feeding strategies.

Spiders can also exert significant top down effects, meaning that plant damage by insect herbivores is lower when spiders are present than when they are absent. Top down effects are evident even when spiders do not (or cannot) actually feed upon the insect herbivores (Maloney et al., 2003). Snyder and Wise (2000) found that spotted cucumber beetles, Diabrotica undecimpunctata howardi Barber, reduced their feeding upon squash plants in the presence of a wolf spider Hogna helluo (Walckenaer) even though the spider was separated from the beetles by a mesh barrier. Similarly, Rypstra (1995) found that the presence of either H. helluo or a theridiid, Achaearanea tepidartorum (Koch), resulted in less feeding upon soybean plants by Mexican bean beetles, Epilachna varivestis Mulsant and japanese beetles, Popillia japonica Newman, even if the spiders could not prey upon the beetles. Spiders are also important in the decline of Lepidoptera larvae in apple orchards, not only they feed on the larvae, but also because the larvae will disperse or otherwise abandon the apple branch when spiders are present (Marc et al., 1999). Similar results have been found in tobacco, where spiders of the family Linyphiidae prevented damage to plants by the
tobacco cutworm, Spodoptera litura (Fabricius). The cutworms abandon plants that were occupied by spiders. Spider-caused abandonment of plants is also known for greenbug, leaf fly, leafhoppers, and planthoppers (Riechert and Lockley, 1984).

Spiders can also control prey populations because they often capture and kill more prey than they consume (Maloney et al., 2003). Riechert and Lockley (1984) reported that a spider may kill as many as 50 times the number of prey it consumes. Persons (1999) found that wolf spiders, Schizocosa ocreata (Hentz) killed more crickets than they could feed upon, even when satiated. This wasteful killing has been documented in other lycosids as well (Riechert and Lockley, 1984; Persons, 1999). Some web-weaving spiders may also trap more insects than they are able to consume. The golden orb weaver, Nephila clavipes (Linnaeus) spins yellow silks, which serves as a super-stimulus, attracting herbivorous insects that would normally be attracted to flowers and new leaves (Craig et al., 1996). Orb-web weaving spiders (Araneidae, Uloboridae) such as the large orb-weaver Argiope, as well as Gastracantha, Salassinia, Micrathena and Uloborus, attract insects to their webs using ultra-violet reflecting designs (called stabilimenta) woven into the webs (Craig and Bernard, 1990; Craig et al., 1996). Up to 1000 insects may be present in a web at a given moment, and many are ignored by the spider (Nyffeler et al., 1994). It has been demonstrated through mathematical modeling that superfluous killing of prey augment the influence of spiders on insect prey populations (Riechert, 1999). A form of wasteful killing, intraguild predation or cannibalism, is when spiders prey upon each other. Little research has been conducted on this phenomenon, but it has been suggested that this type of wasteful killing may benefit insect prey populations (Hodge, 1999).

Numerous researchers have stressed that an assemblage of spider species is more effective at reducing prey densities than a single species of spider (Greenstone, 1999; Sunderland, 1999). Richert and Lawrence (1997) found that insect numbers were lower in test plots that contained a sheet-web weaver, Florinda coccinea (Hentz); an orb-web weaver, Argiope trifasciata (Forskal); and two wolf spiders, Rabidosa rabida (Walckenaer) and Pardosa milvina (Hentz) than in plots that contained only one of these species. Foraging behaviour may be enhanced by the presence of other spider taxa. In agricultural field in Ohio, the cob-web weaver, A. tepidariorum and orb-web weaver, Nuctenea comuta (Clerck) caught more prey per spider when in groups than when alone. Prey capture also was higher in mixed-species groups than in
single-species groups (Rypstra, 1997). However, competition between some spiders may limit their effectiveness at decreasing prey densities (Marshall and Rypstra, 1999).

A diverse group of spiders may be effective at biological control because they differ in hunting strategies, habitat preferences, and active periods (Maloney et al., 2003). Because of the typical diversity of spiders in an agricultural ecosystem, there will probably be one or more species that will attack a given pest (Marc et al., 1999). Different spiders feed on different insects at different times of the day, so a loss in community diversity of spiders can result in some prey species being released from predation pressure (Riechert and Lawrence, 1997). Variation in body size of both predator and prey species also contributes to prey reduction, with larger spiders taking larger prey and smaller spiders taking smaller prey (Nentwig and Wissel, 1986; Nyffeler et al., 1994).

Some degree of specialization or monography by a predator on prey is assumed to be necessary for the predator to reduce populations of that particular prey (Maloney et al., 2003). Because of this assumption, spiders, which are polyphagous, generalist predators, were traditionally thought incapable of controlling prey populations (Riechert and Lockley, 1984). However, spiders may be more specialized on particular prey than is often realized. It is common that when spiders have an excess of prey, they become more selective (Riechert and Harp, 1987). Toft (1999) points out that it might be counterproductive for a spider to feed on any prey since some might be toxic or deficient in nutrients. In addition, each species of spider occupies a specific region of agricultural habitat, from the ground to the top of the canopy. Different prey species can be found in different microhabitats as well. Thus it might be concluded that prey specialization by spiders could be an attribute found in ecosystems, rather than in the laboratory. The question is whether this is true. Temporal differences in prey-capture activities are found among spiders and may lead to specialization of diets. For example, some web-weavers are diurnal, spinning their webs during the day; others are nocturnal, spinning and capturing prey at night. Most hunting spiders that relay on visual and vibratory cues are diurnal, but there are exceptions, with some hunter’s activity chiefly at night. Spiders, therefore, will only catch prey they encounter during active period (Marc and Canard, 1997; Riechert and Lawrence, 1997; Marc et al., 1999). For example, in France, nocturnal and diurnal wandering spiders forage on the trunk and in the foliage of apple trees, while ambush species forage among the leaves and flowers. Tubular web species reside under the
bark of the trees, while other web weavers occupy different microhabitat between leaves and branches (Marc and Canard, 1997).

In addition to microhabitat preferences, spiders have feeding preferences. They usually only eat prey that is 50% to 80% of their size, with web weavers more adapt at catching larger prey; smaller prey are typically ignored (Netwig and Wissel, 1986; Nyffeler et al., 1994; Marc and Canard, 1997; Marc et al., 1999). Some species of spiders also select insect prey that balances their amino acid requirements (Greenstone, 1979). Although spiders are polyphagous predators, their hunting strategies and microhabitat preferences cause each species to be specialized (Nyffeler et al., 1994; Marc and Canard, 1997; Marc et al., 1999; Nyffeler, 1999). In general, hunting spiders have a greater diet breadth than web-weavers (Nyffeler, 1999). Some types of spiders may be adapted towards catching a particular type of prey. The bolas spiders and ladder web spiders (Araneidae) have webs that are specially adapted to catch adult Lepidoptera. Smaller web weavers, such as Linyphiidae and Dictynidae, capture mainly soft-bodied insects such as aphids. Some cobweb weavers (Theridiidae) specialize on ants, including fire ants. A number of species of jumpint spiders (Salticidae) are also behaviorally adapted to feeding on ants (Nyffeler et al., 1994; Jackson and Pollard, 1996). The water spiders (Argyronetidae) are highly specialized in that they forage underwater and feed on fly larvae, including mosquitoes (Nyffeler et al., 1994). Other spiders show remarkable prey preference, despite a wise availability of prey. The lynx spider Oxyopes salticus Hentz preferentially feeds on prey organisms in the 1 to 2.9 mm size class. This size class includes the cotton fleahopper, which was found to be the most important prey in the diet of this spider in Texas cotton fields (Nyffeler et al., 1992).

A desirable biological control agent is a predator hat not only reduces pest densities, but also stabilizes them at low levels, while maintaining stable populations itself (Pedigo, 2001). Stability in predator-prey systems is achieved by density-dependent responses of the predator to the prey. As prey populations increase, predation pressure should increase and predation pressure should lessen as prey population decrease (Maloney et al., 2003).

The functional response depends on feeding and hunting behavior and can be defined as the change in numbers of prey consumed per unit time by a single predator as prey density changes (Richert and Lockley, 1984). There are three commonly recognized types of functional response relationships that describe how consumption
rates vary with prey density Type I, type II and type III. In the type I response, prey intake is proportional to prey density until satiation. This response is typical of filter-feeding organisms and is not seen in spiders. In the type II response, predators increase prey consumption at a decreasing rate, usually because of a reduction in capture rate associated with handling time (time needed to capture, kill, and consume prey). This type of functional response fails to produce stable populations, as prey are either driven to extinction at low densities, or escape predation at high densities. Type II responses are common in spiders, as they may eat fewer insects when insects are abundant (Rypstra, 1995; Marc et al., 1999). The type III response is a sigmoidal response, beginning with a lag time followed by an increase in prey consumption at an increasing rate. Type III responses are a strong stabilizing mechanism and are associated with either prey switching or learning by the predator (Richert and Lockley, 1984; Morin, 1999). Although it was historically thought that only vertebrates exhibit type III functional responses, recent studies have show that many invertebrates, including spiders, show a sigmoidal response to prey densities (Richert and Lockley, 1984; Marc et al., 1999). Type III response relationships have been demonstrated for Cheiracanthium mildei Koch (Clubionidae) feeding on Spodoptera littoralis (Ptilidromidae) feeding on Drosophila, and Lycosidae in rice paddies (Marc et al., 1999).

Both type II and type III functional responses can lead to regulation of prey fluctuations if a strong numerical response is also present (Maloney et al., 2003). A numerical response can be defined as an increase in predator numbers after a rise in prey density. This response may be in the form of aggregation, increased reproduction, or both (Marc et al., 1999). Spiders exhibit both aggregative and reproductive responses to prey numbers (Riechert and Lockley, 1984; Marc et al., 1999). Predator recognition of patches of high prey density and the concentration of foraging activity in these areas can lead to stabilization, since predation pressure will be high where prey numbers are high and low where prey numbers are low. In the field, spiders do inhabit areas where prey are abundant and will migrate from patches of decreasing prey density to patches of higher prey density (Riechert and Lockley, 1984; Harwood et al., 2001). For example, the funnel-web weavers of the species Agelenopsis aperta (Gertsch) aggregate in areas where prey is abundant. The theridiid A. tepidarium will relocate its web if prey density is insufficient, leading to a
clustering of individuals in areas where prey are more numerous. Some crab spiders (Thomisidae) behave similarly in response to low prey densities (Marc et al., 1999).

The reproductive response of spiders is less studied. Some spiders, especially web-weavers, do show an increase in fecundity with increasing amounts of prey ingested. Such spiders include Neriene radiate (Walckenaer) (Liny phiidae), Mecynogea iemniscata (Walckenaer), Metepiera labyrinthea (Hentz) (Araneidae), and Ageienopsis aperta (Agelenidae) (Riechert and Lockley, 1984; Marc et al., 1999). The extent to which this increase in fecundity can permit tracking of prey populations is limited by long generation times compared to those of pest insect’s species. Spiders are usually univoltine while generation times for many insect pests are a few weeks (Riechert and Lockley, 1984; Provencher and Vickery, 1988).

How pesticides effects on spider population?

Many workers have studied on the effect of insecticides on natural enemies, especially on spiders, in the paddy field. Most of the results have shown that insecticides have a negative effect on the population densities of rice field spiders (Kuno 1968, Kuno and Hokyo 1970, Kawahara et al. 1971, Choi et al. 1978, Paik et al. 1979, Jang 1981, Ryu et al. 1984, Kim et al. 1984, Paik and Hwang 1990, Lee et al. 1993b, Bae et al. 1994). The relative toxicity to spiders of various insecticides was tested from time to time. Carbofuran, which is widely used in rice fields, is very toxic to spiders (Bae et al. 1994). It was found that the root zone placement of Carbofuran reduces the density of spiders in rice fields by direct lethal action, and by poisoning their food chain (Choi et al., 1996).

Several studies have shown that the application of insecticides reduces the population density of spiders in rice fields (Park et al. 1972, Kawahara et al. 1971, Paik et al. 1979, Kim 1992, Yoon 1997). They have a negative effect, not only on numbers, but also on species diversity (Lee et al. 1993a, 1993b). Even insecticides which generally protect natural enemies often have a negative effect on spiders (Clausen 1990). Hunting species tend to suffer more damage than web builders (Specht and Dondale 1960, Legner and Oatman 1964, Bostanian et al. 1984), while active hunters suffer more than less active ones (Bostanian et al. 1984).

In general, spiders are more sensitive than many pests to some pesticides, such as the synthetic pyrethroids, cypermethrin and delfamethrin; the organophosphates, dimethoate and malathion and the carbamate, carbaryl. As a result of that the spiders
populations are decreasing that may lead to an outbreak of pest populations (Brown et al., 1983; Birnie et al., 1998; Hull-Veistola, 1998; Yardin and Edwards, 1998; Marc et al., 1999; Holland et al., 2000; Tanaka et al., 2000).

Many farmers use chemical pesticides to control pests. An ideal biological control agent, therefore, would be one that is tolerant to synthetic insecticides. Although spiders may be more sensitive to insecticides than insects due in part to their relatively long life spans, some spiders show tolerance, perhaps even resistance, to some pesticides. Chiu (1979) suggested that it takes longer for spiders to rebuild their population densities after the application of insecticides than plant hoppers and leafhoppers, because spiders have a longer generation interval. Spiders are less affected by fungicides and herbicides than by insecticides (Yardin and Edwards, 1998). Spiders such as the wolf spider P. pseudoannuiata are highly tolerant of botanical insecticides such as Neem-based chemicals (Theiling and Croft, 1988; Markandeya and Divakar, 1999). They are also generally more tolerant or organophosphates and carbamates than of pyrethroids, organochlorines, and various acaricides, although this tolerance may be due to genetic resistance bred over a period of continuous exposure (Theiling and Croft, 1988; Wisniewska and Prokopy, 1997; Yardin and Edwards, 1998; Marc et al., 1999; Tanaka et al., 2000). For example, P. pseudoannuiata (Lycosidae), Tetragnatha maxillosa Thorell (Tetragnathidae), Ummeliata insecticeps (Bosenberg et Strand) and Gnaathonarium exsiccatum (Wider) (Linyphiidae) were highly sensitive to the pyrethroid deltamethrin, but very tolerant of the organophosphate diazinon and the carbamate carbaryl (Tanaka et al., 2000). Some broad-spectrum organophosphates are highly toxic to spiders. For example, dimethoate sprays resulted in 100% mortality to the Lycosid, Trochosa ruricola (De Geer) at concentrations below recommended field application rates (Birnii et al., 1998). The organophosphate methyl parathion and the pyrethroid cypermethrin are highly toxic to spiders in the genus Erigone (Linyphiidae), while the carbamate pirimicarb is almost harmless (Brown et al., 1983; Hull-Veistola, 1998). Toft and Jensen (1989) found that sublethal doses of dimethoate and cypermethrin had no effect on development and predation rates of the wolf spider Pardosa amentatata (Clerck). In fact, with very low doses of cypermethrin, killing rates of the adult and penultimate females increased. However, the insecticides did have knockdown effects that, although not influencing survival in the laboratory, would likely result in death in the field due to desiccation or predation (Toft and Jensen, 1998).
Other factors that influence effects of pesticides on spiders are type of solvent, soil type, moisture, per cent organic matter, temperature, and time of day of spraying. Further, the microhabitat, hunting style, prey preference, and behavior of the spider also influence their response to pesticide application (Marc et al., 1999). Wisniewska and Prokopy (1997) reported that if pesticides were only used early in the growing season, spider populations increased. Presumably, spiders have a chance to recolonize the field if pesticide use ceases after early June. Spatial limitation of pesticides (such as only applying the pesticides to certain plants or certain plots) also results in higher spider numbers, since they can move out of the treated areas and return when the chemicals dissipate (Riechert and Lockley, 1984; Balanca and de Visscher, 1997).

**Spider richness in different Agro-ecosystem:**

All the organisms in a rice field, as in other kinds of ecosystem, are involved in interactions within and between species, including prey-predator and host-parasite relationships (Hijii 1984). In particular, the interaction of prey and predator show a constant numerical interaction. Information about these relationships is fundamental to biological control. Yamano (1977) suggested that spiders are the most important biological control agents regulating insect populations in rice fields, including insect pests. Predators tend to cluster in stable sites where many species of prey are maintained at a high density (Schmitt 1987).
### A. Spider fauna prevalent in rice ecosystem:

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Common name</th>
<th>Scientific name</th>
<th>Habitat</th>
<th>Prey consumed</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Family: Lycosidae</td>
<td>Wolf spider Lycosa pseudoannulata</td>
<td>Lower part of leaves, stem and water surface</td>
<td>BPH, WBPH, Leaf folder, Rove beetle etc.</td>
<td>Khan and Mishra (2003); Bhuyan and Basit (1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pardosa birmanica</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Arctosa himalayensis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Family: Salticidae</td>
<td>Jumping spider Phidippus pateli</td>
<td>Whole plant</td>
<td>BPH, WBPH, GLH</td>
<td>Khan and Mishra (2003); Bhuyan and Basit (1996)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Salticus sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zygoballus pashaneensis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O. pandae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O. ratnae</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>O. shweta</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>T. javana</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Tetragnatha sp.</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
B. Insect prey captured by *Peucetia audax* (Oxyopidae) under cotton ecosystem

<table>
<thead>
<tr>
<th>Taxonomy of prey</th>
<th>Common name</th>
<th>Stage attacked</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Homoptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aleyrodidae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bemisia tabaci (Gennadius)</td>
<td>Whiteflies</td>
<td>Adults</td>
</tr>
<tr>
<td>Membracidae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spissisticus testinus (Say)</td>
<td>Three cornered alfalfa hopper</td>
<td>Adults, nymphs</td>
</tr>
<tr>
<td><strong>Cicadellidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acinopterus sp.</td>
<td>Leafhoppers</td>
<td>Immature, adults</td>
</tr>
<tr>
<td>Draeculacephala spp.</td>
<td>Potato leafhopper</td>
<td>Immature, adults</td>
</tr>
<tr>
<td>Empoasca fabae (Harris)</td>
<td>Damsel bugs</td>
<td>Immature, adults</td>
</tr>
<tr>
<td><strong>Thysanoptera</strong></td>
<td>Thrips (Unknown sp.)</td>
<td>Adults</td>
</tr>
<tr>
<td><strong>Orthoptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acrididae</td>
<td>Short-homed grass hoppers</td>
<td>Immature</td>
</tr>
<tr>
<td>Oecanthus spp.</td>
<td>Green tree cricket</td>
<td>Adults</td>
</tr>
<tr>
<td>Stagmomantis carolina (Johannsen)</td>
<td>Carolina mantid</td>
<td>Immature</td>
</tr>
<tr>
<td><strong>Colleoptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabrotica undecimpunctata hawardi Barber</td>
<td>Spotted cucumber beetle</td>
<td>Adults</td>
</tr>
<tr>
<td><strong>Lepidoptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noctuidae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plathypena scabra (Fab.)</td>
<td>Green clover worms</td>
<td>Immature</td>
</tr>
<tr>
<td><strong>Hemiptera</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudatomecelis seriatus (Reukr.)</td>
<td>Cotton flea hopper</td>
<td>Immature, adults</td>
</tr>
<tr>
<td>Geocoris punctipes (Say)</td>
<td>Big eyed bugs</td>
<td>Immature, adults</td>
</tr>
</tbody>
</table>

Source: Roach (1987)
C. Spiders associated with wheat and mesta:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Family</th>
<th>Species</th>
<th>Prey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Linyphiidae</td>
<td>Erigone atra</td>
<td>Insect pests under Collembola, Diptera, Hymenoptera, Coleopter, Aphididae etc.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E. dentipalpis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Milleriana inernam</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oedothorax sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lephyphant tenuis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bathypantes gracilis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meineta ruestris</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Porrhomma errans</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Micrargus subaequallis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pachygnatha dageeri</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ergonoinae juveniles</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linyphiidae juveniles</td>
<td></td>
</tr>
<tr>
<td>Mesta</td>
<td>Thomisidae</td>
<td>Thomisus katrajghatus</td>
<td>Amarasca biguttela biguttela and other insects.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thomisus sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oxyopidae</td>
<td>Oxyopes sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>O. javanus</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Peucetia viridana</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salticidae</td>
<td>Plexippus paykulli</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clubioniidae</td>
<td>Chiracanthium melanostoma</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Araneidae</td>
<td>Neoscona sp.</td>
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</tr>
</tbody>
</table>

Conservation and enhancement of spider assemblages

To conserve and enhance spider populations, agricultural systems should be manipulated in ways beneficial to the needs of the spiders. The structural complexity of the environment is directly related to spider density and diversity. Highly varied habitats provide a greater array of microhabitats, microclimatic features, alternative food sources, retreat sites, and web attachment sites, all of which encourage colonization and establishment of spiders (Riechert and Lockley, 1984; Agnew and Smith, 1989; Young and Edwards, 1990; Rypstra et al., 1999). Some of the conservation and enhancement measures are:

- Adding mulch to vegetable gardens. It provides protection and humidity.
- Provide places for web attachment or homes: crates, tall plants, bundles of hay.
- Leave areas untilled or leave plant stalks for overwintering habitats.
- Grow flowers that bring in prey.
- If spraying pesticides, spray at the times the spider are less active or use a pesticide that has fewer effects on the spiders.
• In apple orchard: increasing foliage and plant complexing leads to increase in hunting spiders.
• Crop diversification: Leads to availability of alternative prey.

CONCLUSION

In summary, spiders can be effective predators of herbivorous insect pests, and can exert considerable top-down control, often catching more insects than they actually consume. Despite the potential for competition and intraguild predation, a diverse assemblage of spiders may have the greatest potential for keeping pest densities at low levels. Spiders may be potential biocontrol agents because they are relatively long lived and are resistant to starvation and desiccation. Additionally, spiders become active as soon as conditions are favourable and are among the first predators able to limit pests. The risks associated with using spiders to control pests are minimal. Since diverse species of spiders are naturally present in an agricultural system (thus avoiding the problems associated with introductions) and predaceous at all stages of their development, they fill many niches, attacking many pest species at one time (Agnew and Smith, 1989; Marc et al., 1999).

Fagan et al. (1998) indicated that treatments which combine the augmentation of natural enemies with insecticide applications may be counterproductive. However, spiders still play an important role in reducing the numbers of insect pests in agricultural fields, even when insecticides are used. In fact, spiders may be responsible for a significant proportion of insect deaths which were thought to be from insecticide applications. 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.

REFERENCES


