14 Spiders as Potential Ecofriendly Predators Against Pests

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Abstract

Biological control has come a long way towards adapting to the changing needs of agricultural pest suppression. Current trends in agriculture towards reduced pesticide use and ecological sustainability have led to surge of interest in spiders as potential biological control agents. This is because spiders have the capacity to exist in various conditions, with wide-ranging food webs, and are able to exploit the various stages of their prey life cycles. These habit diversifications portray them as efficient predators; the web weavers skewed towards phytophagous pests mainly from Diptera and Hymenoptera, whereas the non-web weavers foraged for foliage-dwelling pests such as Coleoptera and Homoptera. Since different spider species play different predating roles for a specific pest in its life cycle, it may be reliable to sustain the diversity of spider species within the specific area. This will be further discussed in this chapter together with our current results obtained from the botanical garden, dragon fruit, and herbal garden plantations which are suggesting some potential bio-control agents for agricultural ecosystems belonging to the family groups of Araneidae, Lycosidae, Oxyopidae, Tetragnathidae, Thomisidae, and Salticidae. We further discussed the correlation of spider existence with the crop vegetation structures and architectural features.

Keywords

Spiders • Biocontrol • Behavior • Diversity • Agricultural ecosystems

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14.1 Why Biocontrol Alternatives?

The use of natural enemies to control pests originated as early as 324 BC in China where the citrus growers used the fire ants, *Oecophylla smaragdina*, to control the populations of large boring beetles. The farmers used bamboo runways between trees to encourage movements

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and migrations of the ant colonies within the orchard. The ant colonies were both harvested from the wild and moved into the orchards or even in those days could be purchased. Currently, biocontrol has moved far from the days of utilizing the fire ants in the orchards.

In more recent years, biological control is considered to be as a good alternative to chemical pest control for reasons summarized as below: the high costs of pesticide expenditures in pest management, fewer options of synthetic chemical pesticides due to the banning of some compounds and the pesticide treadmill that is associated with the development of pest resistance towards the synthetic chemical pesticides, the possible target pest resurgence and outbreaks of secondary pests, and human health hazards and serious environmental concerns.

Strategies for using biocontrol can be grouped into three major categories:

First is the *classical biocontrol* or the importation method also known as the "enemy release hypothesis" – this type is known for its environment friendliness, and here, the natural enemies are deliberately introduced into a new environment so that it will become established and will regulate the pest population in a natural cycle without further intervention (Van Driesche et al. 2010). The biocontrol agents were identified from the native areas of the pests' home ranges (Shanker et al. 2012). This method is inexpensive and can be long lasting (Cullen et al. 2008). It is well suited to permanent ecosystems, such as forests, natural areas, orchards, and perennial crops. Arthropod pests that are not hidden and are less mobile have been more successfully controlled because natural enemies have easier access to them (Hill and Abang 2005). Second, the augmentation biocontrol is further divided into two types – in general, augmentation means the supplemental release of biocontrol agents boosting the naturally occurring population to control the pest over an extended period. When relatively few natural enemies are released at a critical period in a season, this is known as the inoculative release. Thus, the natural enemies will be established in the habitat and subsequently increased their population within the area (Chanthy et al 2010). This provides a more long-term and self-sustained control than the other method which is inundative release. The inundative biocontrol is when very high quantities of natural enemies are released. This is a short-term strategy directed towards rapid control of pests over a short period of time. This protocol can again be repeated if the pest populations resurged over time. Third, the conservation biocontrol differs from the entire above where the natural enemies are not released but instead the resident populations of identified predator species are conserved or enhanced. Thus the biocontrol agents are already adapted to the area as well as to target pests, making conservation of the existing population simple and effective. The basic requirements for this strategy would be that the biology, behavior, and ecology of the pests and natural enemies must be understood to ensure success and viable resulting outcomes.

In agricultural pest management the main focus should be for the conservation and enhancement of the diversity of the beneficial organisms in which pest suppression could be achieved. Biocontrol is a pest management system provided by nature to sustain existing populations in a habitat to be in equilibrium; thus, applied biocontrol has been applying the fundamental principles of nature. Shanker et al. (2012) postulated that a sustainable agriculture is known to be successful when it has ultimately given rise to reduced inputs, high biodiversity index, reduced pest problems, and ultimately economically viable yields.

14.2 Spider Diversity in Agriculture Ecosystem

Spiders are one of the major groups in the class Arthropoda, to date, consisting of 40,024 species (Platnick 2012). This group has a widespread distribution and commonly exists in agricultural areas which have spurred many interests to research on their potential as pest control. The risks associated with using spiders to control pests are minimal but instead with far greater advantages as biocontrol agents for having the following characteristics: spiders exist in high abundance but do not cause damages to vegetation or crops; they coexist naturally as diverse species in an agricultural system; they have a high diet variety preying on, for example, mites, aphids, thrips, and termites which are common pests of agroecosystems; they display different foraging modes and hunting tactics in prey capture due to differences in feeding behavior, either weaving webs for prey trapping, ambush, and chase or hunting for targeted preys; spiders have a long life cycle which varies from 9 months to 25 years and moreover are predaceous throughout their developmental stages, and not only adults but all also instars feed actively as predators; thus various stages of pests are preyed upon by a variety of spider species as, for example, minute prey items like thrips and mites are important food sources for the young spiderlings (Dippenaar-Schoeman 2006); they are able to occupy many microhabitats and niches within an ecosystem and most of them are polyphagous (can feed on a variety of prey items) predators, thus having a wide range of prey selection which are the available pests found in the agricultural areas (Wise 1993; Marc and Canard 1997). Moreover, spiders are purposed to be able to withstand treatments of broad-spectrum insecticide applications if utilized within the area, whereas all other beneficial enemies were impacted by the insecticidal treatments (Hoque et al. 2002). This makes them resistant beneficial species in which the populations are able to flourish successfully where needed. Biological control method is one of the strategies implemented in the Integrated Pest Management (IPM) to create sustainable agricultural areas. IPM prefers to use organisms or natural enemies to suppress pest populations rather than using pesticide which are known to be harmful to the environment and affect human health.

Spiders are one of the known successful groups of natural predators occupying the agriculture ecosystems, and as efficient predators they were able to suppress populations of major insect pests, at the same time significantly decreased crop damage while increased harvest of crop yields. Globally, they have been successfully adopted as biocontrol agents primarily in orchards and paddy fields. However, different strategies were adopted for the pest management in both agricultural scenarios. The orchard agroecosystems in Europe utilized the spider conservation approaches, while Asian countries reputed for their paddy fields implemented the augmentation method (Marc and Canard 1997).

The spider species composition varied with the different types of agriculture ecosystems, mainly because of the variable environmental conditions and different strata of the plant species communities or zonations in tree species, providing specific niches for different spider species to thrive (Norma-Rashid et al. 2009). This was supported by Noraina (1999) who revealed that spider assemblages divided themselves according to the plant stratifications to avoid competition and also foraged in different plant species in order to exploit the extensive available prey items. Sudhikumar et al. (2005) in their work reported the close relatedness of the plant species with the prey populations that depended on the plant hosts and the predators that exploit the prey species.

Various authors had investigated the beneficial roles of spiders in agricultural situations. The wolf spiders (Lycosidae) and jumping spiders (Salticidae) had been characterized as the two predominant biological control agents in paddy fields (Kiritani and Kakiya 1975; Tahir and Butt 2008). Motobayashi et al. (2007) proceeded to study the effects of spiders on the migrant skipper, *Parnara guttata guttata* (Lepidoptera), which is one of the major paddy field pests in Japan. They conducted the spider removal experiments in the paddy fields lending support to spider predation being the main cause of mortality in the migrant skippers; the late stage larvae were more susceptible to spider predation due to their foraging behavior on rice leaves above soil and nest construction behavior confined to the upper layer of rice crops where spider predators were mostly found. Tahir and Butt (2009, 2008) demonstrated the predatory potential of Lycosidae and Oxyopidae predating on larvae of stem borers, leaf folders, plant hoppers, and grasshoppers in the rice ecosystems. Their work conducted in the rice fields in Punjab, Pakistan, revealed interesting behavioral partitioning between the two active lycosid predators, whereby *Lycosa terrestris* actively pursued preys found on the foliage, while *Pardosa birmanica* restricted their foraging behavior to the ground levels. The combined predatory roles of these two lycosids resulted in efficient pest control in rice fields (Tahir and Butt 2008). Although spiders are known to exist in a variety of species within a habitat structure (Norma-Rashid et al. 2009) with likely potential for competition and intraguild predation, it had been stressed by Nyffeler and Sunderland (2003) that a diverse sympatric living spider species would be more effective at reducing prey densities than a mono spider species. Riechert and Lawrence (1997) in their work on predation effects of spiders concluded that a diverse natural enemy fauna resulted in a more effective regulation of prey populations, where their results revealed for test plots that contained four spider species comprised of sheet-web weaver (*Florinda coccinea*), orb-web weaver (*Argiope trifasciata*), and two wolf spiders (*Rabidosa rabida* and *Pardosa milvina*) had lower prey densities in contrast to plots that contained only one of the listed species. Marc et al. (1999) concluded that diverse assemblages of spiders would be effective in pest control because species variability in habitat choices, activity rhythms, and foraging behavior would probably result in a specific or a number of species that will target a given pest.

Marc and Canard (1997) found that the high abundance of spider communities were beneficial and effective in removing herbivorous insects in apple orchards which included the beetle *Anthonomus pomorum* and Lepidoptera larvae in the family Tortricidae. More interestingly was the behavioral change of these lepidopteran larvae where they displayed avoidance behavior towards the spider by abandoning the apple tree branches when spiders were present (Marc et al. 1999). The spider avoidance behavior was also exhibited by tobacco cutworms, *Spodoptera litura*, towards spiders from the family Linyphiidae which prevented extensive damage to the tobacco plants (Riechert and Lockley 1984).

In order to augment spider populations in agricultural systems, the available structural complexity should be enhanced or manipulated in ways to benefit the spiders. Provision of refugia would be extremely important for the purpose of early colonization and conservation of potential targeted predators. Riechert and Lockley (1984) construed that high structural complexity of the agrosystem would be directly correlated to greater array of microhabitats with varied microclimatic features, alternative resources such as food, and nesting and retreat sites for elevated spider density and diversity. Costello and Daane (2003) found that ground cover affected the population density of spiders and leafhopper in the vineyard. Riechert and Bishop (1990) experimented on the habitat manipulation by adding mulch and flowers in the mixed vegetable plots to increase spider abundance which were successful in removing pests and decrease crop damage; furthermore, through direct observations they confirmed that 84 % of the predators that were foraging were spiders and 98 % of the prey captures were by spiders. Rice growers in China build straw or bamboo shelters to encourage web construction or spider retreat which could be transported to areas of pest outbreaks occurrence (Marc et al. 1999). Similarly, studies by Tanwar et al. (2011) had shown that placement of straw bundles in the sorghum fields to attract or trap spiders there and later transferred to the rice fields had the effect of great reduction in the pest population of common rice pests that were stem borers and leaf folders. Predator refugia could be in various forms, the common ground cover, straw bundles, or mulch, interspacing with intercrops, cover crops, field margins, bunds, and many other forms (Shanker et al. 2012; Luck et al. 2003).

Generally, the orb-web weavers predominate (could achieved to a maximum of 95 % of the spider population in an area) the agriculture ecosystem (Hogg and Daane 2011). Our previous work revealed that the common orb-web weavers were representatives from the family groups Tetragnathidae and Araneidae. Tetragnathidae

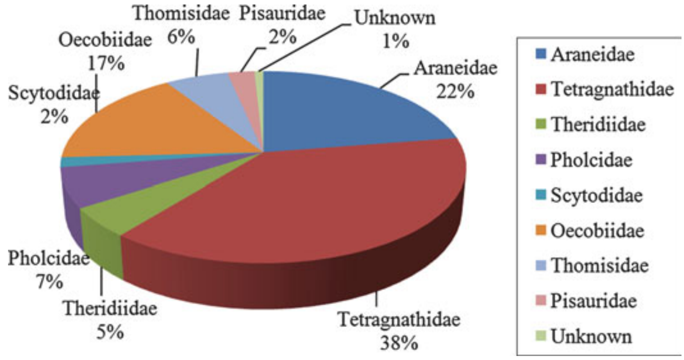

Fig. 14.1 Relative abundance of the spider families in Rimba Ilmu Botanical Garden (Noraina 1999)

Table 14.1 Spider species in Rimba Ilmu Botanical Garden (Noraina 1999)

Families	Species
Araneidae	*Arachnura* sp.
	Araneus mitificus
	Argiope aemula
	Argiope versicolor
	Cyclosa bifida
	Gasteracantha hasselti
	Nephila maculata
	Parawixia dehaani
	Poltys illepidus
Tetragnathidae	*Leucauge argentina*
	Leucauge fastigata
	Tetragnatha josephi
	Tylorida striata
	Tylorida ventralis
Theridiidae	*Achaearanea mundulum*
	Argyrodes argentatus
Pholcidae	*Smeringopus pallidus*
Scytodidae	*Scytodes pallida*
Oecobiidae	*Oecobius*
Thomisidae	Unknown
Pisauridae	Unknown
Unknown	Unknown

dominated the Rimba Ilmu Botanical Garden (Fig. 14.1 and Table 14.1) in which was similarly reported by Okuma (1968) who studied spiders in the rice filed. However our sampling in the dragon fruit plantation resulted in highest representative of Araneidae (Fig. 14.2 and Table 14.2). It seemed likely that the orb-web weavers had higher tendency to act as natural biological control agents in capturing the available prey items that included pests. This predominant group of Araneidae was also highly sampled during our spider trappings on an island in Peninsular Malaysia, which is called Carey Island, densely vegetated with palm oil trees, either young or matured palm trees, harvested for their fruits (Wan Azizi 2008). The results from the Carey Island revealed 40 species of Araneidae with 66 % of individual spiders captured within the areas sampled (Table 14.3). Interestingly when planted plots of young and matured palm trees were contrasted, the young plots revealed higher diversity indexes for Shannon-Wiener, H′ max, Pielou, and Margalef (Table 14.4). Could this be postulated to be an indication of higher available food resources or prey organisms for the spiders? This is a query needing more investigations in order to obtain possible answers.

Noraina (1999) reported that web weavers constructed webs of considerable sizes that were located within certain heights and found to be strategically placed to avoid strong winds and potential predators (mostly birds). This finding was further supported by Wan Azizi (2008) who found that the range of stratification between 120 and 140 m was where the webs are typically found in the palm oil estates. The structures of the webs that were further analyzed portrayed four types from complicated to simple patterns: three-dimensional, two-dimensional, rolled leaf, and simple threads evidential of web presence. Figure 14.3 illustrates contrasting differences between matured and young palm tree plots where the three-dimensional structures were higher in matured tree plot due to easy anchorage

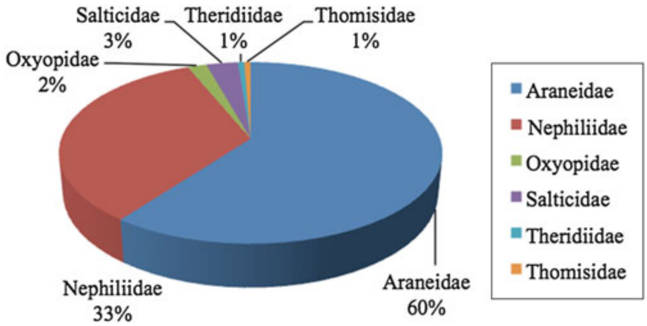

Fig. 14.2 Relative abundance of the spider families in dragon fruit plantation (Dzulhelmi and Norma-Rashid 2014)

Table 14.2 Spider species in dragon fruit plantation (Dzulhelmi and Norma-Rashid 2014)

Family	Species
Araneidae	*Acusilas coccineus*
	Araneus anapastus
	Araneus sp.1
	Araneus sp.2
	Araneus sp.3
	Cyclosa nigra
	Cyrtophora sp.
	Neoscona theisi
	Neoscona sp.1
	Neoscona sp.2
	Neoscona sp.3
	Parawixia dehaani
	Pronous tetraspinulus
	Zygiella laglaizei
	Zygiella medeleii
	Zygiella sp.2
	Zygiella sp.3
	Zygiella sp.4
	Araneidae sp.
Nephilidae	*Nephila* sp.1
	Nephila sp.2
Oxyopidae	*Oxyopes sikkimensis*
Salticidae	*Chrysilla lauta*
	Chrysilla versicolor
	Chrysilla sp.
	Myrmarachne sp.
	Phintella ephippigera
Theridiidae	*Theridiidae* sp.
Thomisidae	*Camaricus* sp.

Table 14.3 List of spider species belonging to the family Araneidae that were sampled in Carey Island, Peninsular Malaysia (Wan Azizi 2008)

Species listings	Species listings
Acusilas coccineus	*Cyclosa bifida*
Anepsion depressum	*Cyclosa centrodes*
Arachnura sp.	*Cyclosa insulana*
Araneidae TH	*Cyclosa* sp.
Araneidae TH 2	*Cyrtophora* A
Araneidae z	*Cyrtophora cicatrosa*
Araneidae?	*Cyrtophora hainanensis*
Araneus 1	*Cyrtophora moluccensis*
Araneus B	*Gasteracantha mammosa*
Araneus IM	*Gasteracantha kuhli*
Araneus sp?	*Mangora hemicraera*
Araneus anapastus	*Nephilengys malabarensis*
Araneus ancurus	*Paraplectana*
Araneus elongates	*Prasonica*
Araneus papulatus	*Pronous* sp.
Argiope aemula	*Singa* sp.
Argiope sp.	*Thelacantha brevispina*
Argiope versicolor	*Zygiella calyptrata*

of the webs with available spread branching of the leaf-frons and the rolled leaf web structures were frequently found in the young tree plots where these areas were exposed to high penetrating sun rays void of tree canopy shades. It seemed apparent here that even specific predator species that could be recommended for certain agriculture types but still need to be paired with the developmental features of the crops to maximize the efficiency of biocontrol agents.

The presence of wandering spiders seemed to be lower in abundance in contrast to the web weavers (Noraina 1999), but this is not common in all situations. Dippenaar-Schoeman (2006) in her extensive work in the agroecosystems in Africa reported high incidence of wandering spiders as beneficial predators, some of which

Table 14.4 Diversity indexes calculated for Shannon-Wiener, H′ max, Pielou J index, and Margalef D index contrasting between matured and young palm tree plots (Wan Azizi 2008)

Diversity index	Matured trees plot	Young trees plot
Shannon-Wiener, H′	2.432	2.797
H′ max	2.890	3.219
Pielou's index, $J = H'/H'$ max	0.841	0.869
Margalef's index, D	4.640	6.200

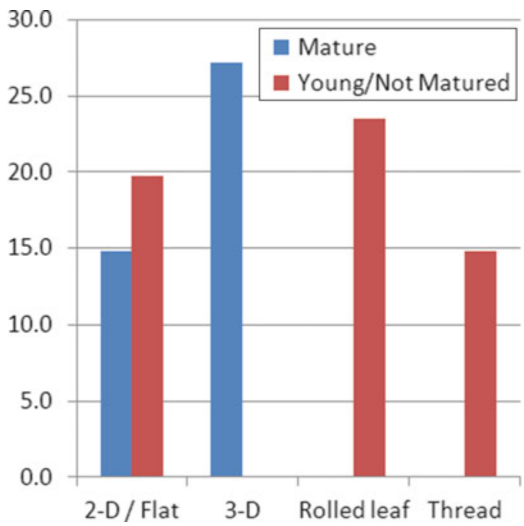

Fig. 14.3 The number of web structure types divided into two-dimensional or flat, three-dimensional, rolled leaf, and simple web threads found in the matured and young palm tree plots (Wan Azizi 2008)

were the wolf spiders *Pardosa crassipalpis* that prey on red spider mites in strawberry hedges; jumping spiders (Salticidae) represented 73 % and preyed upon pests like thrips, mites, midges, and flies in macadamia orchards, whereas for the avocado orchards, the main predators for pest species such as aphids, red spider mites, and thrips were salticids that comprised of 31 % followed by crab spiders (Thomisidae) being the second highest group (24 %). It could probably be because the non-web weavers were sensitive to disturbances within the environment and had the capability to escape and hide in crevices or between leaves which resulted in failure to detect their presence and indirectly underestimate their counts in field samplings (Dzulhelmi and Norma-Rashid 2014). However, it is also possible that non-web weavers were low in abundance because of their cannibalistic habits (Nyffeler 1999). This being apparent during encounters when the bigger-sized individuals would overpower and eat the inferior victims (Jackson 1992). Their diet preference tendencies were selective rather than random choice contributed to their presence within specialized ecosystems (Maimusa et al. 2012).

In many instances spiders portrayed to be prey specialists, favoring prey of specific taxa, age (selection for certain stage prey instar), and size, and displayed behavioral specializations leading to effective elimination of specific pest populations. According to Marc and Canard (1997) the size class prey selection by spider predators was distinctly confined to consumption of prey items that were 50–80 % of their body sizes and ignoring others. Nyffeler (1999) found that web weavers were skewed at catching profitable larger prey and neglecting the smaller ones. Generally wandering spiders showed greater diet breadth than web weavers (Nyffeler 1999). Noraina (1999) found that wandering spiders foraged mainly on lower strata and prey items belonged to the groups of Coleoptera and Homoptera. She also collected and identified the web catches in her study area in the botanical garden, comprised of mixed vegetation with fruit orchard, herbal crops, citrus shrubs, ornamental plants, and rubber trees. The prey included a diverse assortment of arthropods but seemed biased towards flies (Diptera); the majority were fruit flies and Hymenoptera, while other family groups of prey items were in minor proportions (Fig. 14.4).

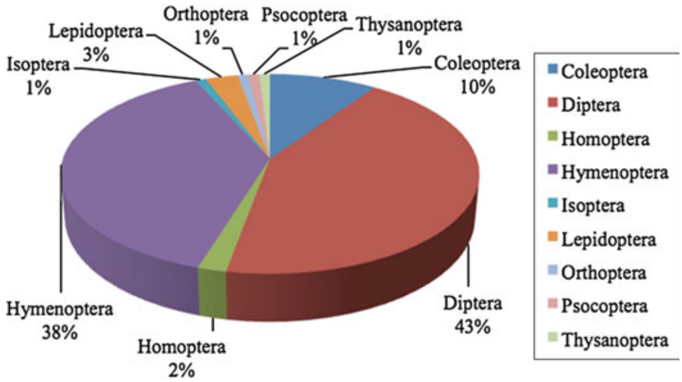

Fig. 14.4 Prey captured by the web-weaver species at Rimba Ilmu Botanical Garden (Noraina 1999)

14.3 Spiders in Herbal Plots

Studies on spiders in herbal-based agricultural areas need a special mention, as it is important to recognize the need to use natural enemies to control pests in herbal farming (Wood 2002). This was perceived to be very important as herb-based products are utilized as health supplements, which should be void of chemical contamination due to synthetic pesticides. Research on herbal plots had been conducted to investigate the potential of spiders as biocontrol in which two types of herbal plots were selected: *Orthosiphon stamineus* commonly known as the cat's whiskers plant belonging to the family Lamiaceae and the mistletoe fig or *Ficus deltoidea* (family Moraceae). These study areas had different vegetation structures: one being bushy branching (*Orthosiphon stamineus*) and the other of simple stem structure and few branches with broad leaves (*Ficus deltoidea*). The spiders collected in both areas showed different domination (Table 14.3) due to the different architectural features of the crops, as well as related to the foraging behaviors of the spider predators on the prey. The *Orthosiphon stamineus* crop, which were covered by foliage, encouraged ambush-typed spiders (Oxyopidae) and small Araneidae to thrive well in such vegetation. Oxyopidae, known to be able to hunt with great agility, equipped with legs of large bristles to capture the insect pests, were found to exploit the bushy area which had the advantage for them to hide and ambush their victims at a close distance, sometimes using a unique foraging strategy to capture the prey in midair by hanging underneath the leaves. Oxyopidae comprised of 45.6 % of the spider population at the foliage level in this herbal crop.

Ficus deltoidea an herbal crop which has broad leaves with few branches attracted Salticidae (26.1 %), Araneidae (23.6 %), and Tetragnathidae (22.9 %). The two conditions that influenced the presence of these family groups were as follows: (1) the broad leaves provided a large surface area which were suitable for the Salticidae that utilized the jumping strategy to forage for the prey and (2) the few number of branches available made it possible for the orb weavers to anchor their silk threads to build large and wider webs which were more efficient in trapping flying prey items. The orb-web spiders made up 46.5 % of spider population collected at the foliage level in *Orthosiphon stamineus*. Two dominant species collected in *Ficus deltoidea* plots were *Tylorida ventralis* and *Cyclosa bifida*. Others include Araneidae (21.5 %) and Salticidae (19.6 %).

Wise (1993) reported that the population of spiders was influenced by the architecture features of habitat and changes of the surrounding environment. Vegetation structures would affect the distance to anchor the silk threads for orb-web spiders. The variety of vegetation structures would also affect the microclimate in the agricultural area impacting on the spider populations in a particular habitat (Turnbull 1973). Whittaker (1975) stated the heterogenous habitat would increase the abundance of natural enemies including spiders.

14.4 Summary

In summary, spiders, by virtue of their top-down effects, were able to decrease and stabilize pest populations, and conclusively it was revealed that plant damage due to insect herbivores was lowered with the presence of spiders than when they were absent. Gone are the days when spiders were thought to be an insignificant component of agroecosystems (Riechert and Bishop 1990). Literature search would reveal many other biological control agent success stories that were utilized for pesticide alternatives and were able to suppress pest populations. Such results on the use of biological control in decreasing pest damage should more importantly be able to increase crop yield as well as quality and, in the long run, improve the economic status for agriculturists that would reflect the ultimate success. Ideal overall biocontrol strategies for IPM are still scarce, and there are urgent needs for more groundwork research (Jonsson et al. 2008).

Farmers are getting disappointed with the high cost for health and environmental concerns in keeping up with the pesticides treadmill (Altieri et al. 1997). Initiatives had been taken in a number of approaches including support from governments and NGOs, community organizations, and farmer-to-farmer networks to encourage farmers to utilize biological applications (Altieri et al. 1997) for the betterment of all concerned. However, biological control application requires in-depth knowledge on the natural enemies and their communities of which they came from (Jonsson et al. 2008). Most of the time, biological control only seeks to "balance" in controlling specific pests in a specific agriculture (Altieri et al. 1997). Some biological control practices had resulted in unpredictable and irreversible impact that may cause negative perceptions by farmers. But one must also consider the cost, benefit, and risk value that are involved to test for biological control efficiency in comparison to economic loss of plants to pests (Simberloff and Stiling 1996). The performance inconsistency in different environmental practices from biotic to abiotic factors does not blend well in this situation. Meanwhile, mass rearing and import-export from countries had been practiced in previous years to ensure stock supply for specific biological control agents.

14.5 Future Challenges

The greatest challenge of all is to enhance local interests to conduct initial groundwork research and providing information for the baseline to biological control practice for farmers. It is obvious from the current scenario that most literature and research in biological control and pest management were mainly obtained from industrialized countries. Thus it is timely for local researchers to embark on this challenge that will be of beneficial contribution to the homeland. It is crucial to stress that scientific research alone cannot guarantee the adoption of biocontrol since what would enable transition to implementation of biocontrol would be economic incentives to reward farmers for undertaking the challenge of adoption.

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