ARACHNIDA

Rivista Aracnologica Italiana

Anno IV, Volume XVIII

ISSN 2421-2091

28 Giugno 2018

Predatory efficacy of dominant spiders on insect pests in Kuttanad rice agro-ecosystem, Kerala, India

Efficacia predatoria dei ragni dominanti sugli insetti infestanti nell'ecosistema agricolo delle risaie in Kuttanad, Kerala, India

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Abstract

Spiders are important biological control agents in agro-ecosystems by suppressing the pest population to a safe level, which emphasizes the concept of integrated pest management in modern agriculture. Faced with the need to reduce pesticide use on crops and optimize natural biological control, the investigation was done to test the influence of spiders on pests. Spiders are considered as convenient model organisms for biological pest management and spiders in agro-ecosystems are used as tools to gain insight into the role of generalist predators in community and ecosystem function. As the part of the implementation of integrated pest management, experiments on feeding potential of the dominant spiders on major insect pests in Kuttanad rice agro-ecosystem revealed that most of the dominant spiders preyed on all insect pests vigorously.

Keywords: feeding potential; insect pest; integrated pest management; pesticides; pollution.

Riassunto

I ragni sono importanti agenti di controllo biologico negli ecosistemi agricoli tramite la repressione di popolazioni infestanti ad un livello di sicurezza, che enfatizza il concetto di gestione integrata delle infestazioni nella moderna agricoltura. Affrontata con il bisogno di ridurre l'uso di pesticidi sulle coltivazioni e di ottimizzare il controllo biologico naturale, la ricerca venne condotta per testare l'influenza dei ragni sui parassiti. I ragni sono considerati come organismi modello, utili per la gestione dei parassiti biologici, ed i ragni negli ecosistemi agricoli sono utilizzati come strumenti per ottenere comprensione nel ruolo di predatori generalisti in funzione di ecosistema e comunità. Come parte dell'attuazione di gestione integrata dei parassiti, esperimenti sulla potenziale alimentazione dei ragni dominanti sui maggiori insetti infestanti nell'ecosistema agricolo delle risaie in Kuttanad rivelava che la maggior parte dei ragni dominanti predava fortemente tutti i parassiti.

Parole chiave: potenziale alimentazione; insetti infestanti; gestione integrata dei parassiti; pesticidi; inquinamento.

Introduction

Spiders are carnivorous polyphagic predators and they form one of the most diversified organisms with 47,116 species found all over the world (World Spider Catalog, 2018). They are unique in their presence, as they inhabit even in water (*Argyroneta aquatica*). Spiders are common generalist predators that play a key role as predators in agro-ecosystems, woodlands, and other terrestrial ecosystems (Nyffeler & Benz, 1987). The factors like habitat fragmentation (Webb, 1990), use of pesticides and herbicides (Newton & Wyllie, 1992), increased use of drainage and fertilizers (Fuller, 1987), the loss and degradation of field boundary features (Barr *et al.*, 1993), and changing patterns of cropping (Gibbons *et al.*, 1993) has resulted in the decline of density and diversity of spiders in agricultural fields.

Insect pests have always been a constant source of threat to the welfare of the human beings since they compete with man for resources (Meena & Mital, 1997). Even though insecticides have been widely used to control rice pests for many decades, the continuous use of 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. The wide range of use of insecticides drastically disturbs the environment especially pose a great threat to the human health. Recently many efforts have been made to combine various non-chemical control methods with insecticides in systems of Integrated Pest Management (IPM). In this backdrop, spiders gain the attention to control the insects especially the rice pests as generalist predators. Spiders are an important animal group and good predators in the functioning of natural ecosystems since they make us free from a large number of pest insects (Samuel & Marcos, 2011). As spiders differ in their hunting strategies and habitat preferences and they show seasonal variation in their occurrence, the knowledge resulted from the spider diversity study in the different agricultural ecosystem is inevitable in IPM because these spiders attack a given pest (Marc *et al*., 1999).

Spiders are of great importance in reducing and preventing outbreaks of insect pests in agriculture since they kill a large number of insects per unit time (Sunderland, 1999). Although spiders mainly prey on insects, little attention has been paid to the use of spiders as a bio control agent of insect pest suppression. Different spiders occurring in different seasons consume different insects, which balance the equilibrium of nature. The population densities and species abundance of spider communities in agricultural fields can be as high as in natural ecosystems (Greenstone & Sunderland, 1999). Despite the attention given to insect predators and parasites in different agro-ecosystems, relatively little is known about the feeding potential of spiders associated with rice agro-ecosystems. Spiders are obligate predators of insects with an immense potential to serve as biological control agents and capable of minimizing the insect populations in the crop field (Ferguson *et al.*1984; Whitmore *et al*. 2002).

Kuttanad is called one of the "Rice Bowls of Kerala", contributing nearly 20% of the total rice production of the state (Fig. 1). The region extends from 9° 17′ N to 9° 40′ N and 76° 19′ E to 76° 33′ E. This major rice-growing tract of Kerala state is facing the serious threat of environmental pollution due to the increased and indiscriminate use of pesticides. The pesticide consumption in Kuttanad during 2009-2010 was 485 tons. Spiders can be potential biocontrol agents because they are relatively long-lived and are resistant to starvation and desiccation. However, a number of entomologists have acknowledged the importance of spiders as one of the major predators regulating the pests of different crops (Gavarra & Raros, 1975). Unfortunately, there has been no information to date on their role as biopesticides in the paddy fields from India and studies on the predatory effect of the spider assemblages in the agriculture crops are meager, especially with regard to rice agro-ecosystem. Since Kuttanad is mainly an agricultural zone of Kerala, cultivation is done using the chemical fertilizers and pesticides, which significantly pollute the environment (Babukutty, 1997). These toxic chemicals being magnified through the biological systems pose a great threat to the natural enemies like spiders. In this paper, we focus to form a baseline data for the research on the role of spiders as biocontrol agents on various insect pests in Kuttanad rice agro-ecosystem. We also discuss the predatory potential of certain commonly encountered spiders and check whether these spiders have any preferences towards leaf and plant hoppers in the rice agro-ecosystem.

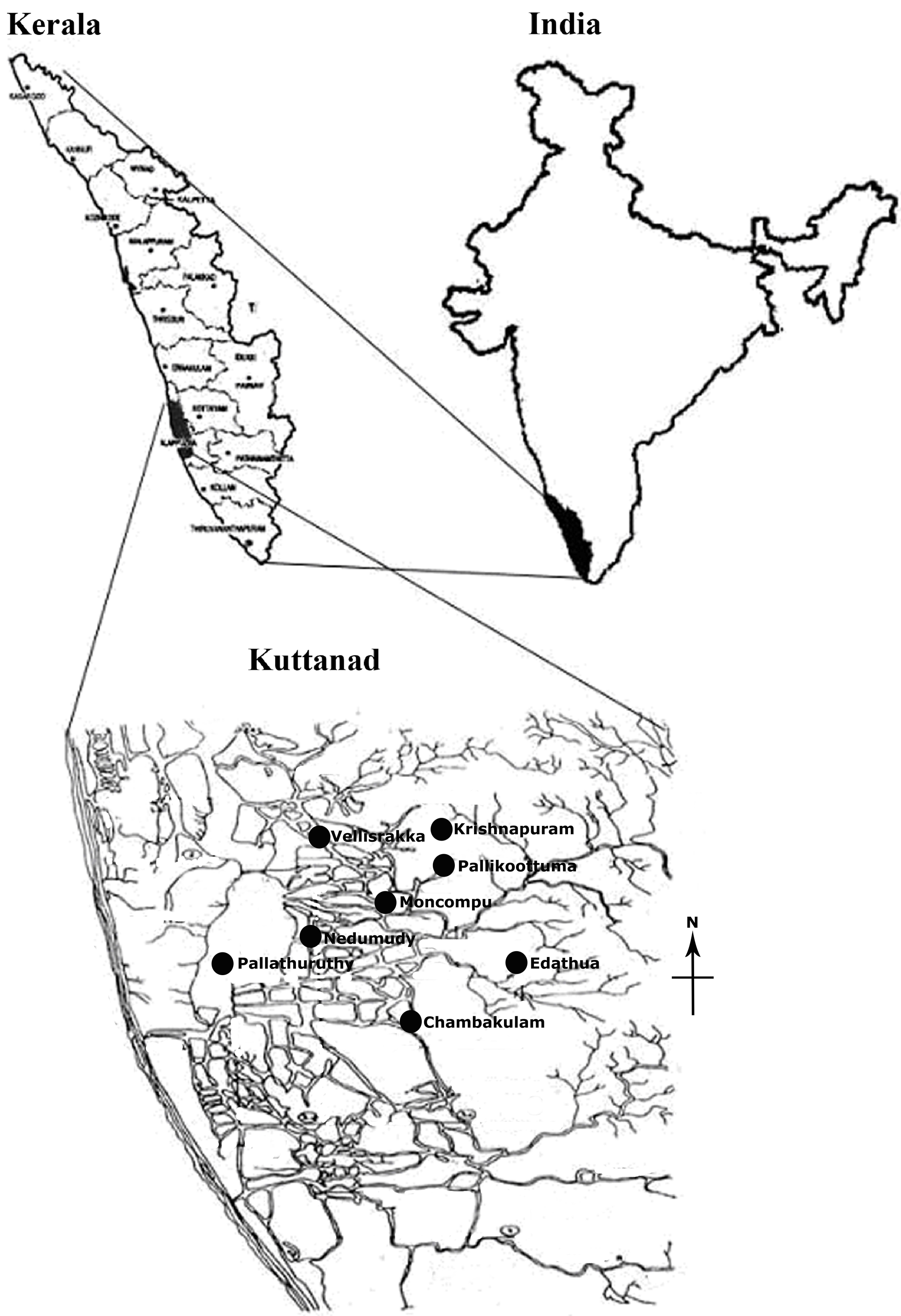

Fig. 1. Map of the study area.

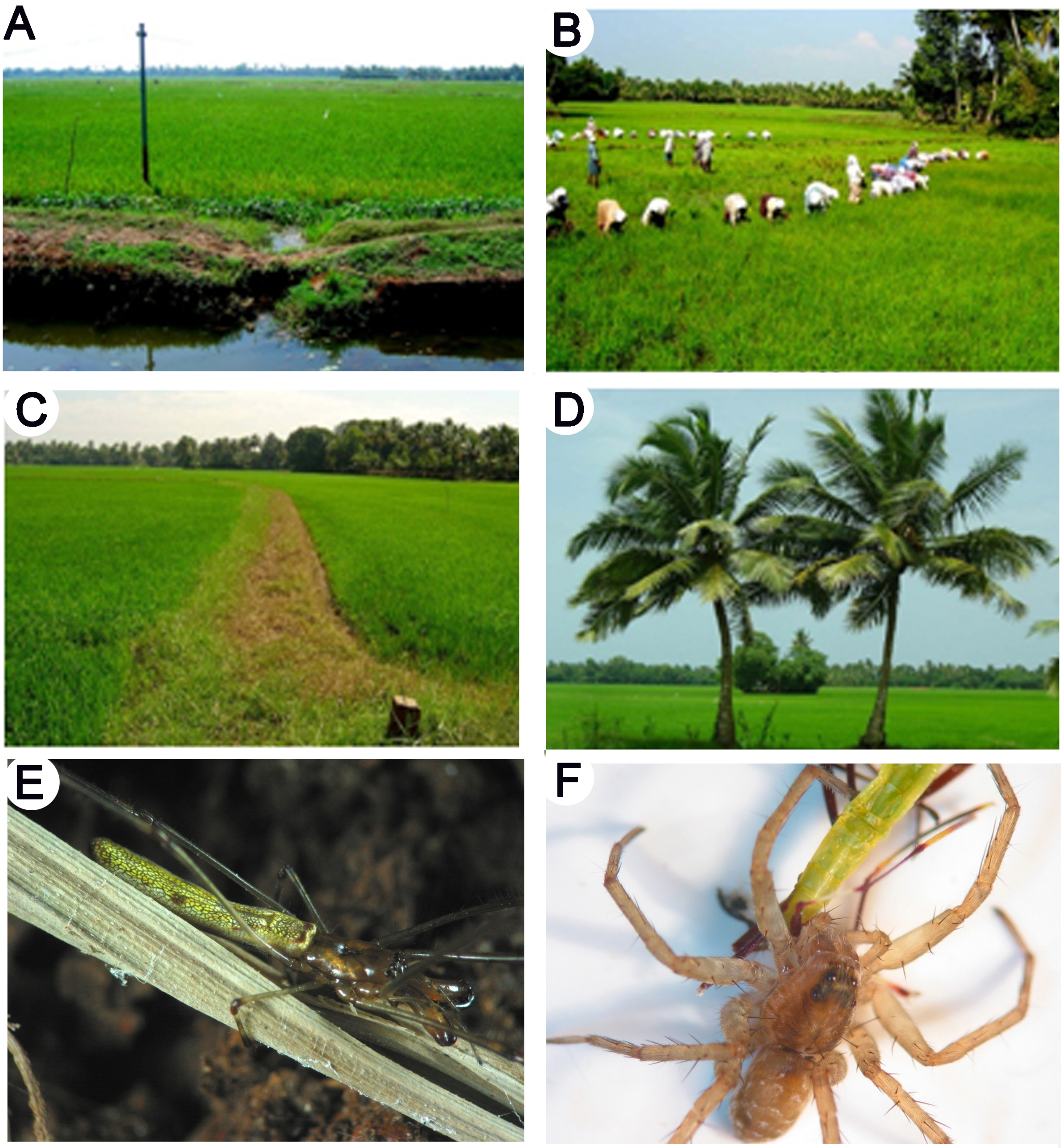

Fig. 2. **A-D**. Different views of the study area. **E**. *Tetragnatha mandibulata* on the rice plant. **F**. *Pardosa pseudoannulata* feeding on *Leptocorisa acuta.*

Materials and Methods

Kuttanad is a low-lying area of coastal Kerala formed by the confluence of four major river systems viz., Meenachil, Manimala, Pamba and Achancoil draining into the Vembanad Lake. It measures approximately 25 km east-west and 60 km north-south on the west coast of Kerala. In Kuttanad, rice is cultivated in 53,639 hectors, which is a warm, humid region

with uniform temperature throughout the year ranging from 21°C to 36°C. Humidity, in general, is very high all throughout the year. The average annual rainfall received is around 300 cm of which about 83% are received during monsoon season.
The selected spiders and preys were collected from the Kuttanad rice agro-ecosystem (Fig. 2) and predatory potential of dominant spiders was evaluated in the laboratory by observing feeding capacity of spiders at various developmental stages in relation to the insect pests. The dominant spiders selected for the study were *Araneus ellipticus* (Tikader *et* Bal, 1981) (Araneidae), *Pardosa pseudoannulata* (Bösenberg *et* Strand, 1906) (Lycosidae) and *Tetragnatha mandibulata* Walckenaer, 1841 (Tetragnathidae). Five individuals of sub-adult males, sub-adult females, adult males and adult females were taken for the experiment. The insect pests selected were rice bug – *Leptocorisa acuta* (Thunberg, 1783) (Hemiptera: Coreidae), green leafhopper – *Nephotettix virescens* (Distant, 1908) (Hemiptera: Cicadellidae) and brown planthopper – *Nilaparvata lugens* (Stal, 1854) (Hemiptera: Delphacidae). Nymphs of the insects were used in the experiment. Spiders were placed individually in plastic Petri dishes, supplied with a certain number of food items and allowed to feed. The addition of the prey was made at such frequency that the prey density remained constant throughout the trial. Preys killed and consumed by the spiders were counted up to 24 hours at an interval of 6 hours. The coefficient of Variation (CV) was calculated to analyze the variation of feeding efficiency in different life stages of spiders.

Abbreviations used: AF = adult females, AM = adult males, BPH = brown planthopper, GLH = green leafhopper, IPM = integrated pest management, SAF = sub adult females, SAM = sub adult males.

Results

Araneidae: *Araneus ellipticus*

The feeding capacity of *A. ellipticus* on the nymphs of rice bug, *Leptocorisa acuta*, brown planthopper *Nilaparvata lugens* and green leafhopper *Nephotettix virescens* is provided (Table 1). *Araneus ellipticus* consumed an average of 2.01 individuals of rice bug with a maximum of 2.8 and a minimum of 1.5. Adult females consumed the maximum number and sub-adult males consumed the minimum. Each life stage of this spider showed much variation in the feeding capacity and the coefficient of variation (CV) was 38.51. The spider ingested an average of 4.4 individuals of BPH with a maximum of 6.2 and a minimum of 2.2. The various life stages showed much variation in the feeding capacity with a CV of 40.22. The spider absorbed an average of 4.12 individuals of GLH with a maximum of 5.2 and a minimum of 2.4 individuals. The different life stages of *A. ellipticus* exhibited more variations in their feeding capacity with a CV of 29.36 (Fig. 3).

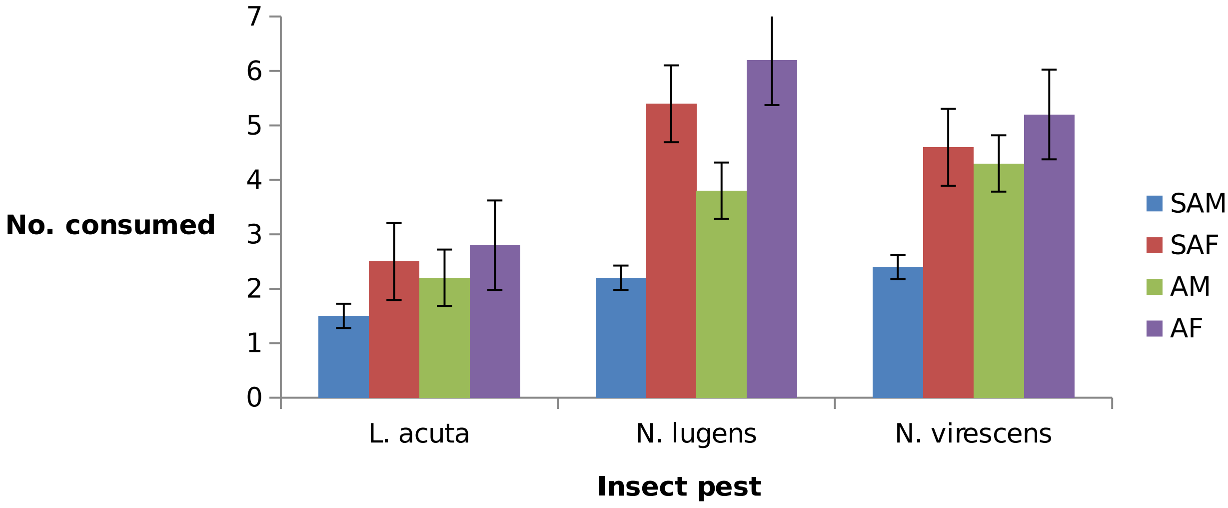

Fig. 3. Feeding potential of *A. ellipticus* on the nymphs of three insect pests.

3.2. Lycosidae: *Pardosa pseudoannulata*

The feeding potential of *P. pseudoannulata* on the nymphs of rice bug, brown planthopper and green leafhopper is experimented and provided (Table 2). *Pardosa pseudoannulata* preyed an average of 2.55 individuals of rice bug with a maximum of 3.6 and a minimum of 1.2**.** Each stage of this spider showed variation in the feeding capacity and the CV was 42.35. The spider consumed an average of 6.07 individuals of BPH with a maximum of 7.5 and a minimum of 5.2**.** The feeding capacity of *P. pseudoannulata* exhibited variations in the different life stages (CV 16.30). An average of 4.77 individuals of *N. virescens* with a maximum of 5.9 and a minimum of 4 were consumed by the spider (Fig. 4).

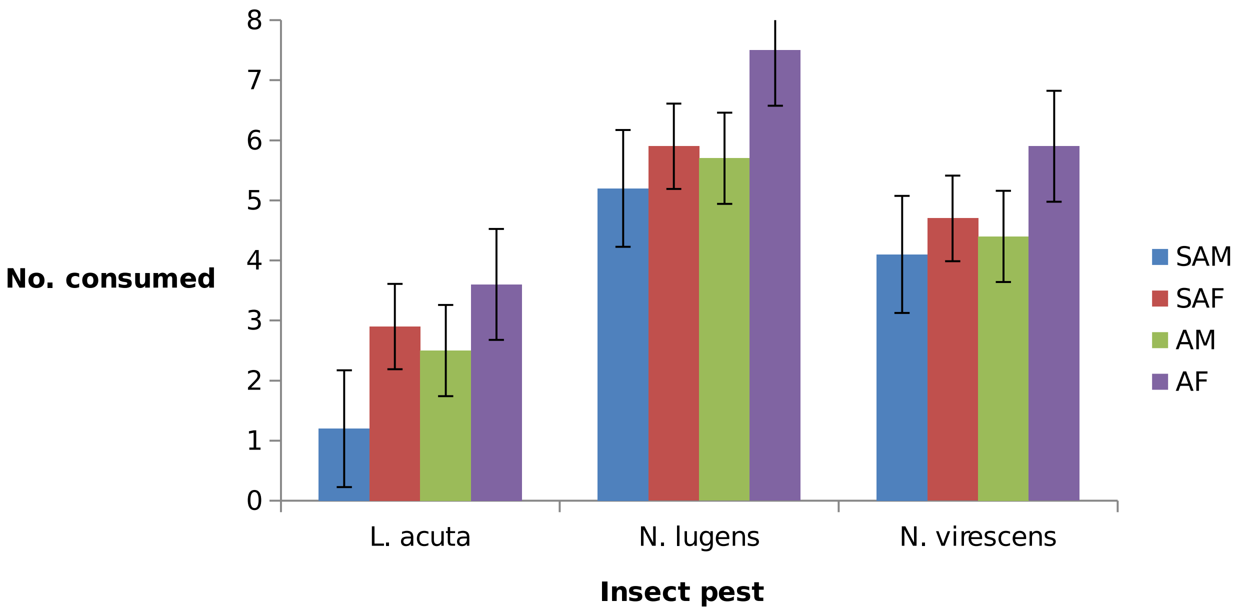

Fig. 4. Feeding potential of *P. pseudoannulata* on the nymphs of three insect pests.

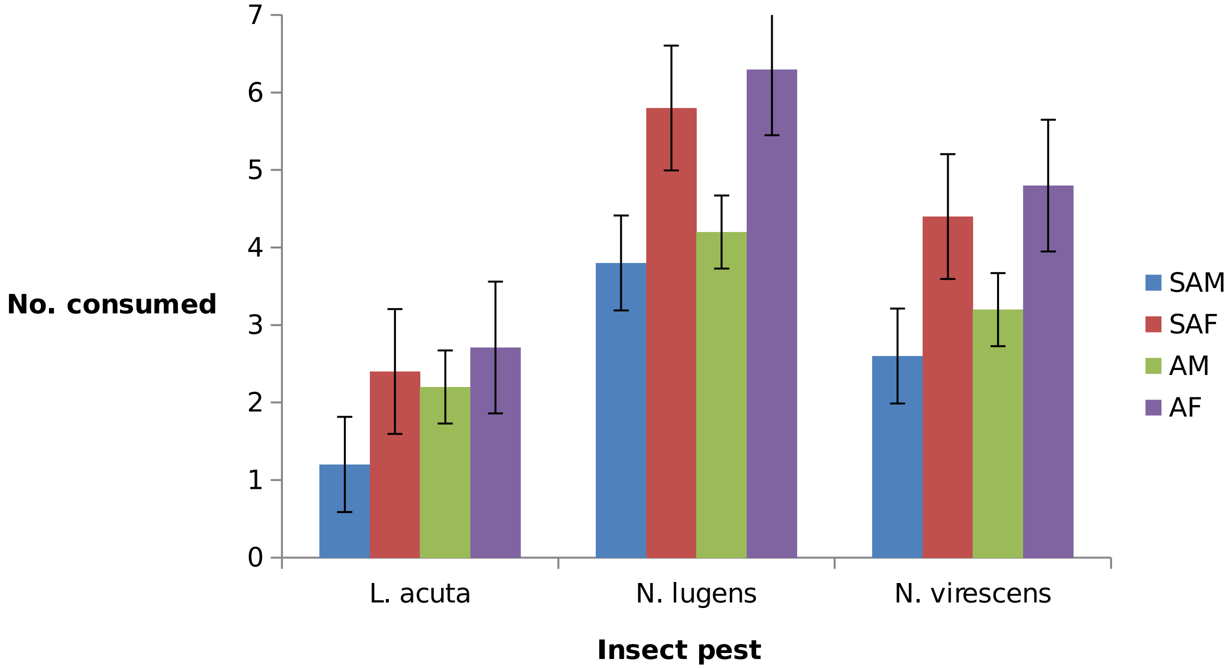

Fig. 5. Feeding potential of *T. mandibulata* on the nymphs of three insect pests.

3.3. Tetragnathidae: *Tetragnatha mandibulata*

The predatory efficacy of *T. mandibulata* on the nymphs of rice bug, brown planthopper, and green leafhopper is provided (Table 3). *Tetragnatha mandibulata* ingested an average of 2.12 individuals of rice bug with a maximum of 2.7 and a minimum of 1.2. Adult females preyed the maximum number and sub-adult males with the minimum number of insects. Variations were observed in the feeding capacity in different life stages with the CV 30.66. The spider happened to prey an average of 5.02 individuals of *N. lugens* with a maximum of 6.3 and a minimum of 3.8 individuals. The different stages of the life cycle showed variations in their predatory efficacy with a CV of 24.10. The feeding rate of the spider is with an average of 3.75 individuals of *N. virescens* with a maximum of 4.8 and a minimum of 2.6 individuals. Adult females consumed the maximum number and the sub adult males did the minimum number of prey. The different life stages showed much variation in the feeding capacity and the CV was 27.20 (Fig. 5).

Discussion

Araneus ellipticus, *P. pseudoannulata* and *T. mandibulata* are the most common spiders in the Kuttanad rice fields and these appear in the rice field immediately after crop establishment. These are significant predators of small-bodied pests such as hopper nymphs, constituting an important component of the natural enemy complex that checks hoppers in irrigated rice. All these three spiders preyed actively on the nymphs of three insect pests.

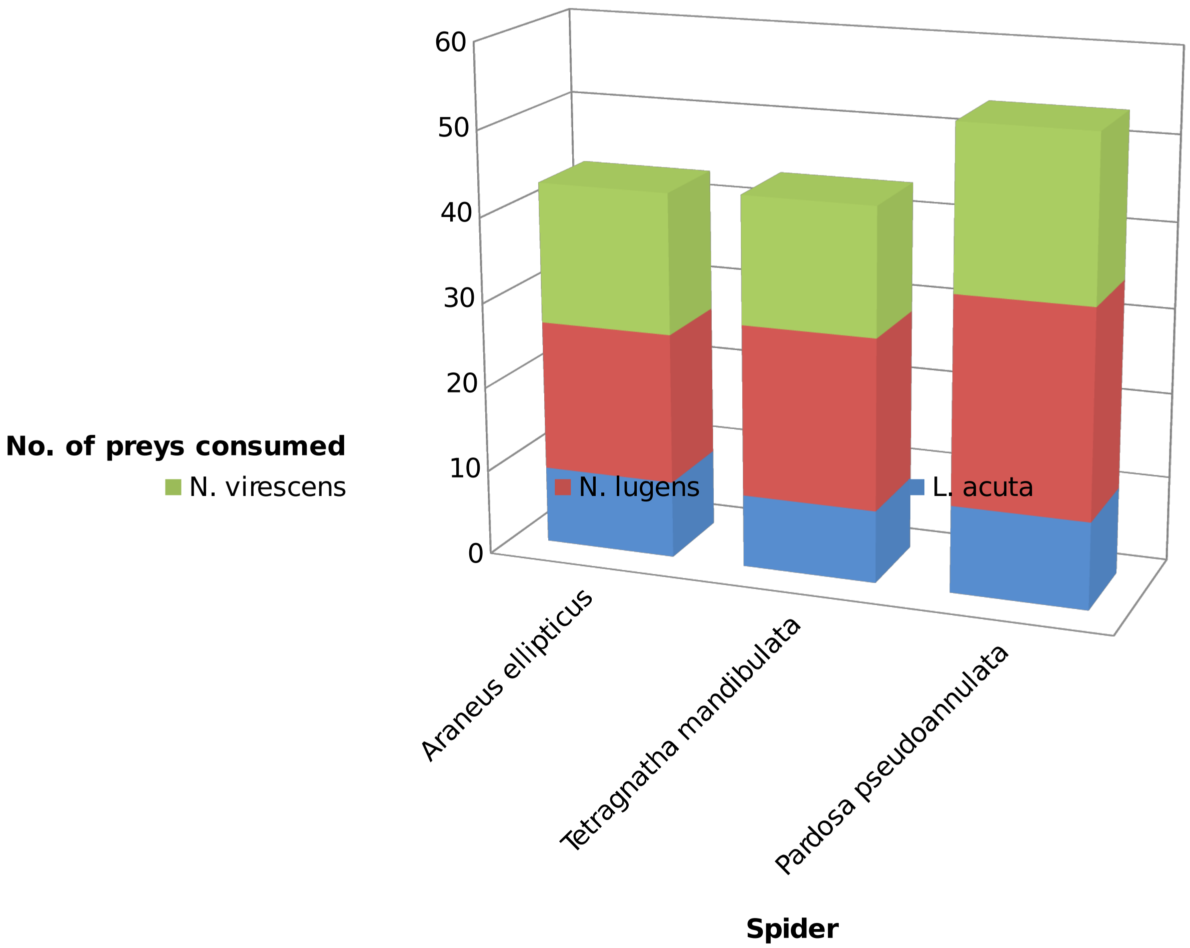

Fig. 6. Comparative predatory potential of three dominant spiders on major pests.

One of the most frequently analysed problems in a prey-predator relationship is the effect of prey and predator density during the course of predation. 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 vice versa. 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 (Harwood *et al*., 2001). We noticed that these three common spiders actively feed on these three nymphs and exhibited an increase in prey capture when greater numbers of prey are available.

Spiders' preference to their prey is a matter of discussion. Bilsing (1920) stated that there is no evidence that any species of spider has a particular preference to the prey. Savory (1928) stated that spiders show no trace of discrimination for prey. However, Turnbull (1966) pointed out that the spiders will tolerate a wide range of species of prey and the preferred species will vary from time to time and from place to place depending on the particular time and place. It is common that when spiders have an excess of prey, they become more selective (Riechert & Harp, 1987). However, Bristowe (1941) has reported that spiders have preferences indicated by disagreeable odors and tastes, which cause them to reject any potential food items. In addition, each species of spider occupies a specific region of the agricultural habitat, from the ground to the top of the canopy. Different prey species can be found in different microhabitats as well. In our experiment, there is no evidence to prove that the tested spiders have a particular prey preference since all the selected spiders consumed the completely selected prey species dynamically. However, we propose that prey specialization by spiders could be an attribute found in ecosystems and some degree of specialization or monophagy by a predator on prey is necessary for the predator to reduce populations of that particular prey.

The rate of predation varied among the different species and sexes of the three spiders. Females of all spiders consumed a number of preys whereas their male counterparts consumed very less. The high rate of predation shown by the females is due to their high metabolic activity and size. In our case, the adult females are the potent predators and sub-adult males consumed very little since they are very small. It is discussed that the rate of predation always depends on the size of the animal and the females feed more because they need more protein for the egg formation as the quality and health of the female influences the fitness of their offspring.

The comparative feeding potential analysis of the three dominant spiders on the nymphs of three insect pests indicates that *P. pseudoannulata* was the most voracious predator on these three insect pests (Fig. 6). The diet of the wolf spider depends on the types of insects that are available but leaf hoppers and plant hoppers are the major preys. Spiders of the genus *Pardosa* feeds on nymphs and adults of the hopper and is considered as a major regulator of brown planthopper populations. A single wolf spider can eat up to 45 hoppers per day (Uetz *et al.*, 1999). The lycosid spider *P. pseudoannulata* is one of the major predators of rice planthoppers and other rice pests because of its mobility and high predation capacity (Riechert & Bishop, 1990). Hunting spiders might be better at controlling pests than web-weavers because most species of hunting spiders are capable of capturing a wide variety of prey types and sizes (Edwards, 1990). *A. ellipticus* and *T. mandibulata* prey very less on the nymphs of three insect pests compared to *P. pseudoannulata*. Since both of these species are web weavers and ‘sit and wait’ predators, they get rare chances to prey and have to wait for it rather than direct hunting spiders. Hunting spiders get more preying chances due to their hunting foraging strategy rather than the ‘sit and wait’ method. A desirable biological control agent is a predator that not only reduces pest densities, but also stabilizes them at low levels, while maintaining stable populations itself (Pedigo, 2001). In our study it is revealed that spiders can lower insect pest densities and stabilize populations by virtue of their microhabitat use, polyphagy and obligate predatory feeding strategies. They also play a significant role in the top-down effects, which means that plant damage by insect herbivores is lower during their presence rather than their absence in the rice field.

Natural rice fields with pure organic manure reasons quick raise in the populations of detritivores (such as collembolans and ephydrid flies) and plankton feeders (such as mosquito larvae and chironomid midge larvae), which are major alternative prey for ground spiders and these habitats carry an elevated abundance of spiders than traditionally farmed fields (Tahir and Butt, 2009). Since organic fields give spiders more safety from natural enemies and improve microhabitat, Organic farming can cause diversity to the soil structure and raise the richness of prey and in turn the abundance of spiders (Öberg, 2007).

In order to facilitate a stable agro-ecosystem, presence of permanent and uninterrupted natural habitat next to the Kuttanad crop field is essential. An undisturbed habitat is an excellent physical milieu for spiders with their sufficient food, refuge, prey availability and sites for web construction (Thomas and Marshall, 1999). A large percentage of perennial crops and heterogeneity of vegetation in the nearby areas of Kuttanad rice agro-ecosystem have been demonstrated to have a positive effect on spider abundance.

Conclusion and Recommendations

Spiders are effective predators of herbivorous insect pests and a diverse assemblage of spiders may have the greatest potential for keeping pest densities at low levels. In a healthy agro-ecosystem, spiders are the best classical natural enemy candidate for a classical biological control program. Natural enemy populations have the unique ability to be able to interact with their prey or host population and to regulate them at lower levels. Therefore, natural enemy conservation is the major step to eradicate the insect pests in the agro-ecosystems. Conservation of the natural enemy should be accomplished by minimizing the use of chemicals and the physical disturbances of the habitat. Natural practices of harvesting, ploughing and grazing instead of mechanical alterations to the land would increase spider diversity in agricultural land. Organic farming should be done avoiding the traditional practices like using insecticides, which threatens the natural enemies and declining the density and diversity of the spiders. Insecticides adversely affect the life cycle of natural enemies and the population density of these natural enemies in the paddy fields has been depressed by the imprudent use of it. The use of bio-pesticides rather than insecticides should be encouraged to preserve and retain the natural enemy population in the rice fields. Recent trends in agriculture towards reduced pesticide use and ecological sustainability have to lead to increased interest in spiders as potential biological control agents. Moreover, as spiders exhibit the ability to lower and stabilize pest populations, making them excellent biological pest management candidates. In order to conserve natural enemies in rice ecosystems of Kuttanad, it is required to adapt natural farming that improve the abundance of spiders or at least have a negligible toxic effect on them. In order to appreciate the ecological basis of biological control, it is desirable to have an idea of different pest groups and their major characteristic natural enemies. Since it is a baseline study focusing only on three preys and three predators, we recommend for a systematic study focusing on more predators and preys to get a more accurate result. It will help in the management of spiders and related pests in the study area so that we may gain a better understanding of the environmental factors that are important in determining the spider inhabitants. This knowledge can be used to influence agricultural habitats to enhance and maintain spider population in integrated pest management.

Pest	Spider life stage					
	SAM	SAF	AM	AF	Mean±SD	CV(%)
L. acuta	1.5±0.70	2.5±1.07	2.2±1.03	2.8±1.06	2.01±0.77	38.51
N. lugens	2.2±0.68	5.4±1.11	3.8±0.84	6.2±1.39	4.4±1.77	40.22
N. virescens	2.4±0.77	4.6±1.12	4.3±1.68	5.2±1.21	4.12±1.21	29.36

Table 1. Feeding potential of *Araneus ellipticus* on the nymphs of three insect pests

Pest	Spider life stage					
	SAM	SAF	AM	AF	Mean±SD	CV(%)
L. acuta	1.2±0.42	2.9±0.87	2.5±0.52	3.6±0.47	2.55±1.08	42.35
N. lugens	5.2 ±1.66	5.9±0.63	5.7±1.15	7.5±0.84	6.07±0.99	16.30
N. virescens	4.1±1.44	4.7±1.47	4.4±1.41	5.9±1.10	4.77±0.78	16.35

Table 2. Feeding potential of *Pardosa pseudoannulata* on the nymphs of 3 insect pests

Pest	Spider life stage					
	SAM	SAF	AM	AF	Mean±SD	CV(%)
L. acuta	1.2±0.52	2.4±0.88	2.2±075	2.71±1.21	2.12±0.65	30.66
N. lugens	3.8±1.32	5.8±1.21	4.2±1.65	6.3±1.87	5.02±1.21	24.10
N. virescens	2.6±0.88	4.4±1.22	3.2±1.33	4.8±1.42	3.75±1.02	27.20

Table 3. Feeding potential of *Tetragnatha mandibulata* on the nymphs of 3 insect pests

Acknowledgements

First and third authors are thankful to Principal, Sacred Heart College, Thevara, Kerala and the second author is grateful to Principal, Christ College, Irinjalakuda, Kerala and for providing laboratory facilities. Second author also acknowledges "Idea Wild" organization, USA, and Encyclopedia of Life program, National Museum of Natural History, Smithsonian Institution, USA for financial assistance.

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