MAJOR SPIDERS IN VEGETABLE ECOSYSTEM AND THEIR PREDATORY POTENTIAL

MANU P. MANI

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Department of Agricultural Entomology
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522

DECLARATION

I hereby declare that this thesis entitled "**Major spiders in vegetable ecosystem and their predatory potential**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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29-12 -2005

MANU P. MANI
(2003-11-45)

CERTIFICATE

Certified that this thesis entitled "**Major spiders in vegetable ecosystem and their predatory potential**" is a record of research work done independently by Ms. Manu P. Mani (2003-11-45) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellayani,
29.12-2005

Dr. HEBSY BAI
(Chairperson, Advisory Committee)
Associate Professor,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram.

Approved by

Chairperson :

Dr. HEBSY BAI
Associate Professor,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

29/12/05

Members :

Dr. T. NALINAKUMARI
Associate Professor and Head,
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

29.12.05

Dr. K.S. PREMILA
Assistant Professor (Sel. Gr.),
Department of Agricultural Entomology,
College of Agriculture, Vellayani,
Thiruvananthapuram-695522.

29-12-05

Dr. L. RAJAMONY
Associate Director of Research (Planning),
Directorate of Research
Kerala Agricultural University,
Vellanikkara, Thrissur.

29.12.05

External Examiner :

29/12/2005

Dr. PALANISWAMI, M.S.
Project Coordinator,
CTCRI, TVPM-17

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Introduction

1. INTRODUCTION

Agro-ecosystems constitute a major part of the terrestrial ecosystems. Adoption of newer technologies in agriculture wrought numerous changes in the systems. Human regulation of the structure, function and duration of agro-ecosystems contributed to their high instability. Commensurate with the changes, vulnerability to pests and diseases increased, leading to reduced productivity. Among the pests, insects are one of the most dominant biota that thrive and at times over dominate in agricultural fields. In natural systems, abnormal increase in insect population is checked by nature's own regulatory mechanism, the natural enemies. Predators, parasitoids and pathogens constitute the major groups of natural enemies, accounting for 40–60 per cent reduction in pest population in nature.

Exploitation of natural enemies is one of the oldest and best methods of pest control. The earliest record on the use of natural enemies for pest suppression dates back to fourth century China when ants were released to combat pests in the store and field. In 1767, mynahs (bird) were imported from India for the control of locusts in Mauritius. Since mid nineteenth century, ladybirds, green lacewings etc were utilized for pest control (Dhaliwal and Arora, 2001). Evidently, the early attempts at biological control were through the predators. Even the first successful biological control obtained was with a predator. In 1888, the predatory beetle, *Rodolia cardinalis* (Mulsant) was introduced in California, USA from Australia to control the cottony cushion scale *Icerya purchasi* Maskell that threatened the citrus industry. Despite these early attempts of control with predators, applied biological control is heavily biased towards parasitoids that show high specificity to a given pest, tracks its density and maintains it at low equilibrium level. The propensity towards specialist bioagents continues even today with the predators being a virtually ignored lot.

The new millennium gearing for an organic evergreen revolution in agriculture is on the look out for newer avenues of pest management devoid of ecological evils. Keeping pace with the changing scenario, the holistic pest regulatory effect of the natural enemies in agro-ecosystems is felt to be the best option for sustainable management of pests. Sustainability as observed by the United Nations is supported by five pillars, biodiversity being one of them (Swaminathan, 2002). Analysis of the biodiversity of the natural enemy community and an endeavour for beneficial use of each of the components will not only enhance the effectiveness of pest management strategies but also help in developing alternate components for a biointensive integrated pest management system. One natural enemy that could play a significant role in ecological pest management is the generalist predator, the spiders.

Spiders are carnivorous arthropods found in almost every kind of habitat, occurring in fairly large numbers and diversity. Although they have a wide range of prey, they feed mainly on insects, devouring a large number of the prey. Besides, they also threaten the prey with various foraging strategies and kill those living in their territory. Thus, a spider community that is diverse and that maintains a fairly constant numerical representation is prevalent in natural systems, exerting considerable control on the associated prey population and limiting their initial exponential growth without extinction (Riechert and Lockley, 1984).

As generalists, spiders may not contribute greatly to targeted control of pests. But being an important part of natural control mechanism they help to stabilize pest population. Spiders are highly abundant in agricultural fields and if conserved or augmented they can regulate many insect pests. As a group, they are highly resilient in agro-ecosystems, long lived and readily seek out new fields after harvest (Riechert and Lockley, 1984). The vital importance of spiders in the ever-growing field of biological pest control is now well recognized at least in certain agro ecosystems. They constitute a large part of the predatory arthropod fauna of rice ecosystem and prey on many insect pests (Barrion and Litsinger, 1980). Cereal and cotton fields are also rich in spiders contributing to pest regulation (Riechert and Lockley, 1984). In orchards, the spiders form the largest group of entomophages and are responsible for the reduction in pest population of almost all pest species (Amalin and Pena 2000; Brown *et al.*, 2003). For the most part, purposeful utilization of the araneae for pest management has been confined to rice and perennials. In vegetables, research efforts have largely being concentrated on pulses. Few studies have been attempted on the spiders in okra, brinjal, bittergourd, and amaranthus

With organic farming playing a pivotal role particularly in vegetable cultivation, it is all the more imperative to generate information on each of the components of natural enemy community for designing an insecticide free, nature friendly, economically viable and socially acceptable pest management strategy. As there is a dearth of information on the spider predators in vegetable ecosystem, the study was undertaken with the following objectives.

- To assess the density and diversity of the spider fauna in vegetable ecosystem.
- To determine their seasonal abundance.
- To evaluate their predatory efficiency
- To study their sensitivity to insecticides

Review of Literature

2. REVIEW OF LITERATURE

The role of spiders in the management of pests of vegetables is less explored even though they are widely exploited for the regulation of pests in rice and fruit orchards. The present study relates to the spiders in vegetable ecosystem, their relative abundance, predatory potential and impact of insecticides on them and the relevant literature is presented in this chapter. The spider fauna associated with annuals other than rice and influence of season and crop stages on their abundance in annuals alone is reviewed under 2.1 and 2.2.

2.1 SPIDERS IN AGRO-ECOSYSTEMS

Among annuals, most of the information available pertains to spiders in vegetable and cotton ecosystems.

2.1.1 Spiders in Vegetable Ecosystem

Despite being an important group of predators in vegetable ecosystem, the literature available on their role in pest regulation is mainly confined to pulses.

2.1.1.1 Spiders in Pulse Crops

Globally, a wide range of spiders associated with various pulse crops have been documented. Eighty one species of spiders in 34 genera belonging to 13 families were recorded from guar in Texas and Oklahoma. Among the species, while *Dictyna volucripes* Keyserling predated on adults of the midge, *Contarinia texana* (Felt) *Pardosa pauxilla* (Rogers) preyed on larvae of the pest (Rogers and Horner, 1977). Population of predatory spiders in soybean fields in Mississippi gradually increased during summer and was high in late than early planted crops (Buschman *et al.*, 1984). Several spiders were found to predate on the larvae of the soybean pest *Hedylepta indicata* (Fabricius) in Taiwan (Chien *et al.*, 1984). Over

25,000 spider species belonging to 17 different families were recorded from soybean fields in Virginia. Oxyopidae, Thomisidae and Salticidae were the dominant foliage dwellers while, Lycosidae and Linyphiidae were the important families retrieved from the ground (Ferguson *et al.*, 1984). A study on the effect of companion crops on the incidence of predatory spiders in rice and soybean fields in Nepal during the wet season revealed that the population densities of *Lycosa* sp., *Oxyopes* sp. and *Tetragnatha* sp. were higher in the maize-soybean intercrop than in soybean alone when observed 88 days after emergence (Gyawali, 1988). *Oxyopes* sp., *Tetragnatha* sp. and *Lycosa* sp. were present in the blackgram agro-ecosystem at Khumaltar in Kathmandu valley (Gyawali, 1989). Six species of spiders were recorded preying on adults of *Anticarsia gemmatalis* (F.) in soybean fields in Florida. *Peucetia viridans* (Hentz) accounted for over 65 per cent of the predation (Gregory *et al.*, 1989).

Studies from India too indicated the prevalence of different species of spiders in pulse plots. Several predatory spiders were seen preying on the leaf rollers, *H. indicata* and *Lamprosema diemenalis* (Gn) infesting soybean (Bhattacherjee, 1976). Similarly, a number of predatory spiders were documented from the fields of *Cajanus cajan* Millsp from Gujarat (Patel *et al.*, 1988). Survey of spiders associated with pigeon pea in Haryana revealed the abundance of four species of araneae *viz.*, *Hippasa haryanensis* Arora & Monga (25.30 per cent), *Pardosa tikaderi* Buchar (19.71 per cent), *Lycosa* sp. (25.35 per cent) and *Cheiracanthium punjabensis* Sadana and Bajaj (18.3 per cent) in the fields. Other species found were *Thomisus* sp., *Thomisus decoratus* Tikader *Neoscona theisi* (Walkenaer). *Oxyopes pandae* Tikader and *Steqodyphus* sp. When evaluated in the laboratory, the spiders fed voraciously on the thrips *Empoasca kerri* Pruthi and moderately on *Clavigralla* sp. None of the species fed on caterpillars of *Helicoverpa armigera* (Hubner) (Arora and Monga, 1993). While *Oxyopes shweta* Tikader, *Thomisus* sp. and *Salticus* sp. constituted predators of the legume pod borer *Maruca testulalis* Guen. (Borah and Dutta, 2001), the spiders *O. shweta*, *Neoscona* sp. and *Plexippus paykulli* (Aud) were found to predate on *H. armigera* in pigeon pea fields of Assam (Borah and Dutta, 2003). The natural enemies of pigeon pea pests included the spiders *Araneus* sp. and *Clubiona* sp. (Kumar and Nath,2003).

2.1.1.2 Spiders in Other Vegetables

Global records indicated that araneae constituted the most abundant predator group in tomato crop in Brazil (Raga *et al.*, 1990). In a mixed vegetable garden comprising of spinach, radish, cabbage, brussels sprout, potato, tomato and maize in USA, spiders formed 84 per cent of the predators and accounted for 98 per cent of observed predation (Riechert and Bishop, 1990). The thrips infesting potato *viz., Thrips palmi* Karny and *Megalurothrips usitatus* (Bagnall) were found to be predated by the spiders *Neoscona pratensis* (Hentz) *Thomisus* sp., *Oxyopes salticus* Hentz and *Argyrodes* sp. in potato fields of Thailand (SEARCA, 1991).

The crab spider *Thomisus* sp. predated on caterpillars and adults of *H. armigera* in tomato fields of Bangalore in India (Ansari and Pawar, 1980). Numerous species of spiders were observed to prey on *Diaphania indica* Saund of pumpkin in Tamil Nadu (Peter and David, 1991) and *Plutella xylostella* (L.) in cabbage fields in the hill zones of Karnataka (Parvathi *et al.*, 2002). Survey conducted on the spiralling whitefly *Aleurodicus dispersus* Russel in vegetable fields of Coimbatore revealed the predation of the pest by the spider *Oxyopes* sp. (Geetha *et al.*, 2002). The intensity of predation by *O. shweta* and *P. paykulli* on *Phthorimaea operculella* (Zeller) was high in store and field (Debnath and Borah, 2002).

2.1.2 Spiders in Cotton Ecosystem

Spiders are the most familiar, efficient and obligate predators, which feed on different types of prey in cotton ecosystem. Several spiders were recorded from Arkansas cotton fields feeding on pests (Whitcomb *et al.*, 1963). Under favourable conditions, an average of about 30 spiders per plant was recorded from the cotton fields of Peru (Aguilar, 1975). Hunting spiders that rest on the plants were the most frequently observed group of spiders. It included the nocturnal hunters (Anyphaenidae and Clubionidae) that pursue their prey until it is caught, diurnal hunters (Saliticidae) that pounce on their prey and hunters that generally hide among plants (Aguilar, 1976). *Aysha gracilis* (Hentz), *P. viridans*, *Cheiracanthium inclusum* (Hentz), and *Neoscona arabesca* (Walckenaer) were observed to predate on eggs of the cotton leaf worm in a cotton field in Texas. Besides, the spiders *Misumenops* sp., *Tetragnatha laboriosa* (Hentz), *A. gracilis*, *P. viridans*, *C. inclusum* and *Hentzia palmarum* (Hentz) were found predating on the first instars of the leaf worm (Gravena and Sterling, 1983). A total of 31 species of spiders belonging to eight families were observed in the cotton fields in Heze county of China. Of these, *Pardosa astrigera* L. Koch., *Misumenops tricuspidatus* (Fabricius) and *Theridion octomaculatum* (Bosenberg and Strand) were the most important spiders preying on cotton aphids (Dong and Xu, 1984).

Natural enemies of *H. armigera* in cotton fields in Indonesia included 24 species of spiders in 10 families (Nurindah and Bondra, 1988). The orb weaver was the numerically dominant group of spiders in Texas cotton fields. Five species *viz.*, *N. arabesca* *Acantheneira* sp., *Gea heptagon* (Hentz), *T. laboriosa* and *Uloborus glomosus* (Nyffeler) constituted more than 80 per cent of the species sampled. They were found to predate on aphids, small dipterans, cicadellids, hymenopterans and coleopterans (Nyffeler *et al.*, 1989). Similarly, spiders formed one of the most important predators of cotton flea hoppers in East Texas. The araneae were worth three times the value of predatory insects (Sterling *et al.*, 1992).

Attempts made in India to record the spider fauna in cotton ecosystem also revealed the prevalence of several species. In Gujarat, the sac spider *Clubiona pashabhaii* Patel and Patel was observed to predate on several insect pests (Patel and Pillai, 1988). The spiders *Cheiracanthium melanostoma* (Thorell), *Oxyopes chittrae* Tikader *O. shweta, Lycosa poonaensis* Tikader and Malhotra and *T. pugilis* were found to prey on all the life stages of the aphid, *Aphis craccivora* Koch. available within its reach in cotton fields of North Gujarat (Sebastian and Sudhikumar, 2002).

2.1.3 Spiders Associated with Other Annuals

Survey conducted in USA in nine field crops *viz*., cotton, soybean, lucerne, guar, rice, grain sorghum, groundnut, maize and sugarcane revealed the presence of 614 species of spiders of 192 genera under 26 families. The most frequent species in field crops were *Oxyopes* sp., *Salticus* sp., *Phidippus audax* (Hentz) and *T. laboriosa* (Young and Edwards, 1990). Natural occurrence of predatory spiders was observed in the lucerne fields of Uzbekistan and the spiders were found to predate on alfalfa bug *Adelphocoris lineolatus* (Goeze)(Shamuratova, 2002).

In India, eight species of spiders were found to predate on the maize borer *Chilo partellus* (Swinhoe) and the jassid *Zyginidia manaliensis* (Singh). The two species of spiders preying on the nymphs and adults of the jassids were identified as *Oxyopes* sp. and *Pardosa* sp. Early instar larvae of the maize borer was predated on by *Thomisus cherapunjeus* Tikader, *Marpissa tigrina* Tikader, *Phidippus punjabensis* Tikader, *Araneus sinhagadensis Tikader*, *Araneus* sp. and *O. pandae* (Singh and Sandhu, 1976). In a study conducted in Dehra Dun, two species of thrips *viz*., *Thrips flavus* Schrank and *Thrips hawaiiensis* Morgan were found to be predated by the spiders *Marpissa* sp., *Tharpyna* sp., *Thomisus* sp., *Misumena* sp. and *Oxyopes* sp. (Veer, 1984).

Survey of spider fauna of groundnut fields in Gujarat revealed the presence of 2833 spiders belonging to 53 species, 34 genera and 14 families Of the 53 species collected, 31 species (55.98 per cent) were hunting spiders 6 species (8.51 per cent) ambushing, 11 species (29.51 per cent) web builders and 5 species (6.00 per cent) belonged to miscellaneus group of spiders (Patel and Pillai, 1988). Natural enemies of the sorghum ear head bug, *Calocoris angustatus* Leth. in sorghum tracts in Karnataka included several species of spiders like *Neoscona mukerjei* Tikader *N. theisi, Clubiona* sp., *Argyrodes* sp., *Oxyopes* sp. *Cheiracanthum* sp., *P. paykulli, Thomisus* sp. etc. (Hiremath, 1989).Larvae of the stem borer (*C. partellus*) of fodder maize were predated by 17 species of predatory spiders in Karnataka (Jalali and Singh, 2002).

2.2 INFLUENCE OF SEASON AND CROP STAGES ON SPIDER ABUNDANCE

2.2.1 In Vegetable Ecosystem

It has been hypothesized that as crops grow, increase in the prey availability supports more spiders to co-exist (Pianka, 1966). In soybean ecosystem in the predators were more abundant during pod fill stages, contributing to heavy larval mortality of *Plathypena scabra* (F), particularly late in the season (Bechinsk and Pedigo, 1981). Similarly, the number of foliage dwelling spiders peaked in early August and again in early September in1981 and in early to mid-August in 1982 in soybean cropping systems in United States of America (Ferguson *et al.*, 1984). Peak activity and higher density of spiders were recorded in summer, while the lowest were in winter in 8 vegetable crop fields in Egypt. The abundance of spiders in summer seemed to be the result of a combination of three factors *viz.*, dense vegetation cover, high temperature and significant relative humidity (Hussein, 1999).

In India, predatory spiders were seen in abundance on *H. indicata* infested soybean plants in September-November (Bhattacherjee, 1976). Appreciable population of the spiders *O. ratnae*, *O. shweta*, *Neoscona* sp. and *P. paykulli* and their predation on *H. armigera* in pigeon pea was seen when *H. armigera* appeared during flowering and remained till the maturity stage of the crop (Borah and Dutta, 2003).

2.2.2 In Other Annuals

The abundance of spiders in the cotton fields of Peru was directly linked to the development of plants rather than the season (Aguilar, 1976). Change in the species composition of spiders in groundnut fields was observed in Gujarat. The species diversity index increased from July through October attaining the peak in October coinciding with the crop growth and consequent increase in prey availability (Patel and Pillai, 1988).

2.3 PREDATORY EFFICIENCY

Spiders predate almost exclusively on insects and consume a large number of the prey. Hence, the feeding potential and prey preference of spiders could play a crucial role in limiting the exponential increase of insect population in agricultural systems.

2.3.1 Feeding Potential

The consumption rate of *L. pseudoannulata* has been estimated to be 24 nymphs or adults of *N. lugens* (IRRI, 1975) or 8.5 nymphs (Chau, 1987) and 15.20 adults of plant hopper per day (Samal and Misra 1975). Studies conducted in Texas indicated that *A. gracilis* and *P. viridans* consumed 4.80 and 0.41 first instar larvae of cotton leaf worm per day respectively (Gravena and Sterling, 1983).

In a laboratory test conducted in Yugoslavia, *Cheiracanthium mildei* L. Koch and *Achaearanea lunata* (Clerck) predated on sycamore lace bug *Corythucha ciliata* (Say) at the rate of 8.2 and 3.1 bugs per day, respectively (Balarin and Polenec, 1984). Similarly, *Araneus marmoreus* Clerck preyed on Diptern and Hymenopteran insects at the rate of 14.1 prey per day (Parquet, 1984).

Shortest developmental period of spiderlings and highest survival rate and fecundity of. *L. pseudoannulata* were obtained when a mixture of larvae of *Drosophila* and nymphs of *N. lugens* were given when compared to spiderlings fed with each prey separately (Thang *et al.*, 1988). Studies on the predation by *T. octomaculatum* an important predator of rice hopper in the laboratory in China indicated that the spider attacked 0.25 to 1.88 individuals of *N. lugens* per day (Ge and Chen, 1989).

N. mukerjei, Cheiracanthium sp., *Thomisus* sp. and *Oxyopes* sp. were found to predate on adult and later instar nymphs of sorghum earhead bug, *C. angustatus* at the rate of 3.00, 4.00, 2.33 and 3.00 bugs per day (Hiremath, 1989). First instar larvae of *C. partellus* were consumed by *Oxyopes* sp. and *Cheiracanthium* sp. at the rate of 2.84 to 3.04 larvae in 24 h in the laboratory (Mohan *et al.*, 1990).

When the feeding efficiency of six predatory spiders *viz.*, *Salticus scenicus* (Clerck), *Pardosa birmanica* Simon, *O. pandae Thomisus* sp, *Neoscona nautica* (L.Koch) and *Cassinoides indica* L. on whitebacked plant hopper was studied, *S. scenicus* was found to be the most efficient predator consuming 4.95 nymphs of white backed plant hopper per day followed by *O. pandae* (3.76), *P. birmanica* (3.67) *Thomisus* sp. (3.45), *N. nautica* (2.55) and *C. indica* (1.83) (Bhathal and Dhaliwal, 1990). Rubia *et al.* (1990) reported that *L. pseudoannulata* fed on a variety of prey, including hoppers, collembolans, flies and the mirid predator *C. lividipennis*. According to them the consumption of prey by individual spiders increased with prey density.

The adult of the spider, *Lyssomanes sikkimensis* Tikader had significantly more predatory potential compared to the developmental instars. While the consumption rate of the different instars ranged from 0.60 to 5.20 mango hoppers per day, it was 9.60 for the adult spider (Sadana and Meenakumari, 1991). Twenty five species of spiders were observed to consume 2.00to 36.00 *Monellia caryella* (Fitch) (black margined aphids) per day in pecan (Bumroongsook *et al.*, 1992).

Tetragnatha sp. consumed 0.90 to 3.50 adult delphacids per day. Similarly, *Synaemops rubropunctatum* Mello-Leitao consumed 1.80 delphacids per day and 2.50, 1.40and 0.60, 1st, 2nd and 6th instar larvae of *Spodoptera frugiperda* (JE Smith) per day. On the other hand *Argiope* sp. consumed 4.10 delphacids per day (Bastidas *et al.*, 1994). While, *O. javanus* could kill 2.00 to 3.00 delphacidsperday, *Pardosa pseudoannulata* (Boesenberg and Strand), *A. catenulata* and *Tetragnatha japonica* Boesenberg and Strand killed 1.00 to 2.00 delphacids per day in rice fields in Philippines (Kamal and Dyck, 1994).

In a trial conducted in India, *Pardosa* sp. consumed 10.33 hopers over a period of five days and *Tetragnatha* sp. and *Oxyopes* sp. consumed 4.81 hoppers each (Samiayyan and Chandrasekharan, 1998). 4.80, 4.23 and 3.79 green leafhoppers were consumed per days by *L. pseudoannulata*, *Clubiona* sp. and *A. catenulata* in rice ecosystem of India (Sahu *et al.*, 1996). *P. pseudoannulata* consumed 3.93 green leaf hopper adults per 24 h (Singh and Singh, 2001).

Lycosa sp. consumed 1.60 *Chilo infuscatellus* Snellen larvae per day, *Argiope* sp. consumed 5.30 *Pyrilla perpusilla* Wlk. adults per day in a laboratory experiment conducted in India (Patil *et al.*, 2001).

O. shweta, C. melanostoma, L. poonaensis and *Thomisus pugilis* Stoliczka consumed 3.40 to 5.40, 6.60 to 10.50, 24.50 to 51.50, 28.00 to 31.60 *A. craccivora* in 24 h in the laboratory (Sebastian and Sudhikumar, 2002). *P. viridana, A. catenulata, O. javanus* and *N. theisi* consumed *A devastans, A. gossypii, B. tabaci, H. armigera* (larva) and *S. litura* (larva) at the rate of 5.40, 7.30, 3.90 and 4.10 and 4.40, 7.50, 7.20, 4.10 and 4.40, 8.00, 7.20, 4.10 and 4.50 and 3.90, 6.40, 7.20, 4.30 and 4.00 per day (Mathirajan and Regupathy, 2003). *T. maxillosa* and *L. pseudoannulata* consumed *N. lugens*, *Sogatella furcifera* (Horvath) and *Nephotettix* sp. at the rate of 12.40, 15.20, 16.60 and 26.60, 22.20 and 17.00 in seven days, respectively (Premila, 2003).

2.3.2 Prey Preference

Eventhough spiders have no discriminatory reaction and consume whatever prey is available, they do show preference when different prey are available.

Lycosa pseudoannulata (Boesenberg and Strand) when fed with a mixture of the adults of *Drosophila, Musca* and Whitefly and larvae of *Musca* had a higher survival rate than those provided with Drosophila alone (Gavarra and Raros, 1975). *Oxyopes* sp. had a greater preference for *Nephotettix virescens* (Distant) (39.23 per cent) followed by *S. furcifera* (19.19 per cent) and *N. lugens* (14.40 per cent) in a mixed population. On the other hand, *Pardosa* preferred *N. lugens* (41.04 per cent) to *S. furcifera* (30.79 per cent) and *N. virescens* (14.05 per cent) (Chiu, 1979).

The spider *Peucetia viridana* Stoliczka preferred *Amrasca devasatans* Distant to *Aphis gossypii* Glover. two important pests of cotton (Nyffeler *et al.*, 1989). In another study *P. viridana*, *O. javanus*, *Argiope catenulate* (Doleschall) and *N. theisi* preferred *A. gossypii* as major food followed by *Bemisia tabaci* (Gennadius) and *A. devastans* in cotton (Alerweireldt, 1994).

Studies conducted in India too revealed the prey preference of several spiders. *Pardosa* had a distinct preference for *N. lugens* and *S. furcifera* than *N. virescens*. *Tetragnatha* sp. preferred significantly more *N. virescens* (16.23 per cent) to *S. furcifera* (11.08 per cent) and *N. lugens* (10.44 per cent) (Nirmala, 1990; Ganeshkumar, 1994). The host preference of *L. pseudoannulata, A. catenulata* and *Clubiona* sp. in the descending order was green leafhopper, rice hispa, stem borer and leaf folder (Sahu *et al.*, 1996).

In another study conducted in Tamil Nadu, *Pardosa* spp. preferred brown plant hopper (BPH), white backed plant hopper (WBPH) and green leaf hopper (GLH), *Tetragnatha* sp. preferred GLH, WBPH and BPH, *Oxyopes* sp. preferred GLH, WBPH and BPH in descending order respectively (Samiayyan and Chandrasekharan, 1998).

Again when the different prey of spiders in cotton ecosystem were tested for their relative preference, *P. viridana* showed highest preference for *A. gossypii* (36 per cent), followed by *B. tabaci* (29 per cent) and *A. devastans* (24 per cent). Similarly, *A. catenulata* preferred *A. gossypii* (24 per cent) to *B. tabaci* (22 per cent) and *A. devastans* (18 per cent). *Oxyopes javanus* Thorell preferred *A. gossypii* (19 per cent), *B. tabaci* (17 per cent) and *A. devastans* 17 per cent), and *N. theisi* preferred *A. gossypii* (19 per cent), *A. devastans* (14 per cent) and *B. tabaci* (13 per cent) in the descending order (Mathirajan and Regupathy, 2003). *Tetragnatha maxillosa* Thorell and *L. pseudoannulata* showed significant preference for *Nephotettix* sp. and *Nilaparvata lugens* (Stal) respectively when a mixed diet of *N. lugens*. *S. furcifera* and *Nephotettix* sp was offered (Premila, 2003).

2.4 EFFECT OF INSECTICIDES

Reports from abroad and India indicated varied effects of chemical, botanical and microbial insecticides on spiders.

2.4.1 Chemical Insecticides

Both toxic and non-toxic effects of synthetic chemical insecticides have been documented.

2.4.1.1 Toxic Effect

Dust (BHC) and granular (methomyl) formulations of insecticides were observed to be highly lethal to spiders (Takahashi and Kiritani, 1973). Application of dimethoate to winter wheat in southern England reduced the population of araneae by 90 per cent seven days after treatment (Vickerman and Sunderland, 1977). Of the seven insecticides commonly used for the control of bean looper *viz.*, carbofuran (0.2 per cent), methamidophos (0.15 per cent), triazophos (0.15 per cent), trichlorphon (0.25 per cent), deltamethrin (0.1 per cent), carbaryl (0.25 per cent) and dimethoate (0.1 per cent) tested, triazophos and dimethoate were most injurious to the spider population in the bean fields of Peru causing 36.49 and 33.31 per cent mortality respectively (Yabar, 1982).

Application of carbofuran (0.56 kg ha^{-1}) in the foliage of alfalfa for a short period caused significant reduction of only *T. laboriosa*, but dimethoate (0.41 kg ha^{-1}) and azinphos-methyl (0.41 kg ha^{-1}) significantly reduced all foliage spiders upto 14 days (Culin and Yeargan, 1983). Initial mortality of more than 92 per cent of Linyphiid spiders occurred due to spraying of deltamethrin (7.5g ai ha^{-1}) in winter wheat in Germany (Basedow *et al.*, 1985). Malathion at 240 g ai ha^{-1} caused greater mortality of spiders than endosulfan and trichlorfon applied at the rate of 240 g ai ha^{-1} in cocoa plantations in Brazil (Mendes *et al.*, 1985). Chlorpyriphos and methomyl were more detrimental than carbaryl to the spiders in lucerne field in Misouri (Brandenburg, 1985). Population of araneae were found adversely affected by dimethoate (400 g ai ha^{-1}) and phosalone (600 g ai ha^{-1}) in wheat fields of France (Fischer and Chambon, 1987).

Three pesticides commonly used to control apple pests in Israel were found to be highly toxic to the spider *C. mildei*, the order of toxicity being endosulfan > azinphos-methyl>cyhexatin when tested by dry film technique and topical application (Mansour *et al.*, 1981).

Far fewer spiders were found in fields treated with insecticides such as monocrotophos, phosphamidon, and fenvalerate at a concentration of 0.02 per cent and even eliminated them completely from the fields due to continuous application of insecticides at higher concentrations (0.03 per cent and0.02 per cent) (Patel and Pillai, 1988). Permethrin (25g ai ha^{-1}) was more toxic to spiders than cypermethrin (25g ai ha^{-1}) and cyfluthrin

(10g ai ha^{-1}) during low rainfall than during high rainfall in soybean fields of Brazil (Link and Costa, 1988). The effect of the insecticides parathion, deltamethrin and endosulfan on the orb weaving spider, *Araneus* sp. when studied in the laboratory indicated that greater mortality of the spider was caused by parathion, followed by deltamethrin and endosulfan (Polesny, 1988). Similarly, spider population in apple orchard was reduced significantly after the application of diazinon, phosphamidon and azinphos-methyl (Sechser, 1988). The epigeal spider fauna in polders, *viz.*, erigonids and linyphids were observed to be sensitive to deltamethrin, fenitrothion and bromophos-ethyl when the effects of above ground application of the insecticides was studied (Everts *et al.*, 1989; Lohuis, 1990). Deltamethrin, fenitrothion and maneb appeared to be moderately harmful to the spider *Oedothorax apicatus* (Blackwall) observed in cereal and vegetable crops in Netherlands (Aukema *et al.*, 1990).

Densities of araneids were significantly reduced by application of chlorpyrifos in groundnut fields in Florida (Funderburk *et al.*, 1990). Fenitrothion, deltamethrin and bromophos-ethyl adversely affected spider fauna of wheat, barley and rape fields (Everts, 1990). Parathion and dimethoate were toxic towards aranea and caused 18 and 11 per cent reduction in population respectively. Fenvalerate reduced araneae population by 30.00 to 33.00 per cent and the toxic side effects were most apparent during the first few weeks after application (Casteels and Clercq, 1990). Ekalux was toxic to araneae in cotton field of Egypt (Darwish and Farghal, 1990).

Application of aldicarb at planting or treatment during the early squaring period with aldicarb, carbofuran or acephate in cotton reduced the number of spiders in Arizona (Terry, 1991). Lambda-cyhalothrin (10 g ai ha^{-1}) almost completely suppressed the activity, density and abundance of males of *Erigone* sp. Cypermethrin (16g ai ha^{-1}) suppressed web building frequency and severely affected web size and building accuracy of *Araneus diadematus* Cl. when tested in the laboratory (Samu and Vollrath, 1992). Deltamethrin and methamidophos adversely affected araneae population in cereal fields (Volkmar and Wetzel, 1993).

Dimethoate was highly toxic to the predatory spiders seen in the citrus fields of Brazil. Application of the insecticide reduced the population of the predator up to four days after application (Bittencourt and Cruz, 1998). Similarly, dimethoate and deltamethrin had severe effect on spiders in cereal fields in United Kingdom (Huusela, 2000).

Avermectin was highly toxic to spiders in vegetable fields (Cheng *et al.*, 2000). While T. *maxillosa* was highly susceptible to diazinon, *L. pseudoannulata* was more susceptible to phenthoate and carbaryl both in laboratory and field experiments (Tanaka *et al.*, 2000). Spiders were negatively affected by chlorpyrifos, but their number increased two weeks after treatment in maize fields in Brazil (Filho *et al.*, 2002).

The effect of insecticides on spiders was extensively studied in India too. The synthetic pyrethroid, cypermethrin was observed to be toxic to araneae in cotton fields in India (Muralidharan and Chari, 1990). Dimecron 85 EC (Phosphamidon) and Parataf 50 EC (methyl parathion when tested at 0.4 per cent concentration were highly toxic to spiders (Shunmugavelu and Palanichamy, 1991). Carbofuran seed treatment reduced the number of spiders in groundnut fields (Rao *et al.*, 2001). Imidacloprid (RIL 18, 20 SL) at all concentrations (100, 125, 400 ml ha^{-1}) were toxic to predatory spiders (30.66 per cent mortality at 100 ml ha^{-1}). Monocrotophos killed 83.33 per cent of spiders (Manjunatha and Shivanna, 2001). Carbofuran (1 and 0.5 kg ai ha^{-1}) and carbaryl (0.1 per cent) were injurious to the predatory spiders in rice fields in Andhra Pradesh, India (Vardhani and Rao, 2002). Ezeetab (deltamethrin 25 per cent tablet) at 10 and 12.5 g ai ha^{-1} recorded moderate toxicity against predatory spiders with 40.66 to 42.66 per cent mortality (Manjunatha *et al.*, 2002). Granular insecticides, carbofuran and fipronil significantly reduced the spider population (65 per cent) in soybean field in Hyderabad (Rao *et al.*, 2003). Commonly used insecticides for rice pest control *viz.*, carbaryl (0.15 per cent) phosphamidon (0.05 per cent) monocrotophos (0.05 per cent), quinalphos (0.05 per cent) and methyl parathion (0.05 per cent) caused 80 to 100 per cent mortality of spider predators in a laboratory study (Premila, 2003).

2.4.1.2 Non Toxic Effect

Single application of acephate, malathion and,methidathion did not cause any significant change in the spider population in citrus orchard of Florida (Fitzpatrick *et al.*, 1978). Carbaryl (0.25 per cent) and trichlorphon (0.25 per cent) caused only a low level of mortality of spiders (18.76 per cent and 21.05 per cent) in bean fields of Peru (Yabar, 1982). Diazinon, permethrin, malathion, methyl parathion and endosulfan did not produce any deleterious effect on predatory spiders in the vegetable patola Luffa cylindrica (L.) (Oben *et al.*, 1986). A laboratory study revealed that endosulfan was relatively harmless to the predatory spider *A. diadematus* (Polesny, 1988)

Carbosulfan and betacyfluthrin when applied to control *B. tabaci* were least toxic to araneae in cotton fields of Egypt (Darwish and Farghal, 1990). Deltamethrin, fenitrothion and maneb appeared to be harmless to moderately harmful to the spider *O. apicatus* (Aukema *et al.*, 1990). Propiconazole and dimethoate had only a weak effect on araneae of winter barley (Volkmar and Wetzel, 1993). Similarly, abundance of spiders was unaffected by imidacloprid and bendiocarb (Kunel *et al.*, 1999). Imidacloprid (Confidor 20 per cent) did not produce any side effects on predatory spiders after 30 days of application in rice fields of China (Ling and Wu 1999). Similarly in bean field of Brazil spraying of imidacloprid had no negative effect on predatory spiders (Marquini *et al.*, 2002). Like wise, imidacloprid did not reduce the number of spiders in citrus orchard in Australia (Mo and Philpot, 2003).

Studies on influence of commonly used insecticides on predatory population of rice indicated that acephate, chlorpyrifos and monocrotophos were safe to *L. pseudoannulata* and *Tetragnatha* sp. in rice fields of Tamil Nadu (Kumar and Velusamy, 2000). Spider population of okra was found unaffected by application of malathion in Orissa (Mishra and Mishra, 2002).

2.4.2 Botanical Insecticides

Population of araneae was not reduced in plots treated with neem seed kernal extract 48 days after treatment (Kareem *et al.*, 1988). Though there was an initial reduction in the number of *L. pseudoannulata* in neem treated rice plots, recolonisation was better (Mohan *et al.*, 1991). Similarly, neem products did not affect the population of *O. javanus* (TNAU, 1992). Commercial formulations of azdirachtin like neemgold (0.5 per cent) and Neemax (20 per cent) were safe to predators (Lakshmi *et al.*, 1998). Another formulation of azadirachtin, Nimbecidine did not show any toxic action or antifeedant effect on *L. pseudoannulata* (Ajayakumar, 2000). Neem formulations (Nimbecidine, Achook, Neemax, Neemgold, Rakshak and azadirachtin) did not reduce population of spiders such as *L. pseudoannulata*, *T. maxillosa* and *A. catenulata* (Dash *et al.*, 2001). Similarly, the neem formulations, Neemark (0.3 per cent) and Achook (0.3 per cent) wassafe to *Oxyopes* sp. in tea bushes in Himachal Pradesh (Sharma and Kashyap, 2002). The botanical insecticides Neemax (neem seed kernel extract) at 1.0 kg ha^{-1} and Multineem (neem oil) at 2.5 l ha^{-1} did not cause any effect on spiders of okra (Mishra and Mishra, 2002).

2.4.3 Microbial Insecticides

Few reports are available on the effect of microbial agents on spiders. The spiders belonging to the families Linyphidae, Lycosidae, Araneidae, Thomisidae and Salticidae when exposed to topical application of *Nomuraea atypicola*, developed mycosis (Greenstone *et al.*, 1987).

A spray of thuricide 90 TS was least injurious to spiders in rice ecosystem (Mendoza, 1972). Spraying of formulations of Bacillus thurinjiensis (Bt) like (Bitoxibacillin, Dendrobacillin, Entotaderin and BIP) in an orchard in USSR brought about an increase in spider population (Sklyarov, 1983). The Bt formulations (Delfin and Bactec) were less toxic to the predatory spiders in cotton fields in India (Patel and Vyas, 2000). Bt formulation Dipel 8L at 0.3 per cent was safe to predatory spiders in tea plantations of Himachal Pradesh. (Sharma and Kashyap, 2002). Spiders of okra were unaffected by the Bt formulation Biotox when applied at the rate of 1 kg ha^{-1} (Mishra and Mishra, 2002). Similarly, Biobit (Rao and Singh, 2003) and Delfin WG (Gopan, 2003) had only low toxic effect on spiders in rice fields.

Materials and Methods

3. MATERIALS AND METHODS

Survey was conducted in Kalliyoor panchayat, an important vegetable growing tract in Thiruvananthapuram district during the summer of 2004 to record the spider fauna in vegetable ecosystem. Studies on the seasonal abundance, predatory potential, prey preference and effect of insecticides on the major spiders encountered in the vegetable plots were conducted at the College of Agriculture, Vellayani.

3.1 DOCUMENTATION OF SPIDER FAUNA

Five vegetables of different architecture *viz*., okra (*Abelmoschus esculentus* (L.) Moench.), brinjal (*Solanum melongena* L.), cowpea (*Vigna unguiculata* subsp. *sesquipedalis* (L.) Walp., bittergourd (*Momordica charantia* L.) and amaranthus (*Amaranthus tricolor* L.), were selected for the study. Four plots (approximately 20 cents) of each vegetable were selected at random in the Kalliyoor ward of the identified panchayat. The crops were examined carefully for the occurrence of spiders at fortnightly intervals from planting till the end of the cropping season (one month for amaranthus and three months for the other vegetables). The spiders observed were collected in small perforated polythene bags, labelled and brought to the laboratory. Additionally, ten plants were selected at random in each plot and the number of spiders on each plant was recorded every fortnight. The sampling units were changed randomly during each observation. The pests prevalent in abundance to moderate abundance in each of the vegetable plots and the plant protection measures adopted by the farmers were recorded.

3.1.1 Identification of Spiders

The spiders collected from the vegetable plots were sorted and the adults were separated and preserved in 70 per cent ethyl alcohol. The specimens were identified by Dr. P.A. Sebastian, Reader, Division of

Arachnology, Department of Zoology, Sacred Heart College, Thevara, Cochin, Kerala.

3.2 ASSESSMENT OF SEASONAL ABUNDANCE

A plot of each of the vegetables (okra, brinjal, cowpea bitter gourd and amaranthus) was selected in the Instructional Farm, Vellayani during summer and rainy seasons for studying the seasonal abundance of spiders. The crops were maintained as per the package of practices of Kerala Agricultural University (KAU, 2002). Plant proteotion measures were applied on need basis. The population of spiders on 10 plants selected at random was recorded as described in 3.1

3.3 DETERMINATION OF PREDATORY EFFICIENCY

The prey range, predatory potential and prey preference of the four major spiders observed in the vegetable ecosystem *viz., O. javanus, C. danieli, N. mukerjei* and *T. mandibulata* were studied in the laboratory.

3.3.1 Raising of Host Plants

Seeds of cowpea, bhindi and bittergourd were sown in clay pots (15 cm diameter) filled with potting mixture (soil, sand and cowdung in 1 : 1 : 1) at the rate of three seeds per pot. Seeds of brinjal and amaranthus were sown in pots filled with potting mixture and the seedlings were transplanted to the pots (15cm diameter) at four leaf stage at the rate of three seedlings per pot. The plants were watered daily. One-month-old plants covered with perforated polyethylene covers (50 x 35 cm) were used for the various studies.

3.3.2 Test Insects and Their Culturing

The pests recorded as mentioned in 3.1 were maintained in the unsprayed fields of the respective vegetables in the Instructional Farm, Vellayani and were collected as and when required.

3.3.3 Evaluation of Prey Range

The pests observed in each of the vegetable plots during the survey as mentioned in 3.1 were tested for their preference for feeding by the four dominant spiders in the vegetable ecosystem.

The adults of the spiders were collected from pesticide unsprayed vegetable plots, sorted to uniform size and starved for 24 hours. The spiders were then caged in the pots containing 30-day-old plants of the respective vegetable at the rate of one spider per cage. The pests (ten numbers each) of each vegetable were released together in a cage. Three replications were maintained for each treatment. Observations were taken daily on the number of individuals consumed for five days. The prey insects were replenished to maintain the prey density at ten after each observation.

3.3.4 Evaluation of Predatory Potential

Five pests preferred most by the spiders in the prey range test (3.3.3) were selected for determining the predatory potential. The experiment was conducted in completely randomized block design with ten replications as described in 3.3.3. The number of insects predated on was recorded 24 hours after release and the observations were continued for seven days.

3.3.5 Evaluation of Prey Preference

The relative preference of the dominant spiders for the preferred hemipteran and lepidopteran pests of different vegetables was determined as described in 3.3.3 and 3.3.4 by supplying a mixed population of the prey.

3.4 ASSESSMENT OF TOXICITY /SAFETY OF INSECTICIDES.

The chemical, botanical and microbial insecticides commonly used for the control of pests of vegetables (Table 1) were evaluated for their relative toxicity/safety to the spiders *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* at their recommended doses. Different doses of the chemical insecticides were also screened to determine their extent of toxicity.

Table1. Chemical, botanical and microbial insecticides tested against spiders in vegetable ecosystem

Sl no	Common name	Trade name	Dose (per cent)	Company/Source
a.	**Chemical insecticides**			
1	Dimethoate	Rogor 30EC	0.025 0.05 0.1	Sree Ramcides Chemicals Pvt. Ltd
2	Carbaryl	Sevin 50WP	0.15 0.2 0.3	Agrochemicals (India) Ltd.
3	Malathion	Malathion 50EC	0.05 0.1 0.2	Sree Ramcides Chemicals Pvt. Ltd
4	Quinalphos	Ekalux 25EC	0.025 0.05 0.1	Novartis India Ltd
5	Imidacloprid	Confidor 200SL	0.02 0.03 0.04	Bayer (India) Ltd.
b	**Botanical insecticides**			
1	NSKE		5	Preparation
2.	Neem leaf extract		5	Preparation
3	Neem oil		2	
4	Pongamia oil		2	
5	Iluppai oil		2	
6.	Marotti oil		2	
7	Azadirachtin 1 %	Neem Azal T/S	2ml/litre	M/S EID Parry (I) Ltd.
c	**Microbial insecticides**		Spores ml^{-1}	
1.	*Fusarium pallidoroseum*		7×10^6	Department of Agricultural Entomology, College of Agriculture, Vellayani
2.	*Fusarium* sp.		5×10^6	
3.	*Metarhizium anisopliae*		1×10^8	
4.	*Beauveria bassiana*		1×10^7	
5.	*Paecilomyces lilacinus*		1×10^8	
6.	*Bacillus thuringiensis* var *kurstaki*	Delfin W.G.	0.2 per cent	Margo Biocontrol Pvt. Ltd.

count in a drop of the suspension was estimated using a haemocytometer. The suspension was further diluted to adjust the spore count to the desired concentration.

3.4.2 Testing for Toxicity

Topical application and release on sprayed plant technique were followed for testing the toxicity of the chemical and botanical insecticides to the spiders. Potted okra plants raised as described in 3.3.1 were used as test plants. Pathogenicity test was conducted to determine the infectivity of the microbial insecticides to the spiders.

3.4.2.1 Topical Application

Five adults of each spider were taken in a clean petridish and the insecticide solutions were sprayed directly on them with an atomizer. Spiders sprayed with water served as control. The treated spiders were kept exposed under a fan for the spray fluid to evaporate. The spiders were then transferred individually to the okra plants and were provided with food (prey insects–aphids, whiteflies and jassids). Three replications were maintained for each treatment. Mortality of the spiders was recorded every 24 hours upto seven days.

3.4.2.2 Release on Sprayed Plants

Bhindi plants sprayed with the respective insecticides were confined in cages and a spider was released to each plant. A set of five such plants served as a treatment and three replications were maintained for each treatment. Mortality of the spiders was recorded daily for seven days.

The mortality of spiders observed in 3.4.2.1 and 3.4.2.2 was corrected using Abbot's formula (Abbot, 1925).

3.4.2.3 Pathogenicity Test

The spiders were placed in small glass jars of 5 cm diameter and 10 cm height. The spore suspension was sprayed on the spiders and the jar

3.4.1 Preparation of Spray Solution

Commercial formulations

The required quantities of the chemical insecticides were weighed or pipetted and mixed with a small quantity of water and made up to 100 ml to prepare the spray solutions

Neem Seed Kernel Extract (NSKE)

Neem seed kernels were crushed to coarse powder and 50g of the powder was taken in a cloth bag and dipped in half a litre of water for 24 hours. The cloth bag was then squeezed repeatedly till the outflow turned light brown. Ordinary bar soap (5g) was sliced and dissolved in half a litre of water. The soap solution was added to the kernel extract and stirred well to prepare neem seed kernel extract.

Neem leaf extract

Fifty grams of neem leaves were macerated in a mixie and soaked in one litre of water for 48 hours. The solution was strained to obtain the neem leaf extract.

Oil emulsions

Sliced soap (5g) was dissolved in 500 ml of water to prepare soap solution. The plant oil (20 ml) were added to the soap solution with continuous stirring and the solution was made upto 1litre to prepare 2 per cent oil emulsion.

Microbial insecticides

The fungi were grown over potato dextrose agar (PDA) plated on sterilized petri-plates. Seven-day-old cultures of the fungi were used for making the spray solutions. Ten ml of distilled water was taken in a sterile test tube and five fungal discs of 7 mm diameter of the respective fungi were added to it and shaken vigorously for two minutes. The suspension obtained was filtered through a muslin cloth and the spore was closed with a wet muslin cloth and kept as such for 15 minutes. The treated spiders were then released individually into caged bhindi plants provided with prey insects. The mortality of the predator was recorded every 24 hours upto seven days.

The dead spiders were transferred to petridishes containing moistened filter paper. When fungal growth was noticed, the spiders were transferred to petridishes plated with PDA. The fungal growth obtained was sub-cultured. One week old fungal growth from the sub-culture was taken and made into spray solution as described in 3.4.1 and the spiders were treated as mentioned above. The experiment was repeated to get the same pathogen from the dead spiders.

3.5 STATISTICAL ANALYSIS

Data of each experiment were analysed, applying suitable methods of analysis (Panse and Sukhatme, 1967).

Results

4. RESULTS

Spiders are ubiquitous group of predators found in agro-ecosystems. Often, they occur in such convincing abundance, signifying the crucial role they could play in the dynamics of every habitat. Results of the study conducted on the spider fauna associated with five popular vegetables of Kerala, their prey range, predatory potential, prey preference and sensitivity to insecticides are presented in Tables 2 to 16.

4.1 SPIDER FAUNA IN VEGETABLE ECOSYSTEM

Survey undertaken in Kalliyoor Panchayat of Thiruvananthapuram district to document the spider fauna in vegetable ecosystem revealed the prevalence of an appreciable population of spiders in okra, brinjal, cowpea, bittergourd and amaranthus fields. Population of the natural enemy ranged from 6 to 35 per 10 plants in a cropping season (Table 2.). High population of spiders was recorded from okra, the number of spiders in the different fields ranging from 17 to 35 per 10 plants. Population of the araneae in brinjal ranged from 15 to 18 per 10 plants. In the climbers *viz.*, cowpea and bittergourd, population of the predator ranged from 14 to 31 and 15 to 21 per 10 plants, respectively. The number of spiders ranged from 6 to 9 per 10 plants in amaranthus.

The two guilds *viz.*, hunting and web building spiders were prevalent in the vegetable fields (Table 3). The hunters were significantly dominant in the vegetable ecosystem, constituting 65.50 per cent of the spider population. The web builders formed only 34.50 per cent of the population. However, among the various vegetable fields, there was no significant difference in the occurrence of hunting and web building spiders. While the occurrence of hunters in okra, brinjal, cowpea, bittergourd, and amaranthus ranged from 62.50 to 70.30 per cent, the presence of web builders ranged from 29.70 to 37.50 per cent.

Table 2. Population of spiders in different vegetable fields in Kalliyoor Panchayat of Thiruvananthapuram district during summer, 2004

Vegetables	Spider population in a crop period (number per ten plants)			
	F1	F2	F3	F4
Okra	35	34	17	32
Brinjal	17	16	15	18
Cowpea	21	31	14	30
Bittergourd	21	16	15	18
Amaranthus	8	9	8	6

F : Field
Crop period : Okra, Brinjal, Cowpea, Bittergourd – 3 months
Amaranthus – 1 month

Table 3. Relative abundance of hunting and web building spiders in vegetable fields (%)

Vegetables	Hunting spiders	Web building spiders
Okra	62.50	37.50
Brinjal	68.00	32.00
Cowpea	70.30	29.70
Bittergourd	62.80	37.20
Amaranthus	64.00	36.00
Mean	65.50	34.50

CD (0.05) Treatments : NS
CD (0.05) Spiders : 4.810

4.1.1 Species Diversity

Thirty species of spiders belonging to nine families were recorded from the vegetable fields during the period of study (Table 4). The hunting spiders included the diurnal hunters and the diurnal ambushers. Four species of *Oxyopes viz*., *O. javanus, O. shweta, O. quadridentatus* and. *Oxyopes* sp., *P. viridana* (Plate1), *Hyllus semicupreus* (Simon), *Hyllus* sp., *Carrhotus* sp., *Phidippus sp.*, *Telamonia dimidiata* (Simon) (Plate2), *Cheiracanthium* sp, *Cheiracanthium danieli* Tikader, *Clubiona* sp.(Plate 3) and *Lycosa* sp. comprised the assemblage of diurnal hunters recorded from the plots. *Thomisus pugilis* Stoliczka, *Thomisus sorajaii* Basu, *Thomisus* sp (Plate3) and *Castineira zetes* Simon were the diurnal ambushers observed in the different vegetable plots.

Neoscona sp. was the important genera of orb weavers recorded, the different species observed being *Neoscona mukerjei* Tikader, *Neoscona vigilans* (Blackwall), *Neoscona molemensis* Tikader & Bal and *Neoscona poonaensis* (Tikader & Bal) and two other species (Plate4). The other web builders observed were *Araneus* sp., *Argiope anasuja* Thorell, *Argiope pulchella* Thorell, *Argiope aemula* (Walkenaer), *T. mandibulata* (Plate5) and *Tetragnatha* sp.

Among the different families of spiders seen, Araneidae consisting of ten species (six species of *Neoscona*, *Araneus* sp and three species of *Argiope*) was the most represented family in the vegetable ecosystem. Oxyopidae (four species of *Oxyopes* and *P. viridana)* and Salticidae (two species of *Hyllus*, *Carrhotus* sp. *Phidippus* sp. and *T. dimidiata*.) each comprising of five species too were well represented. These were followed by Thomisidae having three species and Miturgidae, and Tetragnathidae which were equally represented with two species each. Least diversity was observed in the families Corinnidae, Lycosidae and Clubionidae. Only one species of spider *viz*., *C. zetes*, *Lycosa* sp. and *Clubiona* sp., respectively was recorded in each of the families.

Table 4. Spiders encountered in the vegetable fields in Kalliyoor panchayat of Thiruvananthapuram district and their occurrence in different stages of the crop

Sl. No.	Spider species	Family	Habitat	Occurrence of spiders at various crop stages				
				O	Br	C	Bg	A
I	**Hunting spiders**							
	a. Diurnal hunters							
1	*Oxyopes javanus* Thorell	Oxyopidae	Upper and middle portion of plant – on leaves and stems	V&R	V. R & M	V, R & M	V. R & M	V
2	*Oxyopes shweta* Tikader			-	R	R&M	R&M	-
3	*Oxyopes quadridentatus* Thorell			R&M	R&M	-	-	-
4	*Oxyopes* sp.			V&R	-	R	R	-
5	*Peucetia viridana* (Stoliczka)			-	-	-	-	V
6	*Hyllus semicupreus* (Simon)	Salticidae	Upper. middle and lower portion of plant – on leaves and stems	-	V & R	-	-	-
7	*Hyllus* sp.			V, R & M	-	-	-	-
8	*Carrhotus* sp.			V&R	R	R&M	-	-
9	*Phidippus* sp.			V&R	R	V&R	R	-
10	*Telamonia dimidiata* (Simon)			V, R & M	V, R & M	V, R & M	V&R	-
11	*Cheiracanthium danieli* Tikader	Miturgidae	Upper portion of plant on inflorescences and inside tubular folds in leaves	V. R & M	V. R & M	V, R & M	V. R & M	V
12	*Cheiracanthium* sp.			V, R & M	V&R	V, R & M	R&M	V
13	*Clubiona* sp.	Clubionidae	Upper portion of plant – on leaves	V&R	V&R	R&M	V&R	V
14	*Lycosa* sp.	Lycosidae	Middle portion – leaves and stems	-	-	R&M	V&R	-
	b. Diurnal ambusher							
15	*Thomisus pugilis* Stoliczka	Thomisidae	Upper portion of plant – more on flowers	-	-	-	V&R	-
16	*Thomisus sorajaii* Basu			-	-	-	V&R	-
17	*Thomisus* sp.			-	-	-	R	-
18	*Castineira zetes* Simon	Corinnidae	Upper portion of plant – on upper surface of leaves in web like coverings	V&R	-	-	-	-

Table 4. Continued

Sl. No.	Spider species	Family	Habitat	Stage of the crop				
				O	Br	C	Bg	A
II	**Web building spiders**							
	Orb web weavers							
19	*Neoscona mukerjei* Tikader	Araneidae	Upper and middle portion of plant – inside small leaf foldings and webs	R &M	R &M	R &M	V&R	V
20	*Neoscona vigilans* (Blackwall)			R &M	-	-	-	-
21	*Neoscona molemensis* Tikader & Bal			-	-	-	R &M	-
22	*Neoscona poonaensis* (Tikader & Bal)			-	-	-	-	V
23	*Neoscona* sp.			V&R	V&R	V&R	R	V
24	*Neoscona* sp.			V&R	V&R	V&R	-	-
25	*Araneus* sp.			-	-	R	-	-
26	*Argiope anasuja* Thorell			-	-	V&R	-	-
27	*Argiope pulchella* Thorell			-	R&M	-	-	-
28	*Argiope aemula* (Walkenaer)			R&M	-	-	-	-
29	*Tetragnatha mandibulata* Cambridge.	Tetragnathidae	Upper and middle portion – in webs constructed in between plant parts and plants	R&M	R&M	V,R&M	V,R&M	V
30	*Tetragnatha* sp.			-	R&M	R&M	V,R&M	V

O – Okra Br – Brinjal C – Cowpea Bg – Bittergourd A – Amaranthus

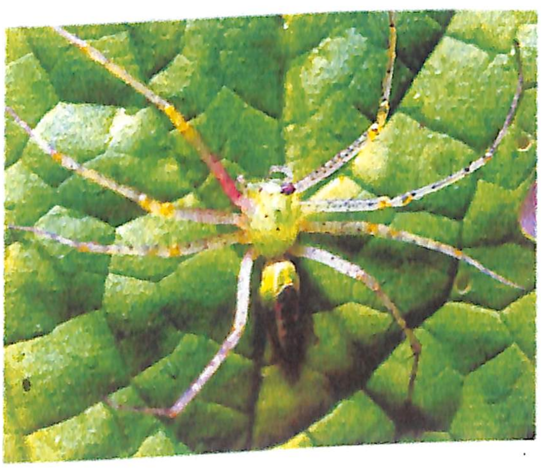
V – Vegetative R – Reproductive M – Maturity

Oxyopes javanus

Oxyopes shweta

Oxyopes quadridentatus

Oxyopes sp.



Adult

Spiderlings

Peucetia viridana

Plate 1. Lynx spiders recorded from vegetable fields

Hyllus semicupreus

Hyllus **sp.**

Carrhotus **sp.**

Phidippus **sp.**

Adult

Nymph

Telamonia dimidiata

Plate 2. Jumping spiders recorded from vegetable fields

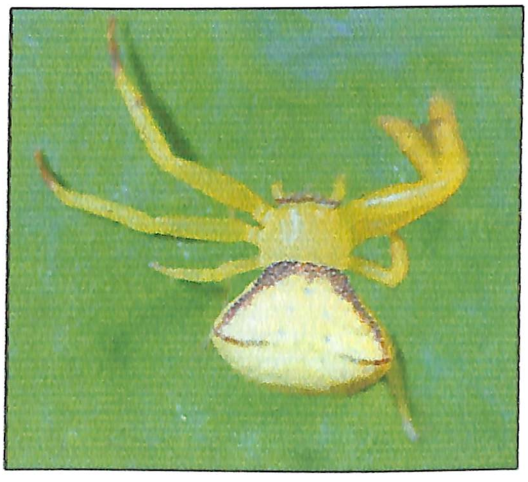
Cheiracanthium danieli

Cheiracanthium sp.

Clubiona sp.

Thomisus pugilis

Thomisus sorajaii



Thomisus sp.

Plate 3. Running and crab spiders recorded from vegetable fields

Neoscona mukerjei

Neoscona vigilans

Neoscona molemensis

Neoscona poonaensis

Neoscona sp.

Neoscona sp.

Plate 4. Species of *Neoscona* recorded from vegetable fields

***Araneus* sp.**

Argiope anasuja

Argiope pulchella

Argiope aemula

Tetragnatha mandibulata

Plate 5. Orb weavers recorded from vegetable fields

Considering the habitat of the various spiders, the lynx spiders (Family: Oxyopidae) were found on the upper and middle portion of the plants, on leaves and stems moving over the vegetation with great agility. Members of the Salticidae family were observed in the upper, middle and lower portions of the plants. *Cheiracanthium* spp. (Miturgidae) and *Clubiona* sp. (Clubionidae) mostly prevailed on the upper part of the plants, inflorescences and inside tubular folds in leaves. The lycosid was seen in the middle portion of the plants on leaves and stems. The diurnal ambushers (Thomisidae and Corinnidae) preferred the upper part of the plants. While the crab spiders (Thomisidae) were mostly recorded from the buds and flowers, *C. zetes* (Corinnidae) was seen on upper surface of leaves in web like coverings. Habitat of the orb weavers was generally in the upper and middle parts of the plants. Members of the araneidae family were usually found inside leaf foldings and webs. *Tetragnatha* spp. remained in webs constructed either between different parts of the plant or neighbouring plants.

4.1.1.1 Spider Fauna in Okra Fields

Seventeen species of spiders belonging to seven families were recorded from the okra fields. The spider fauna included, *O javanus*, *O quadridentatus*, *Oxyopes* sp, *Hyllus* sp., *Carrhotus* sp., *Phidippus* sp., *T. dimidiata*,. *C. danieli*, *Cheiracanthium* sp., *Clubiona* sp, *C. zetes*, *N mukerjei*, *N. vigilans*, two other species of *Neoscona*, *A. aemula and T. mandibulata*. Of these, four species *viz.*, *Hyllus* sp, *C. zetes*, *N vigilans* and *A. aemula* were noticed only in the okra plots.

Among the families recorded, Araneidae with five species and Salticidae with four species were the well represented families in the okra plots followed by Oxyopidae with three species. The other families seen were Miturgidae with two species, Clubionidae, Corinnidae and Tetragnathidae with a single species each.

Most of the spiders appeared during the vegetative and reproductive stages of the crop. *O. javanus* and *Oxyopes* sp., were seen both in the vegetative and reproductive stages. *O. javanus* was seen in abundance during the flowering stage. Contrarily, *O. quadridentatus* was noted in the reproductive and later stages of the crop. *Hyllus* sp. which was recorded exclusively from okra plots was seen from the vegetative to the maturity stage of the crop, more population of the spider being observed in the flowering and fruiting stages. *Carrhotus* sp., *Clubiona* sp., *Phidippus* sp. and *C. zetes* were recorded both in the vegetative and reproductive stages. *T. dimidiata, C. danieli* and *Cheiracanthium* sp. were prevalent from the vegetative to the maturity stage of the crop. With the exception of two species of *Neoscona* which occurred in the vegetative and reproductive stages, all the other orb weavers *viz., N. mukerjei, N. vigilans, A. aemula* and *T. mandibulata* were seen from the reproductive to the maturity stages of okra.

4.1.1.2 Spider Fauna in Brinjal Fields

Sixteen species of spiders distributed in six families were recorded from the brinjal fields. Fourteen species of the spiders noted *viz., O.javanus, O. shweta, O. quadridentatus, Carrhotus* sp, *Phidippus* sp, *T. dimidiata C. danieli, Cheiracanthium* sp, *Clubiona* sp., *N. mukerjei,* two other species of *Neoscona, T. mandibulata* and *Tetragnatha* sp. were common to the other vegetable fields too. The spiders recorded exclusively from the brinjal fields were *H. semicupreus* and *A. pulchella.*

Araneidae and Salticidae, with four species each were the well represented families in brinjal plots closely followed by Oxyopidae with three species. Miturgidae and Tetragnathidae with two species each were equally represented in the plots. The family Clubionidae was represented by only one species.

Most of the spiders appeared in the plots one month after transplanting. *O. javanus* was recorded from the vegetative to the maturity stages. However, another species of the lynx spider, *O. shweta* was observed only in the reproductive stage of the crop. *H. semicupreus* and *Clubiona* sp. were recorded in the vegetative and reproductive stages. *T. dimidiata* and *C. danieli* were seen from the vegetative to the maturity stages of the crop. *Carrhotus* sp. and *Phidippus* sp. appeared during the reproductive stage. The web builders *N. mukerjei, A. pulchella, T. mandibulata* and *Tetragnatha* sp. were observed only from the reproductive stage and prevailed up to the maturity of the crop. On the other hand, two species of *Neoscona* were observed in the vegetative and reproductive stages of brinjal.

4.1.1.3 Spider Fauna in Cowpea Fields

The spiders recorded from the cowpea fields comprised of seventeen species in seven families. While *O javanus, O. shweta, Oxyopes* sp., *Carrhotus* sp., *Phidippus* sp., *T. dimidiata, C. danieli, Cheiracanthium* sp., *Clubiona* sp., *Lycosa* sp., *N. mukerjei*, two species of *Neoscona, T. mandibulata, Tetragnatha* sp., which prevailed in other vegetable fields were seen in the crop. *A. anasuja* and *Araneus* sp. were recorded only from cowpea fields.

Araneidae consisting of five species was the most represented family in the cowpea fields closely followed by Oxyopidae and Salticidae with three species and Tetragnathidae and Miturgidae with two species each. Clubionidae and Lycosidae with one species each were the least represented families.

O. *javanus* was prevalent in cowpea plots from the vegetative stage and throughout the cropping season. *O. shweta, Carrhotus* sp., *Clubiona* sp. and *Lycosa* sp. appeared in the reproductive stage and continued to be observed up to the maturity stage of the crop too. *Oxyopes* sp and *Araneus* sp. were observed during the reproductive stage. As in other crops, *T. dimidiata, C. danieli* and *Cheiracanthium* sp. were seen from the vegetative to the maturity stages of the crop. *A. anasuja, Neoscona* spp. and *Phidippus* sp appeared in the field during the vegetative stage and were present in the reproductive stage also. *N. mukerjei* was recorded in the reproductive and maturity stages. *T. mandibulata* was noticed from the vegetative to the maturity stage while *Tetragnatha* sp. was seen only during reproductive and maturity stages.

4.1.1.4 *Spider Fauna in Bittergourd Fields*

Seventeen species of spiders, distributed in eight families, were recorded from bittergourd fields. They included *O. shweta*,, *O. javanus*, *Oxyopes* sp., *C. danieli*, *Cheiracanthium* sp., *Clubiona* sp., *Phidippus* sp, *Lycosa* sp., *T. mandibulata*, *Tetragnatha* sp., *T. dimidiata* *N. mukerjei* *Neoscona* sp., *N. molemensis*, *T. sorajaii*, *T. pugilis* and *Thomisus* sp. Of these, *N. molemensis*, *T. sorajai*, *T. pugilis* and *Thomisus* sp. were seen only in bittergourd fields.

Oxyopidae, Araneidae and Thomisidae with three species each were equally represented in bittergourd plots. Tetragnathidae and Salticidae were represented by two species each while Clubionidae and Lycosidae were represented with only one species each.

In bittergourd too *O. javanus* appeared during the vegetative stage and prevailed up to the end of the cropping season. *O. shweta*, *Cheiracanthium* sp. and *N. molemensis* appeared only during the reproductive stage and were seen up to the maturity stage too. *Oxyopes* sp., *Phidippus* sp., *Thomisus* sp. and *Neoscona* sp. were noticed only in the reproductive stage of the crop. Like *O. javanus*, *C. danieli*, *T. mandibulata* and *Tetragnatha* sp. too appeared during the vegetative stage and were seen throughout the cropping season. *T. dimidiata*, *Clubiona* sp., *Lycosa* sp., *T. pugilis*, *T. sorajaii* and *N. mukerjei* were noticed during the vegetative and reproductive stages of the crop.

4.1.1.5 *Spider Fauna in Amaranthus Fields*

Ten species of spiders belonging to five families were recorded from the amaranthus field. The species observed included *O. javanus*, *P. viridana*, *C. danieli*, *Cheiracanthium* sp., *Clubiona* sp., *N. mukerjei*, *N. poonaensis*, *Neoscona* sp., *T. mandibulata* and. *Tetragnatha* sp. Of these, *P. viridana* and *N. poonaensis* were recorded only from amaranthus fields.

Araneidae with three species was the most represented family in amaranthus. Oxyopidae, Miturgidae and Tetragnathidae were equally represented in the field by two species each. Only one species was recorded for Clubionidae.

All the spiders were observed throughout the cropping season.

4.1.2 Dominant Spiders in Vegetable Ecosystem

Among the different genera of spiders recorded from okra, brinjal, cowpea, bittergourd and amaranthus, the hunters *O. javanus* and *C. danieli* and the web weavers *N. mukerjei* and *T. mandibulata* were dominant in all the vegetable plots. The occurrence of the four major spiders was statistically on par, the percentage of abundance ranging from 17.22 to 21.34 (Table 5).

Among the four spiders, the hunting spiders *O. javanus* (24.50 per cent) and *C. danieli* (23.43 per cent) were dominant in the vegetable ecosystem and were on par in their abundance. They were followed by the web builders, *T. mandibulata* (14.44 percent) and *N. mukerjei* (14.06 per cent), occurrence of which did not differ significantly.

Regarding the relative abundance of the four spiders in each vegetable plot, the hunting spiders *O. javanus* (28.78 per cent) and *C. danieli* (28.74 per cent) were equally dominant in okra fields. Comparatively, population of the web builders, *T. mandibulata* (17.70 per cent) and *N. mukerjei* (11.94 per cent) was low. In brinjal plots too, *O. javanus* (26.34 per cent) and *C. danieli* (18.36 per cent) were the dominant spiders seen and their percentage abundance was statistically on par. The other spiders *T. mandibulata* (13.50 per cent) and *N. mukerjei* (12.20 per cent) were on par which in turn were on par with *C. danieli* in their abundance. Again, *O. javanus* and *C. danieli* dominated in cowpea fields, their percentage abundance being 28.90 and 24.73 per cent respectively and their abundance was superior to that of *T. mandibulata* (10.83 per cent) and *N. mukerjei* (6.92 per cent). Both *T. mandibulata* and *N. mukerjei* were on par in their occurrence in the plot. *O. javanus* (27.99) was the major spider in

Table 5. Relative abundance of four dominant spiders in different vegetable crops (%)

Vegetables	*O. javanus*	*C. danieli*	*N. mukerjei*	*T. mandibulata*	Mean
Okra	28.78 (5.36)	28.74 (5.36)	11.94 (3.46)	17.70 (4.21)	21.16 (4.60)
Brinjal	26.34 (5.13)	18.36 (4.29)	12.20 (3.50)	13.50 (3.67)	17.22 (4.15)
Cowpea	28.90 (5.38)	24.73 (4.97)	6.92 (2.63)	10.83 (3.29)	16.56 (4.07)
Bittergourd	27.99 (5.29)	17.90 (4.23)	14.57 (3.82)	13.33 (3.65)	18.06 (4.25)
Amaranthus	12.78 (3.57)	28:76 (5.36)	28.75 (5.36)	17.47 (4.18)	21.34 (4.62)
Mean	24.50 (4.95)	23.43 (4.84)	14.06 (3.75)	14.44 (3.80)	

CD (0.05) Treatments : 1.026

CD (0.05) Spiders : 0.459

CD (0.05) Vegetables : Not Significant (NS)

Figures in parentheses are $\sqrt{x}$ transformed values bittergourd and was superior to the other spiders in its abundance. No significant difference was observed in the occurrence of *C. danieli* (17.90 per cent), *N. mukerjei* (14.57 per cent) and *T. mandibulata* (13.33 per cent) in the vegetable. On the other hand, *C. danieli* and *N. mukerjei* were the dominant spiders in amaranthus plots, the percentage abundance being 28.76 and 28.75 respectively. Statistically, the spiders were superior in their prevalence to *T. mandibulata* and *O. javanus* (12.78) which were on par.

Considering the abundance of each spider in the different vegetable fields, there was no significant difference in the occurrence of *O. javanus* in okra, brinjal, cowpea and bittergourd plots. In contrast, the abundance of the spider was significantly lower in amaranthus. Similarly, there was no significant difference in the occurrence of *C. danieli* in okra, amaranthus and cowpea fields. The percentage abundance of the spider in brinjal and bittergourd plots was statistically on par with the occurrence of the carnivore in cowpea plots. *N. mukerjei* was more abundant in amaranthus and it differed significantly from its abundance in the other vegetable plots. The abundance of the spider in bittergourd brinjal and okra were on par. Comparatively, prevalence of the spider was low in cowpea plots. However, it was on par with the abundance of the spider in brinjal and okra plots. The relative abundance of *T. mandibulata* in the different vegetable plots did not differ significantly.

4.1.3 Major Pests in the Vegetable Fields

The pests observed in the different vegetable plots during the period of survey are presented in Table 6. Most of the pests recorded were in the orders Hemiptera, Lepidoptera and Coleoptera.

Okra (*A. esculentus*)

The hemipteran pests observed in the okra plots were the aphid *A. malvae*, the leaf hopper *A. biguttula biguttula*, the whitefly *B. tabaci* and the red cotton bug *D. cingulatus*. Of these, *A. biguttula biguttula* was

Table 6. Pests prevalent in the vegetable plots in Kalliyoor panchayat of Thiruvananthapuram district during summer, 2004

Order	Family	Common name	Scientific name
Okra			
Hemiptera	Aphididae	Aphid	*Aphis malvae* Koch.
	Aleurodidae	Whitefly	*Bemisia tabaci (Gennadius)*
	Cicadellidae	Leaf hopper	*Amrasca biguttula biguttula* (Ishida)
	Pyrrhocoridae	Red cotton bug	*Dysdercus cingulatus* (F.)
Lepidoptera	Pyralidae	Leaf roller	*Sylepta derogata* F.
	Noctuidae	Semi looper caterpillar	*Xanthodes groellsi* Fsth.
		Leaf caterpillar	*Spodoptera litura* (F.)
		Fruit and shoot borer	*Earias vitella* (F.)
Coleoptera	Meloidae	Flower beetle	*Mylabris pustulata* Thunb
Brinjal			
Hemiptera	Aphididae	Aphid	*Aphis gossypii* Glover
	Pseudococcidae	Mealy bug	*Coccidohystrix insolitus* Gr
	Tingidae	Lace wing bug	*Urentius hystricellus* (Richt)
Lepidoptera	Noctuidae	Leaf folder	*Antoba olivaceae* Wlk
	Pyralidae	Leaf webber	*Psara bipunctalis* F.
		Fruit and shoot borer	*Leucinodes orbonalis* Guen.
Coleoptera	Coccinellidae	Epilachna beetle	*Henisepilachna vigintioctopunctata* (F.)
	Chrysomelidae	Flower beetle	*Popillia complanata* Newm
	Meloidae	Flower beetle	*Mylabris pustulata* Thunb
Cowpea			
Hemiptera	Aphididae	Pea aphid	*Aphis craccivora* Koch
	Coreidae	Pod bug	*Riptotus pedestris* F.
		Pod bug	*Clavigralla horrens* D.
	Pentatomidae	Green shield bug	*Nezara viridula* Linn.
	Pentatomidae	Lablab bug	*Coptosoma cribraria* F.
	Membracidae	Cow bug	*Anchon pilosum* W.
Lepidoptera	Lycaenidae	Pod caterpillar	*Lampides boeticus* Linn.
	Pyralidae	Pod borer	*Maruca testulalis* Guen.
Coleoptera	Coccinellidae	Leaf beetle	*Aphidenta misera* (F.)
Diptera	Tephritidae	Fruit fly	*Bactrocera cucurbitae* Coq.
Bittergourd			
Hemiptera	Aphididae	Aphid	*Aphis gossypii* Glover
Lepidoptera	Pyralidae	Pumpkin caterpillar	*Diaphania indica* Saund
Coleoptera	Coccinellidae	Epilachna beetle	*Epilachna septima* (F.)
	Chrysomelidae	Pumpkin beetle	*Aulacophora foveicollis* Lucas.
	"	"	*Aulacophora lewesi* Baly.
	"	"	*Aulacophora stevensi* Baly.
	Meloidae	Flower beetle	*Mylabris pustulata* Thunb
Diptera	Tephritidae	Melon fly	*Bactrocera cucurbitae* Coq.
Amaranthus			
Lepidoptera	Pyralidae	Leaf webber	*Hymenia recurvalis* (F.)
		Leaf webber	*Psara basalis* F.
	Noctuidae	Leaf caterpillar	*Spodoptera litura* (F.)
Orthoptera	Acridiidae	Grass hopper	*Atractomorpha crenulata* F.
Coleoptera	Curculionidae	Amaranthus weevil	*Hypolixus truncatulus* (F.)

seen in abundance in all the plots surveyed while population of *B. tabaci* and *A. malvae* was moderately abundant. The lepidopterans recorded on the crop included the shoot and fruit borer *E. vitella*, the leaf roller *S. derogata*, the semilooper *X. groellsi* and the leaf caterpillar *S. litura*. Incidence of *E. vitella* was low in all the plots surveyed. Several coleopterans were also seen in the plots of which only the blister beetle *M. pustulata* was moderately abundant.

Brinjal (*S. melongena*)

High population of the aphid, *A. gossypii* was observed in the brinjal plots. Besides the mealy bug *C. insolitus* and the tingid *U. hystricellus* were the other hemipteran pests prevalent in the plots. The important lepidopteran pests observed included the shoot and fruit borer *L. orbonalis*, and the leaf webber *P. bipunctalis* and the leaf folder A. olivaceae. *H. vigintioctopunctata*, *P. compianata* and *M. pustulata* were the coleopteran pests seen in the plots

Cowpea (*V. unguiculata* subsp. *sesquipedalis*)

The cowpea aphid *A. craccivora* and the coreid bug *R. pedestris* were the major hemipteran pests recorded from the cowpea fields. The green shield bug *N. viridula*, the lab lab bug *C. cribraria* and the cow bug *A. pilosum* were also observed infesting the crop. Only low population of *C. horrens* was seen in the plots. The pod borers *L. boeticus* and *M.testulalis* were seen damaging the pods of which population of *L. boeticus* was moderately abundant. The leaf beetle *Aphidenta misera* was the important coleopteran pest recorded from the cowpea plots. Incidence of the fruitfly *B. cucurbitae* was also observed in the crop.

Bittergourd (*M. charantia*)

The major hemipteran and lepidopteran pests observed in the bittergourd fields were the aphid *A. gossypii* and the pumpkin caterpillar *D. indica*. respectively. The pests were seen in moderate abundance. Several coleopteran pests like epilachna beetle *E. septima*, the pumkin beetles *A. foevicollis*.

A. lewesi and *A. stevensi* and the flower beetle *M. pustulata* were observed in the fields. Incidence of epilachna beetle was high, whereas the other coleopteran pests were moderately abundant. Only one dipteran pest was observed, the melon fly *B.cucurbitae* and it was moderately abundant.

Amaranthus (*A. tricolor*)

Incidence of the three lepidopteran pests, *H. recurvalis* and *P. basalis* (leaf Webbers) and *S. litura* (leaf caterpillar) was high in the amaranthus plots. The grasshopper *A. crenulata* was also noticed feeding on amaranthus. The amaranthus weevil *H. truncatulus* was also observed damaging the crop.

4.2 SEASONAL ABUNDANCE OF SPIDERS

Studies on the abundance of the spiders during summer and rainy seasons indicated that the seasons did not significantly influence the population of the spiders in the vegetable crops, the number of spiders observed per ten plants being 16.05 and 14.52 respectively (Table7).

Contrarily, the growth stage of the crops influenced the population of spiders significantly. The number of spiders was significantly higher during the reproductive phase, being 29.47 per 10 plants. Only 5.45 spiders were recorded from ten plants in the vegetative phase. The difference in the level of population in the two stages of the crops was reflected during the two seasons too. While the population of spiders in the vegetables was 5.12 and 5.82 per 10 plants in the vegetative phase during summer and rainy seasons respectively, it was 32.42 and 26.59 per 10 plants, respectively in the reproductive phase.

4.3 PREDATORY EFFICIENCY

Results of the laboratory studies conducted on the prey range, predatory potential and prey preference of the four dominant spiders in the vegetable ecosystem *viz*., *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* are presented in Tables 8 to 12.

Table 7. Relative abundance of spiders in summer and rainy seasons in vegetable ecosystem

Season	Crop stage		Mean
	Vegetative	Reproductive	
	Number per 10 plants		
Summer	5.12 (2.47)	32.42 (5.78)	16.05 (4.13)
Rainy	5.82 (2.61)	26.59 (5.26)	14.52 (3.94)
Mean	5.45 (2.54)	29.47 (5.52)	

CD (0.05) Growth stages : 0.701

CD (0.05) Treatments : 0.992

CD (0.05) Season : NS

Figures in parentheses are $\sqrt{x+1}$ transformed values

4.3.1 Prey Range

4.3.1.1 Pests of okra

Among the pests of okra tested *viz*., *A. biguttula biguttula*, *A. malvae* and *B. tabaci* (adults), *S. derogata*, *S. litura* and *X. groellsi* (moths and caterpillars), *D. cingulatus* (bugs and nymphs)) and *M. pustulata*(beetles), the five prey preferred by the four spiders were the hemipterans, *A. biguttula biguttula*, *A. malvae*, *B tabaci* and the caterpillars of the lepidopterans *S. derogata* and *S. litura*. The rate of consumption of *D. cingulatus*, *S. derogata* (moths), *X. groellsi* (moths and caterpillars), *S. litura* (moths) and *M. pustulata* was negligible.

4.3.1.2 Pests of Brinjal

Results of the study on the prey range of the spiders tested with pests of brinjal indicated that among the insect pests, the feeding rate of the spiders was greater for *A. gossypii*, *C. insolitus*, *U. hystricellus*, caterpillars of *A. olivaceae* and eggs of *H. vigintioctopunctata* . The rate of consumption of the beetles and grubs of *H. vigintioctopunctata*, nymphs of *A. crenulata* and the moths and caterpillars of *P. basalis* was comparatively low.

4.3.1.3 On Pests of Cowpea

Among the seven pests screened *viz*., *A. craccivora* (Adults), *R.*, *pedestris*, *N. viridula*, *C. cribraria*, *A. pilosum* (bugs and nymphs), *L. boeticus* (moths and caterpillars) and *A. misera* (adults, grubs and eggs), the extent of predation of the spiders was more on soft bodied insects like aphids, nymphs of *A. pilosum*, caterpillars of *L. boeticus*, and grubs and egg masses of *A.misera*. The araneae showed lesser preference for *R. pedestris*, *N. viridula* and *C. cribraria* (bugs and nymphs) and moths of *L. boeticus*.

4.3.1.4 Pests of Bittergourd

Of the seven pests *viz*., *A. gossypii*, *D. indica* (caterpillars and moths), *E. septima* (eggs, grubs and adults), *A. foveicollis*, *A. lewesi* and *A. stevensi* (beetles) and *B. cucurbitae* (flies) evaluated for prey range, the spiders showed greater preference for aphids ,caterpillars and moths of *D. indica* , eggs of *E. septima* and fruit flies for feeding. The extent of predation on the other prey was negligible.

4.3.1.5 Pests of Amaranthus

Among the five insects *viz.*, *H. recurvalis*, *P. basalis* and *S. litura* (caterpillars and moths), *H. truncatulus* (weevils) and *A. crenulata* (adults and nymphs) screened for prey range, the four spiders showed greater preference for *H. recurvalis* (caterpillars and moths), *P. basalis* (caterpillars and moths) and caterpillars of *S. litura* (early instar). *H. truncatulus* and *A. crenulata* were least preferred..

4.3.2 Predatory Potential

The predatory potential of the spiders is expressed in terms of the number of prey consumed per spider per seven days.

4.3.2.1 Pests of Okra

Results of the study on the predatory potential of the spiders on the five preferred pests of okra (Table 8) indicated a significant difference among the spiders in their rate of consumption of the hemipteran prey *A. biguttula biguttula*, *A. malvae* and, *B. tabaci*. The lynx spider, *O. javanus* consumed the maximum number of the jassid *A. biguttula biguttula* (54.47). The rate of consumption of the spider was significantly superior to that of the other spiders. It was closely followed by *C. danieli* (47.14) and *T. mandibulata* (41.22) which too differed significantly in their extent of feeding of the pest. Comparatively, *N. mukerjei* consumed lesser number of the jassid (31.48). Similarly, *O. javanus* preyed on the maximum number of *A. malvae* (59.82) closely followed by *C. danieli* (57.39). Both the spiders were on par in their rate of consumption and were significantly superior to *T. mandibulata* (54.18) and *N. mukerjei* (36.05) which too differed significantly in their predatory potential. Regarding consumption of *B. tabaci*, *T. mandibulata* preyed on the maximum number of the white fly (62.79) and the feeding potential of the spider was significantly superior to that of the other spiders. *N. mukerjei* predated on 46.57 whiteflies in seven days and was significantly superior to *O. javanus* (43.18) and *C. danieli* (35.04) in its predatory potential .

Considering the predatory potential of the spiders on the caterpillars of the lepidopteran pests *S. derogata* and *S. litura*, *O. javanus* consumed the maximum number of caterpillars of *S. derogata* (13.04). The rate of consumption of the spider differed significantly from that of the other three spiders. *T. mandibulata* consumed 6.01 caterpillars in seven days and was superior to *N. mukerjei* and *C. danieli* in its consumption of the pest. *N. mukerjei* and *C. danieli* were on par in their feeding potential on the leaf roller, the rate of consumption being 1.38 and 1.26 caterpillars in seven days, respectively. Similarly, *O. javanus* (8.91) consumed the maximum number of caterpillars of *S. litura* and was significantly superior to the other spiders. *C. danieli* (4.22) and *T. mandibulata* (3.37) were on par in their predatory potential. *N. mukerjei* showed least preference for the pest, the number consumed being 1.38 caterpillars.

4.3.2.2 Pests of Brinjal

Determination of the predatory potential of *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* on *A. gossypii*, *C. insolitus*, *U. hystricellus*, *A. olivaceae* and *H. vigintioctopunctata* revealed a significant difference in their feeding efficiency (Table 9). *O. javanus* consumed the maximum number of *A. gossypii* (52.81) closely followed by *C. danieli* (50.32).Both the spiders were on par in their feeding potential and were significantly superior to *T. mandibulata* (34.37) and *N. mukerjei* (33.39) which were on par in their rate of consumption of the pest. Similarly, *O. javanus* consumed the maximum number of mealy bugs (45.90) and was superior to the other spiders in its extent of predation. Comparatively, the number of mealy bugs consumed by *C. danieli* (14.34), *T. mandibulata* (14.24) and *N. mukerjei* (9.13) was less. While *C. danieli* and *T. mandibulata* showed no significant difference in their predatory potential, they were superior to

Table 8. Feeding potential of spiders on pests of okra

Spider	Prey (Mean number consumed in seven days)*				
	A. biguttula biguttula (Adult)	*A. malvae* (Adult)	*B. tabaci* (Adult)	*S. derogata* (Caterpillar)	*S. litura* (Caterpillar)
O. javanus	54.47 (7.45)	59.82 (7.80)	43.18 (6.65)	13.04 (3.75)	8.91 (3.15)
C. danieli	47.14 (6.94)	57.39 (7.64)	35.04 (6.00)	1.26 (1.50)	4.22 (2.28)
N. mukerjei	31.48 (5.70)	36.05 (6.09)	46.57 (6.90)	1.38 (1.54)	1.38 (1.54)
T. mandibulata	41.22 (6.50)	54.18 (7.43)	62.79 (7.99)	6.01 (2.65)	3.37 (2.09)
CD (0.05)	(0.335)	(0.189)	(0.167)	(0.217)	(0.275)

Table 9. Feeding potential of spiders on pests of brinjal

Spider	Prey (Mean number consumed in seven days)*				
	A. gossypii (Adult)	*C. insolitus* (Adult)	*U. hystricellus* (Adult)	*A. olivaceae* (Caterpillar)	*H. vigintioctopunctata* (Egg-mass)
O. javanus	52.81 (7.34)	45.90 (6.85)	19.78 (4.56)	11.76 (3.57)	4.17 (2.27)
C. danieli	50.32 (7.16)	14.34 (3.92)	25.94 (5.19)	10.76 (3.43)	10.02 (3.32)
N. mukerjei	33.39 (5.86)	9.13 (3.18)	29.84 (5.55)	3.76 (2.18)	3.81 (2.19)
T. mandibulata	34.37 (5.95)	14.24 (3.90)	36.76 (6.15)	8.69 (3.11)	2.36 (1.83)
CD (0.05)	(0.271)	(0.424)	(0.296)	(0.312)	(0.273)

*Mean of 10 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

N. mukerjei. All the four spiders showed significant difference in their predatory potential on the lacewing bug *U. hystricellus. T. mandibulata* consumed the maximum number of the tingid (36.76) followed by *N. mukerjei* (29.84), *C. danieli* (25.94) and *O. javanus* (19.78).

Considering the number of caterpillars of *A. olivaceae* preyed on by the spiders in seven days, *O. javanus* (11.76) and *C. danieli* (10.76) showed no significant difference in their predatory potential. However, while *O. javanus* differed significantly from *T. mandibulata* (8.69) in its feeding potential, *C. danieli* was on par with the spider. The number of larvae consumed by *N. mukerjei* (3.76) was the least.

Unlike other spiders, *C. danieli* showed a remarkable preference for the eggs of *H. vigintioctopunctata*, consuming the maximum number of the egg-masses (10.02) and the rate of consumption was superior to that of the other spiders. *O. javanus* (4.17) and *N. mukerjei* (3.81) were on par in their feeding of the eggs of the coleopteran pest and differed significantly from *T. mandibulata* (2.36).

4.3.2.3 Pests of Cowpea

Significant differences were seen in the feeding potential of the four dominant spiders on the hemipteran pests of cowpea (Table 10). *O. javanus* (63.78) consumed the highest number of *A. craccivora*, the major pest of the crop. The feeding rate of the lynx spider was superior to that of *T. mandibulata, C. danieli* and *N. mukerjei*. The number of aphids consumed by these spiders were 53.54 (*T. mandibulata*), 47.75 (*C. danieli*) and 33.09 (*N. mukerjei*) and the feeding potential of the three spiders differed significantly. The same trend was observed in the consumption of nymphs of the cowbug, *A. pilosum*. Again *O. javanus* consumed the maximum number of the prey (7.81) followed by *N mukerjei* (5.20). *C. danieli* and *T. mandibulata* consumed only a few nymphs of the pest being 2.87 and 1.28, respectively.

As in the case of the hemipteran pests, *O. javanus* showed greater preference for the lepidopteran pest, *L. boeticus*, predating on the maximum number of caterpillars of the pest (12.44) and was significantly superior to *T. mandibulta* (7.49), *N. mukerjei* (4.15) and *C. danieli* (3.87) in its consumption of the larvae. *N. mukerjei* and *C. danieli* were on par in their predatory potential on *L. boeticus*.

Considering the predatory potential on the coleopteran pest *A. misera*, *C. danieli* preyed on the maximum number of grubs (11.04) and was significantly superior to the other spiders. *O. javanus*, also showed an appreciable preference for the grubs, consuming 6.81 grubs in seven days. *T. mandibulata* and *N. mukerjei* were on par in their predatory potential, the number of grubs, consumed being 1.28 and 0.95 respectively. The consumption of the egg-masses of epilachna beetle by *C. danieli* was also high, the number of egg- masses consumed being 9.10.The feeding potential of the spider was significantly superior to that of *O. javanus* (1.66), *N. mukerjei* (1.28) and *T. mandibulata* (1.18) which were on par in their extent of feeding of the egg-masses.

4.3.2.4 *Pests of Bittergourd*

Among the five prey evaluated, all the spiders showed significant difference in the number of aphids (*A. gossypii*) consumed (Table11). *O. javanus* consumed the maximum number of aphids (61.10) followed by *C. danieli* (48.75), *T. mandibulata* (28.56) and *N. mukerjei* (25.42).

Regarding their feeding on fruit flies, all the spiders differed significantly in their predatory potential. *O. javanus* preyed on the maximum number of the pest (17.50) It was followed by *N. mukerjei*, which consumed 13.98 fruit flies in seven days. *C. danieli* preyed on 9.72 fruit flies. *T. mandibulata* (1.81) consumed the least number of the prey.

Significant difference was also observed among the spiders in their consumption of both the moths and caterpillars of *D. indica*. *T. mandibulata*

Table 10. Feeding potential of spiders on pests of cowpea

Spider	Prey (Mean number consumed in seven days)*				
	A. craccivora (Adult)	*A. pilosum* (Nymph)	*L. boeticus* (Caterpillar)	A. misera Grub	A. misera Egg-mass
O. javanus	63.78 (8.05)	7.81 (2.97)	12.44 (3.67)	6.81 (2.79)	1.66 (1.63)
C. danieli	47.75 (6.98)	2.87 (1.97)	3.87 (2.21)	11.04 (3.47)	9.10 (3.18)
N. mukerjei	33.09 (5.84)	5.20 (2.49)	4.15 (2.27)	0.95 (1.39)	1.28 (1.51)
T. mandibulata	53.54 (7.39)	1.28 (1.51)	7.49 (2.91)	1.28 (1.51)	1.18 (1.48)
CD (0.05)	(0.275)	(0.384)	(0.384)	(0.378)	(0.197)

Table 11. Feeding potential of spiders on pests of bittergourd

Spider	Prey (Mean number consumed in seven days)*				
	A. gossypii (Adult)	*B. cucurbitae* (Fly)	*D. indica* (Moth)	*D. indica* (Caterpillar)	*E. septima* (Egg mass)
O. javanus	61.10 (7.89)	17.50 (4.30)	1.38 (1.54)	17.75 (4.33)	13.18 (3.77)
C. danieli	48.75 (7.05)	9.72 (3.27)	6.05 (2.65)	14.11 (3.89)	22.90 (4.89)
N. mukerjei	25.42 (5.14)	13.98 (3.87)	18.32 (4.40)	4.53 (2.35)	6.79 (2.79)
T. mandibulata	28.56 (5.44)	1.81 (1.68)	23.23 (4.92)	7.72 (2.95)	6.45 (2.73)
CD (0.05)	(0.290)	(0.256)	0.230	(0.368)	(0.398)

*Mean of 10 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

(23.27)consumed the maximum number of moths and was closely followed by *N. mukerjei* which preyed on18.32 moths. The number of moths consumed by *C. danieli* (6.05) and *O. javanus* (1.38) was significantly low. On the other hand, *O. javanus* (17.75) consumed the maximum number of caterpillars of the pest and was statistically superior to the other spiders. *C. danieli* too consumed significantly more number of the caterpillar (14.11) when compared to *T. mandibulata* (7.72) and *N. mukerjei* (4.53).

C. danieli showed remarkable preference for the eggs of *E. septima*, consuming the maximum number of egg-masses (22.90). The feeding rate of the spider was significantly superior to that of *O. javanus*, *N. mukerjei* and *T. mandibulata*. *O. javanus*, which consumed 13.18 egg-masses, was significantly superior to *N. mukerjei* (6.79) and *T. mandibulata* (6.45) in its predatory potential. *N. mukerjei* and *T. mandibulata* were on par in their rate of consumption of the egg-masses of *E. septima*.

4.3.2.5 *Pests of Amaranthus*

The four spiders differed significantly in their extent of consumption of caterpillars of *H. recurvalis* (Table 12). *O. javanus* consumed the maximum number of caterpillars (21.56) followed by *C. danieli* (11.20). The feeding rate of *T. mandibulata* (6.66) and *N. mukerjei* (3.44) was low. Contrarily, *T. mandibulata* preyed on the maximum number of moths of *H. recurvalis* the number consumed being 24.15.Statistically, the predatory potential of the spider was significantly superior to that of the other spiders. The number of moths consumed by *N. mukerjei* was 11.61 and it was significantly superior to the number of moths consumed by *O. javanus* (2.42) and *C. danieli* (1.66) which were on par in their predatory potential on the pest.

A similar trend was seen in the consumption of caterpillars of *P. basalis*. *O. javanus* consumed the maximum number of caterpillars (22.48) and was significantly superior to *C. danieli* (11.42) *T. mandibulata* (3.43) and *N. mukerjei* (3.20) were on par in their rate of consumption of the caterpillars. Contrarily, *N. mukerjei* consumed maximum number of moths of *P. basalis* (19.63) and was

Table 12. Feeding potential of spiders on pests of amaranthus

Spider	Prey (Mean number consumed in seven days)*				
	H. recurvalis		*P. basalis*		*S. litura*
	Caterpillar	Moth	Caterpillar	Moth	Caterpillar
O. javanus	21.56 (4.75)	2.42 (1.85)	22.48 (4.85)	2.61 (1.90)	16.51 (4.18)
C. danieli	11.20 (3.49)	1.66 (1.63)	11.42 (3.52)	1.47 (1.57)	10.44 (3.38)
N. mukerjei	3.44 (2.11)	11.61 (3.55)	3.20 (2.05)	19.63 (4.54)	1.56 (1.60)
T. mandibulata	6.66 (2.77)	24.15 (5.02)	3.43 (2.11)	19.40 (4.52)	2.45 (1.86)
CD (0.05)	(0.280)	(0.241)	(0.292)	(0.258)	(0.275)

*Mean of 10 replications

Figures in parentheses are $\sqrt{x+1}$ transformed values

on par with *T. mandibulata* (19.40). These two spiders were significantly superior to *O. javanus* (2.61) in their rate of consumption of the pest. The predatory potential of *C. danieli* was significantly low (1.47). Regarding the predation on early instar caterpillars of *S. litura*, *O. javanus* consumed the maximum number of caterpillars (16.51) and was significantly superior to the other three spiders. *C. danieli* preyed on 10.44 caterpillars and was significantly superior to *T. mandibulata* (2.45) and *N. mukerjei* (1.56) ,which were on par.

4.3.3 Prey preference

Results of the studies on the predatory potential of *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* on different pests of okra, brinjal, cowpea, bittergourd and amaranthus indicated that the spiders preferred hemipteran and lepidopteran pests to other insects for consumption. Based on the results, trials were conducted to determine the relative preference of the spiders when hemipteran and lepidopteran pests of different vegetables were supplied as a mixed diet. The predatory rate expressed as number of prey consumed per spider per day is presented in Tables 13 and 14.

4.3.3.1 Relative Preference for Hemipteran Pests

Studies on the relative preference of the four spiders for the hemipteran pests, *A. craccivora*, *B. tabaci* and *A. bigttula biguttula* when supplied as a mixed diet indicated that the spiders did not show any significant difference in their preference for the pests (Table 13).

4.3.3.2 Relative Preference for Lepidopteran Pests

Preference of different spiders

When the spiders were provided with a mixed diet of lepidopteran pests, *O. javanus* showed a higher preference for the lepidopterans as evidenced by its rate of consumption (1.60) (Table 14). Statistically, the lynx spider was superior to other spiders in its preference for the lepidopteran pests. *T. mandibulata* with a feeding rate of 1.29 pests per day too preferred the lepidopterans and its

Table 13. Relative preference of the major spiders for different hemipteran prey in a mixed diet

Spider	Prey (mean number consumed in one day)*			Mean
	A. craccivora	*B. tabaci*	*A. biguttula biguttula*	**
O. javanus	7.90 (2.98)	4.13 (2.27)	6.32 (2.71)	6.02 (2.65)
C. danieli	8.40 (3.07)	5.21 (2.50)	4.74 (2.40)	6.02 (2.65)
N. mukerjei	4.26 (2.29)	5.42 (2.53)	3.23 (2.06)	4.29 (2.30)
T. mandibulata	4.97 (2.44)	7.15 (2.85)	4.64 (2.38)	5.55 (2.56)
Mean	6.29 (2.70)	5.45 (2.54)	4.71 (2.39)	

**NS

Table 14. Relative preference of the major spiders for different lepidopteran prey in a mixed diet

Spider	Prey (mean number consumed in one day)*						Mean
	D. indica		*P. basalis*		*H. recurvalis*		
	Caterpillar	Moth	Caterpillar	Moth	Caterpillar	Moth	
O. javanus	1.67 (1.68)	0.65 (1.29)	3.21 (2.05)	1.95 (1.72)	2.06 (1.75)	0.52 (1.23)	1.60 (1.61)
C. danieli	2.16 (1.78)	0.08 (1.04)	1.33 (1.53)	0.08 (1.04)	2.66 (1.91)	0.12 (1.06)	0.94 (1.39)
N. mukerjei	0.38 (1.17)	2.59 (1.89)	0.22 (1.11)	0.06 (1.03)	1.75 (1.66)	2.04 (1.74)	1.06 (1.43)
T. mandibulata	0.26 (1.12)	3.35 (2.08)	1.82 (1.68)	0.80 (1.34)	2.17 (1.78)	0.15 (1.07)	1.29 (1.51)
Mean	1.03 (1.43)	1.49 (1.58)	1.53 (1.59)	0.65 (1.28)	2.15 (1.78)	0.63 (1.28)	

*Mean of 10 replications

CD(0.05) treatments : 0.076

CD(0.05) spiders : 0.044

CD(0.05) prey : 0.038

Figures in parenthesis are $\sqrt{x+1}$ transformed values preference was significantly superior to that of *N. mukerjei* (1.06) and *C. danieli* (0.94), which in turn were on par in their preference for the lepidopteran prey.

Considering the preference of the individual spiders for the different prey, *O. javanus* showed maximum preference for caterpillars of *P. basalis* (3.26), the preference being superior to its preference for other prey. Preference of the spider for the caterpillars of *H. recurvalis* (2.06), moths of *P. basalis* (1.95) and caterpillars of *D. indica* (1.67) was on par. Preference for the moths of *D. indica* (0.65) and *H. recurvalis* (0.52) was significantly less, the number consumed being on par.

C. danieli displayed a significantly higher preference for the caterpillars of the three pests for predation. The rate of consumption was higher for the caterpillars of *H. recurvalis*, the number of larvae consumed in a day being 2.66. Its preference for *H. recurvalis* was significantly superior to that for the other prey. The rate of predation of caterpillars of *D. indica* and *P. basalis* were 2.16 and 1.33 per day respectively. The preference for the two pests differed significantly. The spider showed significantly less preference for the moths, its rate of feeding being on par. While the number of moths of *D. indica* (0.08) and *P. basalis* (0.08) preyed on were similar, the number of *H. recurvalis* consumed was only 0.12.

N. mukerjei preferred the moths of *D. indica* for feeding, the number of larvae consumed being 2.59 and was significantly superior to its preference for other pests. This was followed by its preference for the moths (2.04) and caterpillars (1.75) of *H. recurvalis*. The preference for these prey too differed significantly. Less preference was shown for caterpillars of *D. indica* (0.38) moths of *P. basalis* (0.06) and caterpillars of *P. basalis* (0.22).

D. indica was preferred to other prey for consumption by *T. mandibulata*, the number of moths consumed being 3.35 per day. This was followed by its preference for caterpillars of *H. recurvalis* (2.17) and *P. basalis* (1.82). The preference for the two prey too differed significantly. Preference for larvae of *D. indica* (0.26), moths of *P. basalis* (0.80) and *H. recurvalis* (0.15) was low.

Preferred prey

Among the two stages of the lepidopteran pests screened for their relative preference by the spiders, caterpillars of *H. recurvalis* was the most preferred food of the spiders, the number consumed being2.15 and the preference was significantly superior to that for other prey. It was followed by the preference for caterpillars of *P. basalis* (1.53) and moths of *D. indica* (1.49), the preference for the prey being on par. The caterpillars of *D. indica* was the next preferred prey of the spiders (1.03). Moths of *P. basalis* (0.65) and *H. recurvalis* (0.63) were the least preferred prey.

Analysis of the relative preference of the different spiders for caterpillars of *D. indica* indicated that the prey was most preferred by *C. danieli* and its preference was superior to that of the other spiders. *O. javanus* too had an appreciable preference for the prey. *N. mukerjei* and *T. mandibulata* least preferred the prey. All the spiders differed significantly in their preference for the moth of the pest. It was preferred most by *T. mandibulata* , the preference being superior to that of the other spiders. *N. mukerjei* too preferred the moth for predation, differing significantly from *O. javanus* and *C. danieli*, which preferred the prey least.

A similar trend was seen in the preference of the spiders for the caterpillars of *P. basalis*. The prey was most preferred by *O. javanus*.. Comparatively, *T. mandibulata* and *C. danieli* showed lesser preference for the prey. The prey was least preferred by *N. mukerjei*.

The caterpillars of *H. recurvalis* was highly preferred by the spider *C. danieli*. Statistically, the preference of the spider was superior to the preference shown by *T. mandibulata* and *O. javanus* which were on par in their preference for the pest. *N. mukerjei* consumed only lesser number of the prey. Contrarily, preference of *N. mukerjei* for moths of *H. recurvalis* was high and its preference was superior to that of the other spiders. The consumption rate of *O. javanus*, *C. danieli* and *T. mandibulata* was low for the pest. *C. danieli* and *T. mandibulata* were on par in their preference for the pest.

4.4 EFFECT OF INSECTICIDES

4.4.1 Chemical and Botanical Insecticides

Synthetic and botanical insecticides commonly used for the control of pests of vegetables varied significantly in their effect on spiders when tested at the dose recommended for the control of pests (Table 15). The mortality of the spiders was significantly higher when treated with synthetic insecticides. While the percentage mortality of different spiders ranged from 45.30 to 78.65 when applied topically and 13.95 to 33.55 when released on treated plants, it was 2.37 to 22.35 and 0.05 to 11.85, respectively when treated with botanical insecticides. Between the two methods of application mortality of the spiders was significantly higher in topical application (2.37 to 78.65 per cent) than when released on treated plants (0.05 to 33.55 per cent).

Among the spiders tested, *T. mandibulata* was most susceptible to both synthetic and botanical insecticides. The mortality of the spider was 78.65 and 29.90 and 22.35 and 11.85 per cent when treated with synthetic and botanical insecticides through topical application and when released on treated plants respectively. It was closely followed by *C. danieli*, the mortality of the spider being 65.25 and 33.55 when treated with chemical insecticides and 17.95 and 7.95 when treated with botanical insecticides through topical application and when released on treated plants respectively. Excepting the effect of chemical insecticides when applied topically, both the spiders were on par in their response to the insecticides when released on treated plants. Sensitivity of *O. javanus* to the synthetic insecticides was higher when it was applied topically, the percentage mortality being 61.05. Lower mortality of the spider (15.15 per cent) was recorded when released on treated plants, and it was on par with the effect on *N. mukerjei* (13.95 per cent). The botanical insecticides did not have any appreciable toxic effect on both the spiders, the percentage mortality

Table 15. Effect of chemical and botanical insecticides on major spiders in vegetable ecosystem

Treatment	Percentage mortality							
	TOPICAL APPLICATION				RELEASE ON TREATED PLANTS			
	Spiders							
Chemical	*O. javanus*	*C. danieli*	*N. mukerjei*	*T. mandibulata*	*O. javanus*	*C. danieli*	*N. mukerjei*	*T. mandibulata*
Dimethoate 0.05 per cent	60.00 (50.75)	80.00 (63.41)	100.00 (90.00)	100.00 (90.00)	32.90 (35.00)	60.64 (51.12)	32.90 (35.00)	40.00 (39.22)
Carbaryl 0.2 per cent	97.64 (81.14)	100.00 (90.00)	53.35 (46.90)	100.00 (90.00)	32.90 (35.00)	60.00 (50.75)	40.00 (39.22)	53.35 (46.90)
Malathion 0.10 per cent	60.64 (51.12)	73.80 (59.19)	32.90 (35.0)	73.80 (59.19)	20.00 (26.55)	20.00 (26.55)	9.25 (17.70)	20.00 (26.55)
Quinalphos 0.05 per cent	32.90 (35.00)	32.90 (35.00)	26.20 (30.77)	40.00 (39.22)	9.25 (17.70)	32.90 (35.00)	9.25 (17.70)	20.00 (26.55)
Imidacloprid 0.02 per cent	32.90 (35.00)	13.95 (21.92)	2.37 (8.85)	32.90 (35.00)	0.00 (0.00)	9.25 (17.70)	0.00 (0.00)	20.00 (26.55)
Mean	61.05 (51.37)	65.25 (53.90)	45.30 (42.30)	78.65 (62.47)	15.15 (22.85)	33.55 (35.38)	13.95 (21.92)	29.90 (33.15)
Botanical								
Neem Azal 1 per cent	2.37 (8.85)	9.25 (17.70)	2.37 (8.85)	40.00 (39.22)	2.37 (8.85)	2.37 (8.85)	2.37 (8.85)	20.00 (26.55)
NSKE 5 per cent	2.37 (8.85)	9.25 (17.70)	0.00 (0.00)	32.90 (35.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Neem leaf extract 5 per cent	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Neem oil 2 per cent	20.00 (26.55)	32.90 (35.00)	2.37 (8.85)	26.20 (30.77)	0.00 (0.00)	9.25 (17.70)	0.00 (0.00)	20.00 (26.55)
Pongamia oil 2 per cent	26.20 (30.77)	40.00 (39.22)	20.00 (26.55)	32.90 (35.00)	0.00 (0.00)	32.90 (35.00)	0.00 (0.00)	26.20 (30.77)
Iluppai oil 2 per cent	2.37 (8.85)	26.20 (30.77)	2.37 (8.85)	26.20 (30.77)	0.00 (0.00)	20.00 (26.55)	0.00 (0.00)	26.20 (30.77)
Marotti oil 2 per cent	2.37 (8.85)	32.91 (35.00)	2.37 (8.85)	20.00 (26.55)	0.00 (0.00)	20.00 (26.55)	0.00 (0.00)	20.00 (26.55)
Mean	5.25 (13.25)	17.95 (25.05)	2.37 (8.85)	22.35 (28.19)	0.05 (1.26)	7.95 (16.38)	0.05 (1.26)	11.85 (20.17)

CD (0.05) Treatment : 13.333
CD (0.05) Mean : 5.443
Figures in parentheses are angular transformed values

of the spiders being 5.25 and 2.37 respectively when applied topically and 0.05 each when released on treated plants.

4.4.1.1 Effect of each Insecticide on Different Spiders

Chemical insecticides

Dimethoate

Among the synthetic insecticides evaluated dimethoate 0.05 per cent was highly toxic to *T. mandibulata* and *N. mukerjei* when applied topically recording 100 per cent mortality for each spider. The effect of the insecticide on the spiders differed significantly from that on *C. danieli* (80.00 per cent) and *O. javanus* (60.00 per cent), which were on par in their response.

When the spiders were released on plants treated with the insecticide, maximum mortality was recorded for *C. danieli* (60.64 per cent). The effect of the insecticide on the spider was significantly superior to that on the other spiders. *T. mandibulata* (40.00 per cent), *O. javanus* (32.90 per cent) and *N. mukerjei* (32.90 per cent) were on par in their sensitivity to dimethoate.

Carbaryl

Carbaryl 0.2 per cent when applied topically, caused 100 percent mortality of both *T. mandibulata* and *C. danieli* and 97.64 per cent mortality of *O. javanus* and the effect on the spiders were on par. Only 53.35 per cent mortality was noted for *N. mukerji*

When the spiders were released on plants treated with the insecticide, maximum mortality was observed for *C.danieli* (60.00 per cent) closely followed by *T. mandibulata* (53.35 per cent). Both the spiders were on par in their reaction to carbaryl. Toxicity of the insecticides to *N. mukerjei* (40.00 per cent) and *O. javanus* (32.90 per cent) was on par.

Malathion

Topical application of malathion 0.1per cent resulted in maximum mortality of *T. mandibulata* (73.80 per cent) and *C. danieli* (73.80 per cent), closely followed by the mortality of *O. javanus* (60.64 per cent). the effect of the insecticide on the three spiders being on par. Lowest mortality was observed for *N. mukerjei* (32.90 per cent).

Toxicity of the insecticide to the spiders was low when the araneae were released on treated plants. Only twenty per cent mortality was recorded for *T. mandibulata*, *O. javanus* and *C. danieli* respectively. Similarly only 9.25 per cent mortality was seen for *N. mukerjei*.

Quinalphos

Quinalphos 0.05 per cent caused only 40 per cent mortality of *T. mandibulata*. Toxicity of the insecticide to *O. javanus* and *C. danieli* was also low each registering 32.90 per cent mortalities. The three spiders were on par in their sensitivity to the insecticide. closely followed by *N. mukerjei* (26.20 per cent).

Release of the spiders on quinalphos treated plants resulted in 32.90 and 20.00 per cent mortalities of *C. danieli* and *T. mandibulata* respectively. Toxicity to *O. javanus* and *N. mukerjei* was negligible (9.25 per cent).

Imidacloprid

Among the insecticides screened, imidacloprid 0.02 per cent was less toxic to the spiders. When applied topically, the neonicotinoid caused 32.90 per cent mortality of both *T. mandibulata* and *O. javanus* and 13.95 per cent mortality was observed for *C. danieli*. The lowest mortality was recorded for *N mukerjei* (2.37 per cent). The effect of the insecticide on *C. danieli* and *N. mukerjei* differed significantly.

When released on plants treated with the insecticide only low toxicity was recorded for *T. mandibulata* (20.00 per cent) and *C. danieli*

When the spiders were released on plants treated with the oil emulsion, 20 per cent mortality was observed for *T. mandibulata*, followed by 9.25 per cent mortality of *C. danieli* and statistically they were on par. No mortality was observed for *O. javanus* and *N. mukerjei*.

Pongamia oil

Pongamia oil 2 per cent caused 40.00 and 32.90 per cent mortality of *C. danieli* and *T. mandibulata* respectively, and the treatments were on par. The toxicity of the botanical pesticide to *O. javanus* and *N. mukerjei* too was on par, the percentage mortality of the spiders being 26.20 and 20.00 per cent, respectively.

When sprayed on plants and spiders were released, the oil resulted in 32.90 and 26.20 per cent mortality of *C. danieli* and *T. mandibulata* respectively, the effect on the spiders being on par. The insecticide was non-lethal to *O. javanus* and *N. mukerjei*.

Iluppai oil

Application of iluppai oil 2 per cent resulted in 26.20 per cent mortality of both *T. mandibulata* and *C. danieli*. The effect of the oil on the spiders was significantly superior to that on *O. javanus* and *N. mukerjei* each of which recorded only 2.37 per cent mortality.

Only 26.20 per cent mortality was observed for *T. mandibulata* when the spider was released on plants treated with the oil and it was on par with *C. danieli*(20.00 per cent) in its response to the botanical insecticide. No mortality was observed for *O. javanus* and *N. mukerjei*.

Marotti oil

Marotti oil 2 per cent when applied topically caused 32.90 per cent mortality of *C. danieli* and this was followed by *T. mandibulata* (20.00 per cent). The treatments were on par. Low mortality was observed for *O. javanus* (5.25 per cent) and *N. mukerjei* (2.37 per cent) and these were on par.

(9.25 per cent) respectively and the effects were on par. No mortality was observed for *O. javanus* and *N. mukerjei.*

Botanicals

None of the botanicals caused more than 50 per cent mortality of the spiders.

Neem Azal

NeemAzal T/S (2ml/litre) when applied topically, caused 40 per cent mortality of *T. mandibulata* and this was significantly superior to the mortality of *C. danieli* (9.25 per cent), *O. javanus* (2.37 per cent) and *N. mukerjei* (2.37) which were on par in their response to the botanicals.

When the spiders were released on NeemAzal sprayed plants, maximum mortality was recorded for *T. mandibulata* (20.00 per cent). Only 2.37 per cent mortality was observed for each of the other spiders.

Neem Seed Kernel Extract (NSKE)

Topical application of NSKE 5 per cent resulted in 32.90 per cent mortality of *T. mandibulata* and this was significantly superior to the other treatments. The neem preparation was on par in its effect on *C. danieli* (9.25 per cent) and *O. javanus* (2.37 per cent).

Release of the spiders on NSKE treated plants did not kill any of the araneae.

Neem leaf extract

Neem leaf extract was non toxic to the spiders when applied topically and when released on sprayed plants.

Neem oil

Highest mortality was observed for *C. danieli* (32.90 per cent) when neem oil 2 per cent was applied topically, closely followed by *T. mandibulata* (26.20 per cent) and *O. javanus* (20.00 per cent). The treatments were on par. Lowest mortality was observed for *N. mukerjei* (2.37 per cent).

N. mukerjei

When the insecticides were applied topically on *N. mukerjei*, dimethoate was highly toxic causing 100 per cent mortality. Application of carbaryl too resulted in more than 50.00 per cent mortality, the two insecticides differing significantly in their effect. Carbaryl was also on par with malathion in its effect on the spider. This was closely followed by quinalphos which was on par with malathion. Lowest mortality of the spider was observed in imidacloprid treatment.

All the insecticides gave only less than 50 per cent mortality when the spider was released on insecticide treated plants. While, carbaryl and dimethoate were on par in their effect on the spider, quinalphos and malathion too were on par. The extent of mortality caused being negligible. No mortality of the spider was observed in imidacloprid treatment.

T. mandibulata

Among the synthetic insecticides screened, for their relative toxicity / safety to *T. mandibulata*, dimethoate, carbaryl and malathion were highly toxic to the spider, the percentage mortality ranging from 73.80 to 100 per cent, when applied topically. Quinalphos and imidacloprid recorded only low mortality, the percentage mortality being less than 50 per cent.

Release of the spider on insecticide treated plants resulted only in low mortality of the predator. Comparatively, treatment with carbaryl and dimethoate killed more spiders and they were on par in their effect. Toxicity of malathion, quinalphos and imidacloprid to the spider was low.

Botanicals

O. javanus

When the botanicals were applied topically on *O. javanus*, none of them resulted in more than 50 per cent mortality. Comparatively higher mortality was recorded for pongamia oil and neem oil which were on par in their toxicity to the

Twenty per cent mortality was observed for *T. mandibulata* and *C. danieli* respectively when released on plants sprayed with the marotti oil. No mortality was observed for *O. javanus* and *N. mukerjei*.

4.4.1.2 Effect of Different Insecticides on each Spider

Chemical insecticides

O. javanus

More than 50 per cent mortality of the spider was observed when treated with carbaryl, malathion and dimethoate through topical application. Malathion and dimethoate were on par in their effect on the spider. Quinalphos and imidacloprid were less toxic, registering less than 50 per cent mortality.

When the spider was released on insecticide treated plants, only less than 50 per cent mortality was recorded in dimethoate, carbaryl malathion and quinalphos treatments. No mortality was observed in imidacloprid treatment.

C. danieli

Considering the effect of the different insecticides on *C. danieli*, 100 per cent mortality of the spider was observed in carbaryl and the insecticide differed significantly from the other insecticides in its toxicity . Dimethoate and malathion also caused more than 50 per cent mortality when applied topically and the treatments were on par. Quinalphos and imidacloprid were less toxic to the spiders and were on par in their effect on the spider.

When released on treated plants dimethoate and carbaryl were more toxic to the spider registering more than 50 per cent mortality, recording 60.64 and 60.00 per cent mortality of the spider respectively. Quinalphos and malathion were on par in their effect. Very low mortality of the spider was observed when released on plants treated with imidacloprid.

the spider, all the treatments were on par in their extent of toxicity to the spider. Neem leaf extract did not kill the spider.

Still lower mortality of the spiders was observed when the spiders were released on the treated plants. Pongamia oil and Ilappai oil recorded 26.20 per cent mortality each and these were closely followed by NeemAzal and marotti oil. No mortality was observed in both NSKE and neem leaf extract treatments.

4.4.1.3 *Effect of Different Doses of Synthetic Insecticides*

Dimethoate

Significant difference was observed in the toxicity of different doses of dimethoate to the lynx spider *O. javanus* when applied topically (Table 16) The insecticide was highly toxic at the higher dose (0.1 per cent), causing 100 per cent mortality of the spider and was significantly superior to 0.05 and 0.025 per cent concentrations. No significant difference was observed in the toxicity of the insecticide at 0.05 and 0.025 per cent, the mortality of the spiders being 60.00 and 53.35 per cent respectively. Contrarily, the different doses had a similar effect on *C. danieli*, the mortality of the spider at 0.1, 0.05 and 0.025 per cent being 86.06, 80.00 and 67.09 per cent, respectively. Similarly, dimethoate was highly toxic to *N. mukerjei* and *T. mandibulata* at all the concentrations tested, the effects being on par. The mortality recorded was 100.00, 100.00 and 97.64 per cent at 0.1, 0.05 and 0.025 per cent respectively for each of the spiders.

Comparatively, toxicity of the insecticide to the spiders was lower when they were released on treated plants. No significant difference was observed in the toxicity of dimethoate at the different concentration to *O. javanus, N. mukerjei* and *T. mandibulata*. While the per cent mortality recorded for *O. javanus* was 40.00, 32.90 and 32.90, it was 53.35, 32.90 and 32.90 for *N. mukerjei* and 46.65, 40.00 and 32.90 for *T. mandibulata*, respectively. The insecticide was toxic to *C. danieli* at 0.1 and 0.05 per cent concentrations, the mortality of the spider observed being 73.80 and 60.64, respectively and the treatments were on par. Only 40.00 per cent mortality of the spider was recorded spider. All the other botanicals had only negligible effect on the spider. No mortality was observed in neem leaf extract treatment.

Excepting in NeemAzal treatment, no mortality of the spiders was recorded when released on plants treated with the other botanicals.

C. danieli

None of the botanicals caused more than 50 per cent mortality of *C. danieli* when applied topically. Comparatively higher mortality was observed for pongamia oil, neem oil, marotti oil and iluppai oil and these were on par. Low mortality of the spiders was observed when treated with Neem Azal and NSKE. No mortality was observed when treated with neem leaf extract.

When the spider was released on plants treated with the botanical insecticides, comparatively higher mortality was recorded in pongamia oil, iluppai oil and marotti oil and these were on par in their toxicity. Neem oil and Neem Azal were less toxic. No mortality of the spider was observed in NSKE and neem leaf extract treatments.

N. mukerjei

When the effect of botanicals on *N. mukerjei* was considered none of the botanicals caused more than 50 per cent mortality when applied topically. With the exception of pongamia oil which caused 20 per cent mortality of the spider, all the other treatments were on par. No mortality was observed for NSKE and neem leaf extract.

When the spiders were released on treated plants, 2.37 per cent mortality was observed for NeemAzal. The remaining botanicals did not cause any mortality of *N. mukerjei*.

T. mandibulata

Considering the effect of the different botanical insecticides on *T. mandibulata*, none of the botanicals caused more than 50 per cent mortality of at 0.025 concentration and it was on par with the effect at 0.05 per cent concentration.

Considering the effect of each dose of the insecticide on the different spiders, 0.1 per cent concentration was highly toxic to *O. javanus*, *N. mukerjei* and *T. mandibulata*, causing 100 per cent mortalities of the spiders when the insecticide was applied topically. Lesser toxicity was observed for *C. danieli* (86.06 per cent) and the effect differed significantly. At 0.05 per cent concentration, the insecticide was highly toxic to *N. mukerjei* and *T. mandibulata* and the effect was significantly superior to that on *C. danieli* and *O. javanus* which were on par in their sensitivity to the insecticide. Similarly, high mortality was recorded for *N. mukerjei* and *T. mandibulata* at the lower dose (0.025 per cent). The toxicity of the insecticide at this dose to *C. danieli* and *O. javanus* were on par and differed significantly from that on the other spiders.

When released on treated plants, more than 50 per cent mortality was observed for *C. danieli* and *N. mukerjei* at 0.1 per cent concentration. Only lower toxicity was recorded for *O. javanus* and *T. mandibulata* which were on par with *N. mukerjei*. At 0.05 per cent concentration more than 50 per cent mortality was recorded only for *N. mukerjei*. At 0.025 none of the spiders registered more than 50 per cent mortality and they were on par.

Carbaryl

Topical application of carbaryl at 0.3 and 0.2 per cent concentrations was highly toxic to *O. javanus*, the percentage mortality being 100.00 and 97.64, respectively. Both the treatments were on par and significantly superior to 0.15 per cent concentration (73.80 per cent). A similar trend was seen in the effect of the carbamate insecticide on *C. danieli*. While 0.3 and 0.2 per cent concentrations caused 100.00 per cent mortality of the spider, 0.15 per cent concentration resulted in 60.00 per cent mortality .The toxicity of the insecticide at the three doses to *N. mukerjei* was on par, causing 60.64, 53.35 and 40.00 per cent mortalities at 0.3, 0.2 and 0.15 per cent respectively. Hundred per cent mortality was recorded for *T. mandibulata* at 0.3 and 0.2 per cent concentrations and the

Table 16. Effect of different doses of chemical insecticides on major spiders in vegetable ecosystem

Treatment	Percentage mortality					
	TOPICAL APPLICATION			RELEASE ON TREATED PLANTS		
	Concentration (per cent)			Concentration (per cent)		
Dimethoate	0.1	0.05	0.025	0.1	0.05	0.025
O. javanus	100.00 (90.00)	60.00 (50.75)	53.35 (46.90)	40.00 (39.22)	32.90 (35.00)	32.90 (35.00)
C. danieli	86.06 (68.05)	80.00 (63.41)	67.09 (54.97)	73.80 (59.19)	60.64 (51.12)	40.00 (39.22)
N. mukerjei	100.00 (90.00)	100.00 (90.00)	97.64 (81.14)	53.35 (46.90)	32.90 (35.00)	32.90 (35.00)
T. mandibulata	100.00 (90.00)	100.00 (90.00)	97.64 (81.14)	46.65 (43.06)	40.00 (39.22)	32.90 (35.00)
CD (0.05) Treatments : 13.087						
Carbaryl	0.3	0.2	0.15	0.3	0.2	0.15
O. javanus	100.00 (90.00)	97.64 (81.14	73.80 (59.19)	40.00 (39.22)	32.90 (35.00)	20.00 (26.55
C. danieli	100.00 (90.00)	100.00 (90.00)	60.00 (50.75)	86.06 (58.05)	60.00 (50.75)	40.00 (39.22
N. mukerjei	60.64 (51.12)	53.35 (46.90	40.00 (39.22)	40.00 (39.22)	40.00 (39.22)	20.00 (26.55)
T. mandibulata	100.00 (90.00)	100.00 (90.00)	86.06 (68.05)	73.80 (59.19)	53.35 (46.90)	32.90 (35.00
CD (0.05) Treatments : 12.920						
Malathion	0.2	0.1	0.05	0.2	0.1	0.05
O. javanus	67.09 (54.97)	60.64 (51.12)	60.00 (50.75)	40.00 (39.22)	20.00 (26.55)	0.00 (0.00)
C. danieli	80.00 (63.41)	73.80 (59.19)	40.00 (39.22)	32.90 (35.00)	20.00 (26.55)	9.25 (17.70)
N. mukerjei	40.00 (39.22)	32.90 (35.00)	20.00 (26.55)	32.90 (35.00)	9.25 (17.70)	0.00 (0.00)
T. mandibulata	100.00 (90.00)	73.80 (59.19)	67.09 (54.97)	32.90 (35.00)	20.00 (26.55)	0.00 (0.00)
CD (0.05) Treatments : 10.824						
Quinalphos	0.1	0.05	0.025	0.1	0.05	0.025
O. javanus	40.00 (39.22)	32.90 (35.00)	26.20 (30.77)	20.00 (26.55	9.25 (17.70)	0.00 (0.00)
C. danieli	53.35 (46.90)	32.90 (35.00)	20.00 (26.55)	40.00 (39.22	32.90 (35.00)	26.20 (30.77)
N. mukerjei	40.00 (39.22)	26.20 (30.77)	20.00 (26.55)	20.00 (26.55	9.25 (17.70)	0.00 (0.00)
T. mandibulata	67.09 (50.75)	40.00 (39.22)	32.90 (35.00)	32.90 (35.00	20.00 (26.55)	0.00 (0.00)
CD (0.05) Treatments : 9.985						
Imidacloprid	0.04	0.03	0.02	0.04	0.03	0.02
O. javanus	67.09 (54.97)	53.35 (45.90)	32.90 (35.00)	32.90 (35.00	9.25 (17.71)	0.00 (0.00)
C. danieli	54.01 (47.28)	32.90 (33.00)	13.95 (21.92)	32.90 (35.00	9.25 (17.70)	9.25 (17.70)
N. mukerjei	32.90 (35.00)	20.00 (26.55)	2.37 (8.85)	20.00 (26.88	0.00 (0.00)	0.00 (0.00)
T. mandibulata	67.09 (54.97)	53.35 (46.90)	32.90 (35.00)	40.00 (39.22	20.00 (26.55)	9.25 (17.70)

CD (0.05) Treatments : 8.401

Figures in parentheses are angular transformed values

Malathion

The different doses of malathion (0.2, 0.1 and 0.05 per cent) did not show any significant difference in their extent of toxicity to *O. javanus*, the mortality of the spider in the different treatments being 67.09 60.64 and 60.00, per cent respectively when applied topically. The toxicity of the insecticide to *C. danieli* at 0.2 (80.00 per cent) and 0.1 (73.80 per cent) per cent concentration was on par, and differed significantly from its effect at 0.05 per cent (40.00 per cent). A similar trend was observed in the effect of the different doses on *N. mukerjei*. Both 0.2 (40.00 per cent) and 0.1 (32.90 per cent) per cent concentrations were equally toxic to the spider. Least mortality (20 per cent) was observed when the spider was treated with malathion 0.05 per cent. *T. mandibulata* recorded 100 per cent mortality when treated with malathion 0.2 per cent concentration and the dose was superior to the lower doses. At 0.1 and 0.05 per cent concentrations, 73.80 and 67.09 per cent mortalities were as recorded for the spider respectively and they were on par.

When released on plants sprayed with malathion (0.2 per cent) 40.00 per cent mortality was observed for *O. javanus*. The treatment was superior to 0.1 and 0.05 per cent concentrations of the insecticide. While release of the spider on plants treated with malathion 0.1 per cent registered 20 per cent mortality, no mortality was observed with malathion 0.05 per cent, the treatments differing significantly. Considering the effect on *C. danieli*, 0.2 and 0.1 per cent concentrations were on par in their toxicity causing 32.90 and 20.00 per cent mortality, respectively. At 0.05 per cent concentration, 9.25 per cent mortality was observed for the spider and the dose was on par with 0.1 per cent concentration. The insecticide was toxic to *N. mukerjei* and *T. mandibulata* only at 0.2 and 0.1 per cent concentration. Maximum mortality of *N. mukerjei* was observed at 0.2 per cent concentration (32.90 per cent) and the treatment was superior to 0.1 per cent concentration (9.25 per cent). Both the doses were on par in their toxicity to *T. mandibulata*, the per cent mortality being 32.90 (0.2 per cent) and 20.00 (0.1 per cent), respectively.

doses were superior to 0.15 per cent concentration, which resulted in 86.06 per cent mortality of the spider.

Mortality of *O. javanus* at the different concentrations did not differ significantly when released on plants treated with the insecticide. The percentage mortality of the spider was 40.00, 32.90 and 20.00 in 0.3, 0.2 and 0.15 per cent concentrations respectively. Toxicity of the insecticide to *C. danieli* at 0.3 (86.06 per cent) per cent concentration was significantly superior to the effect at 0.15 per cent (40.00 per cent) . The toxicity to the spider at 0.2 and 0.15 per cent concentrations was on par. The three doses were on par when tested for their relative toxicity to *N. mukerjei.* The per cent mortality recorded for the spider was 40.00, 40.00 and 20.00 at 0.3, 0.2 and 0.15 per cent concentrations, respectively. Considering the effect on *T. mandibulata,* significantly higher mortality of the spider occurred when it was released on plants treated with carbaryl 0.3 per cent (73.80 per cent). This was followed by the mortality in 0.2 per cent concentration (53.35 per cent). Both doses were on par in their effect. The toxicity of the insecticide4 at 0.15 per cent concentration (32.90 per cent) was on par with that at 0.2 per cent concentration.

Regarding the toxicity of each dose to the different spiders, high toxicity was recorded for *T. mandibulata*, *C. danieli* and *O. javanus* at 0.3 and 0.2 per cent concentration when applied topically . More than 50 per cent mortality was also observed for *N. mukerjei.* Similarly, more than 50 per cent mortality was recorded for the spiders at 0.15 per cent concentration. Contrarily only less than 50 per cent mortality was recorded for N.mukerjei. When released on treated plants the insecticide was highly toxic to *C. danieli* and *T. mandibulata* at 0.3 per cent concentration. Significantly lower toxicity was recorded for *O. javanus* at these doses. At 0.2 per cent the insecticide was equally toxic to *C. danieli* and *T. mandibulata* causing more than 50 per cent mortality of the spider. Toxicity to *N. mukerjei* and *O.javanus* was significantly lower at the dose. The effect of carbaryl 0.15 per cent on the four spiders was on par when released on treated plants, recording only less than 50 per cent mortality.

With respect to the toxicity of each dose on different spiders at 0.2 per cent concentration 100.00 per cent mortality was recorded for *T. mandibulata* when malathion was applied topically. High mortality was also observed for *C. danieli* and *O. javanus* and they were on par. Only less than 50 per cent mortality was recorded for *N. mukerjei*. With the exception of *N. mukerjei*, the insecticide at 0.1 per cent concentration was equally toxic to *C. danieli*, *T. mandibulata* and *O. javanus*. At 0.05 per cent concentration the insecticide was equally toxic to *T. mandibulata* and *O. javanus*. Only less than 50 per cent mortality was recorded for *C. danieli*. Least toxicity was observed for *N. mukerjei*.

With respect to the effect of each dose of the insecticide on different spiders when released on treated plants, only less than 50 per cent mortality was recorded in all the treatments. The effect at 0.2 and 0.1 concentrations was the same. Except for *C. danieli* none of the other spiders were killed when released on plants treated with malathion 0.05 per cent.

Quinalphos

The different doses of quinalphos did not differ significantly in their toxicity to *O. javanus* when applied topically. The mortality of the spider at 0.1, 0.05 and 0.025 per cent concentrations were 40.00, 32.90 and 26.20 per cent respectively. The toxicity of the insecticide to *C. danieli* at 0.1 per cent concentration (53.35 per cent) differed significantly from that at 0.05 per cent (32.90 per cent) which in turn was on par with the toxicity at 0.025 per cent concentration (20.00 per cent). Considering the effect on *N. mukerjei*, toxicity of the insecticide at 0.1 (40.00) and 0.05 (26.20) per cent concentrations was on par. The extent of mortality caused at 0.025 concentration was on par with the effect observed at 0.05 concentration. Similarly, maximum mortality of *T. mandibulata* was at 0.1 per cent concentration (67.09) and the dose differed significantly from 0.05 per cent concentration (40.00 per cent) which again was on par with at 0.025 per cent concentration, the mortality at the dose being 32.90 per cent.

When released on plants treated with quinalphos, only 20 per cent mortality was recorded for *O. javanus* at 0.1 per cent concentration and it was on par with the mortality observed at 0.05 concentration (9.25 per cent). No mortality was observed at 0.025 per cent concentration. No significant difference was observed in the effect of the three doses on *C. danieli*, the percentage mortality being 40.00 and 32.90 and 26.20 per cent respectively. Similarly, the toxicity of the insecticide to *N. mukerjei* and *T. mandibulata* was on par at 0.1 and 0.05 per cent concentrations,the extent of mortality registered being 20.00 and 9.25 per cent for *N. mukerjei* and 32.90 and 20.00 per cent for *T. mandibulata* respectively. None of the spiders were killed when released on plants treated with 0.025 per cent concentration of the insecticide.

Considering the effect of each concentration of the insecticide to the different spiders, at 0.1 per cent concentration the insecticide was significantly more toxic to *T. mandibulata* and *C. danieli* than to *O. javanus* and *N. mukerjei*. Only less than 50 per cent mortality of all the spiders was recorded at the two doses *viz*., 0.025 and 0.05 the treatments being on par, when applied topically.

Similarly, only less than 50 per cent mortality was recorded for all the spiders when released on plants treated with the three doses of the insecticide.

Imidacloprid

When applied topically, imidacloprid 0.04 per cent resulted in 67.09 per cent mortality of *O. javanus*. The effect of the neonicotinoid at the higher dose was significantly superior to the effect at the lower doses. While 53.35 per cent mortality of the spider was noticed at 0.03 per cent concentration; it was 32.90 per cent at 0.02 per cent concentration and the effects differed significantly. The effect of the insecticide on *C. danieli* and *N. mukerjei* was similar, the toxicity of the insecticide at the three doses differing significantly. Maximum mortality of both the spiders was recorded at 0.04 per cent concentration, the percentage mortality being 54.01 and 32.90 respectively. At 0.03 per cent concentration, the mortality of the spiders was 32.90 and 20.00 per cent respectively. The toxicity at 0.02 per cent concentration was low, the mortality of the spiders observed being 13.95 and 2.37 respectively. Both 0.04 (67.09 per cent) and 0.03 (53.35 per cent) per cent concentrations resulted in significantly higher mortality of *T. mandibulata* than 0.02 (32.90 per cent) per cent concentration.

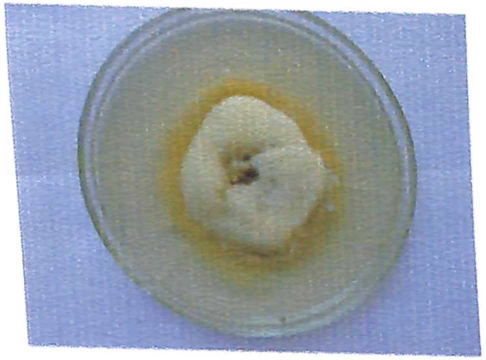
Only the higher concentration of the insecticide caused appreciable mortality of *O. javanus* (32.90 per cent) when the spider was released on treated plants. The percentage mortality at 0.03 per cent concentration was only 9.25. No mortality was seen when released on plants treated with imidacloprid 0.02 per cent. Similarly 32.90 per cent mortality of *C. danieli* was recorded at 0.04 per cent and the treatment was superior to 0.03 and 0.02 per cent concentrations at which only 9.25 per cent mortality of the spider was recorded. Considering the effect on *N. mukerjei,* only 0.04 per cent concentration caused mortality of the spider (20 per cent). The other two concentrations had no adverse effect on the spider. In the case of *T. mandibulata,* 0.04 per cent concentration was superior to the other doses in its toxicity to the spider, the mortality recorded being 40 per cent in the treatment. Only 20 and 9.25 per cent mortality was observed when the spider was released on plants treated with 0.03 and 0.02 per cent imidacloprid.

Considering the effect of each dose on the different spiders, more than 50 per cent mprtality at 0.04 per cent concentration was recorded for *T. mandibulata, O. javanus* and *C. danieli* the effects being on par and it differed significantly from its effect on *N. mukerjei*. Imidacloprid 0.03 per cent was equally toxic to *T. manibulata* and *O. javanus*. Only less than 50 per cent mortality was observed for *C.danieli* and *N. mukerjei* when applied topically. At 0.02 per cent concentration the extent of mortality recorded for the spiders was less than 50 per cent. Likewise, release of the spiders on plants treated with different concentrations of the insecticide resulted in only less than 50 per cent mortality of the spiders

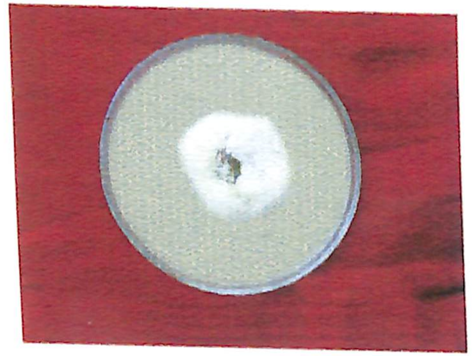
4.4.2 Effect of Microbial Insecticides

M. anisopliae, *P. lilacinus* and Bt were not pathogenic to any of the spiders.

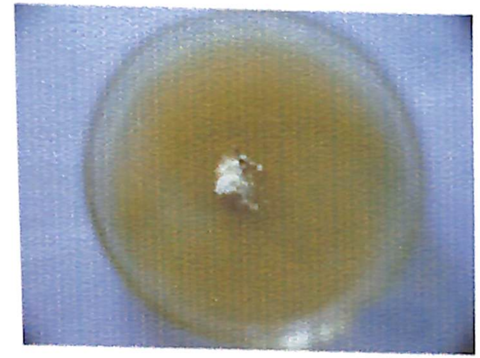
F. pallidoroseum at 7 x 10^6 spores /ml was pathogenic, causing 10 to 30 per cent mortality of the spiders. Maximum mortality was observed for *T. mandibulata* (30 per cent) followed by *C. danieli* (20 per cent). Only 10 per cent mortality was observed for *O. javanus* and *N. mukerjei*



O. javanus

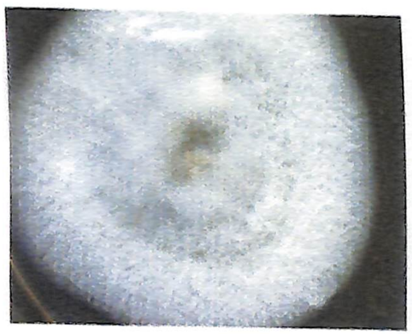


N. mukerjei



T. mandibulata

Infected with *Beauveria bassiana*



C. danieli

N. mukerjei

T. mandibulata

Infected with *Fusarium* sp.

T. mandibulata

Infected with *Fusarium pallidoroseum*

Plate 6. Fungal infection on different spiders

Mortality of the spiders treated with *Fusarium* sp. ranged from 10 to 40 per cent. Again maximum mortality was recorded for *T. mandibulata* (40 per cent). The extent of mortality observed for *O. javanus*, *N. mukerjei* and *C. danieli* were 20, 10 and 20 per cent respectively.

Treatment of the spiders with *B. bassiana* produced 10 to 50 per cent mortality of the spiders. Highest mortality was recorded for *T. mandibulata* (50 per cent). Ten per cent mortality was observed for *N. mukerjei*. For both *O. javanus* and *C. danieli*, 20 per cent mortality was recorded.

The death of the spiders occurred within one week of inoculation. The cadavers were hard and mummified and were seen covered with mycelial growth of the fungus (Plate 6).

Discussion

5. DISCUSSION

The history of plant protection is inseparably intertwined with the growth of agriculture. From dependence on nature's regulatory forces in the ancient days to integrated pest management lately, pest control passed through several phases as agriculture evolved. Biological control envisaging utilization of bio agents like parasitoids, predators and pathogens for pest suppression forms the core of any integrated pest management strategy. Most of the biocontrol programmes today are concentrated on the host specific parasitoids, predators being seldom considered for pest control. Increasing realization of the potential of several predators has currently triggered of much debate on the relative efficacy of parasitoids and predators in pest management.

With the introduction of the concept of bio intensive integrated pest management recently, manipulation of the holistic effect of the natural enemy community at large, rather than a specific agent is increasingly felt to be ideal for sustainable management of pests. Biodiversity being the very essence of sustainability, an intimate knowledge of the heterogeneous biocontrol agents in agro ecosystems is of paramount importance. Exhaustive information is available on parasitism and to a lesser extent on predation. Among the predators, the spiders have received least attention as pest control agents. Although, the natural carnivore on their own may be incapable of controlling major pest outbreaks, their role in a predatory community is important as they effectively suppress pest species at low densities and at all stages of the crop. Despite being exploited to some extent in rice, cotton and orchards for combating pest, few attempts have been made to utilize the predator in vegetable fields. In view of the emerging new vision in pest management focusing on nature friendly management practices, an understanding of the distribution of the predator in vegetable fields and its pest regulatory potential will be worthwhile.

5.1 SPIDER FAUNA IN VEGETABLE ECOSYSTEM

Spiders abound in agricultural fields, the prevailing diverse fauna being characteristic of a habitat. An account of the population abundance and species composition in an agro ecosystem is vital to the study on the role of spiders in pest suppression. Efforts made to identify and quantify the spider fauna in the vegetable ecosystem of Kalliyoor panchayat of Thiruvananthapuram district of Kerala, revealed the prevalence of an appreciable population and diversity of the predator. The population of the carnivore in okra, brinjal, cowpea, bittergourd and amaranthus, five important vegetables of Kerala ranged from 8 to 30 per 10 plants (Fig. 1). While the mean number of spiders observed in bushy vegetables like okra and brinjal was 30 and 17 per 10 plants respectively, it was 24 and 18 per 10 plants, respectively in the climbers like cowpea and bittergourd. Population of the predator in the relatively short duration crop, amaranthus was 8 per 10 plants. The result clearly indicated the abundance of spiders in vegetables like okra, brinjal, cowpea, bittergourd and amaranthus. Similar observations had been made earlier in rice (Barrion and Litsinger, 1980; Zhu and Zheng, 1984; Qi, 1990; Sudhikumar and Sebastian, 2001) and cotton fields (Aguilar, 1976; Gravena and Sterling, 1983; Nyffeler *et al.*, 1989) and orchards (Riechert and Lockley, 1984; Brown *et al.*, 2003). In vegetables, high population of spiders has largely been recorded in pulse crops like soybean (Ferguson *et al.*, 1984; Gregory *et al.*, 1989) and *C. cajan* (Patel *et al.*, 1988), tomato (Raga *et al.*, 1990) and pumpkin (Peter and David, 1991).

Of the two guilds of spiders observed, the hunting spiders were more abundant than the web builders in all the vegetable fields, constituting 60 to 70 per cent of the spider population (Para 4.1). The web weavers formed only 30 to 38 per cent of the population. Inconsistency has been observed in the distribution of the two groups of spiders in different agro-ecosystems. The hunters were the dominant group of

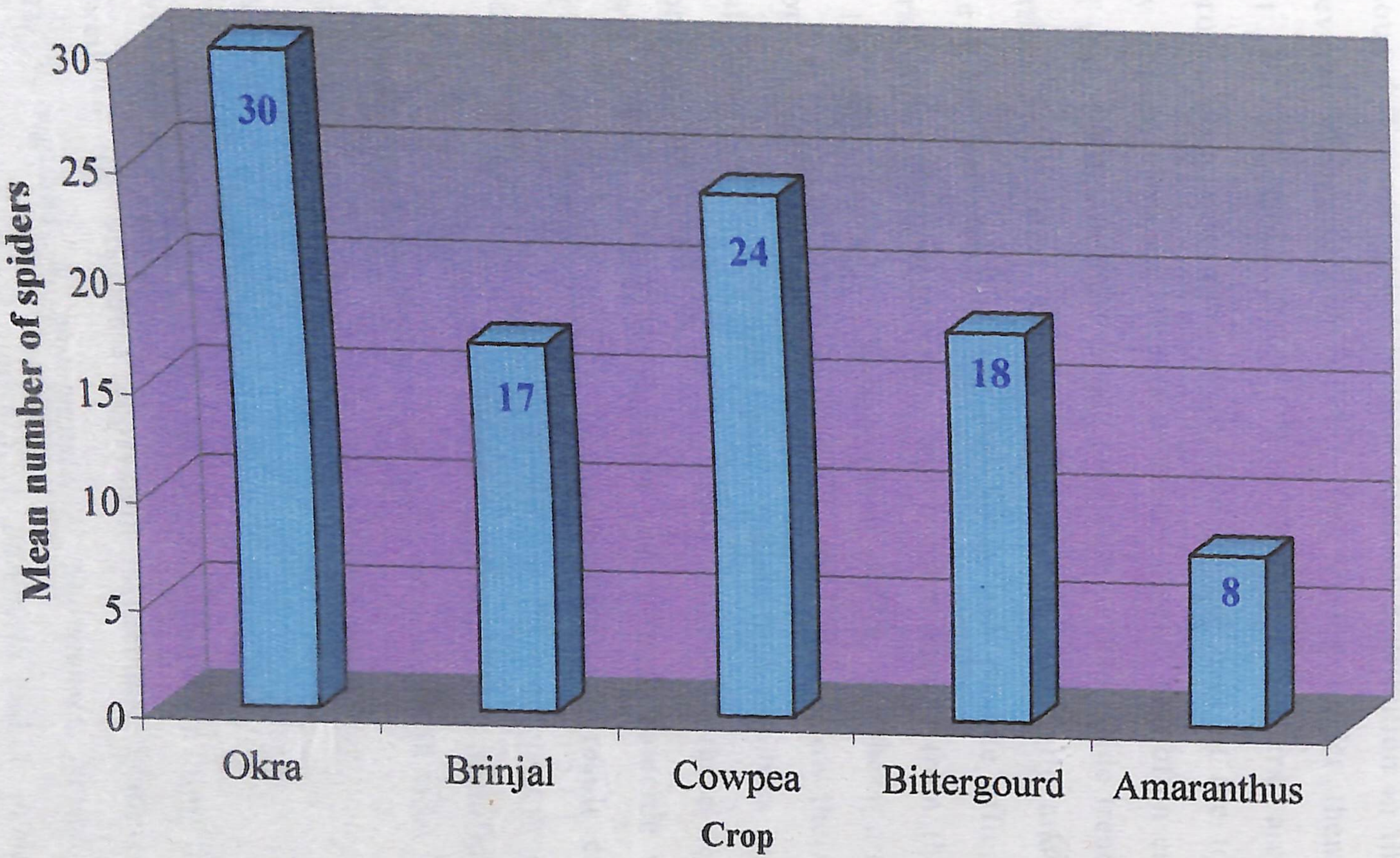


Fig. 1. Population of spiders in different vegetables in a cropping season

spiders recorded in cotton (Aguilar, 1975), groundnut (Patel and Pillai, 1988) and orchards (Amalin and Pena, 2000; Addante *et al.*, 2003). On the other hand, web builders were the major spiders seen in rice ecosystem (Sudhikumar and Sebastian, 2001; Patel, *et al.*, 2004). Inspite of the conspicuous difference noted in their relative distribution in the present study, several characteristics of the two guilds render them equally important in vegetable fields. Web building spiders are strictly insectivorous, insects forming more than 99 per cent of the total prey. They stay hidden away in retreats or under objects and often escape the impact of insecticides and are hence available in insecticide treated fields for predation. In contrast, the hunters are bold and agile and actively search the plant surface for prey and hence can predate efficiently on lepidopteran and coleopteran pests, which often escape from the fragile webs of the orb weavers. Though these active searchers are highly polyphagous compared to the web builders, they can narrow their feeding niche significantly when a suitable prey reaches high numbers in relation to other prey groups (Nyffeler *et al.*, 1994). Moreover, these aggressive spiders often remain in specific habitats and if these coincide with the habitat of a particularly noxious insect species, the result could be phenomenal (Coppel and Mertins, 1997). Thus, the collective presence of these two guilds even in varying ratios could contribute significantly to pest regulation as has been observed in some crop fields in USA (Nyffler *et al.*, 1994).

Species diversity

A wide range of spiders (30 species distributed in nine families) was observed in the vegetable ecosystem. Araneidae comprising of *N. mukerjei*, *N. vigilans*, *N. molemensis*, *N. poonaensis*, *Neoscona* sp., *Neoscona* sp., *Araneus* sp., *A. anasuja*, *A. pulchella* and *A. aemula* and accounting for 33.33 per cent of the spider species was the most represented family in the vegetable ecosystem (Fig.2). Oxyopidae

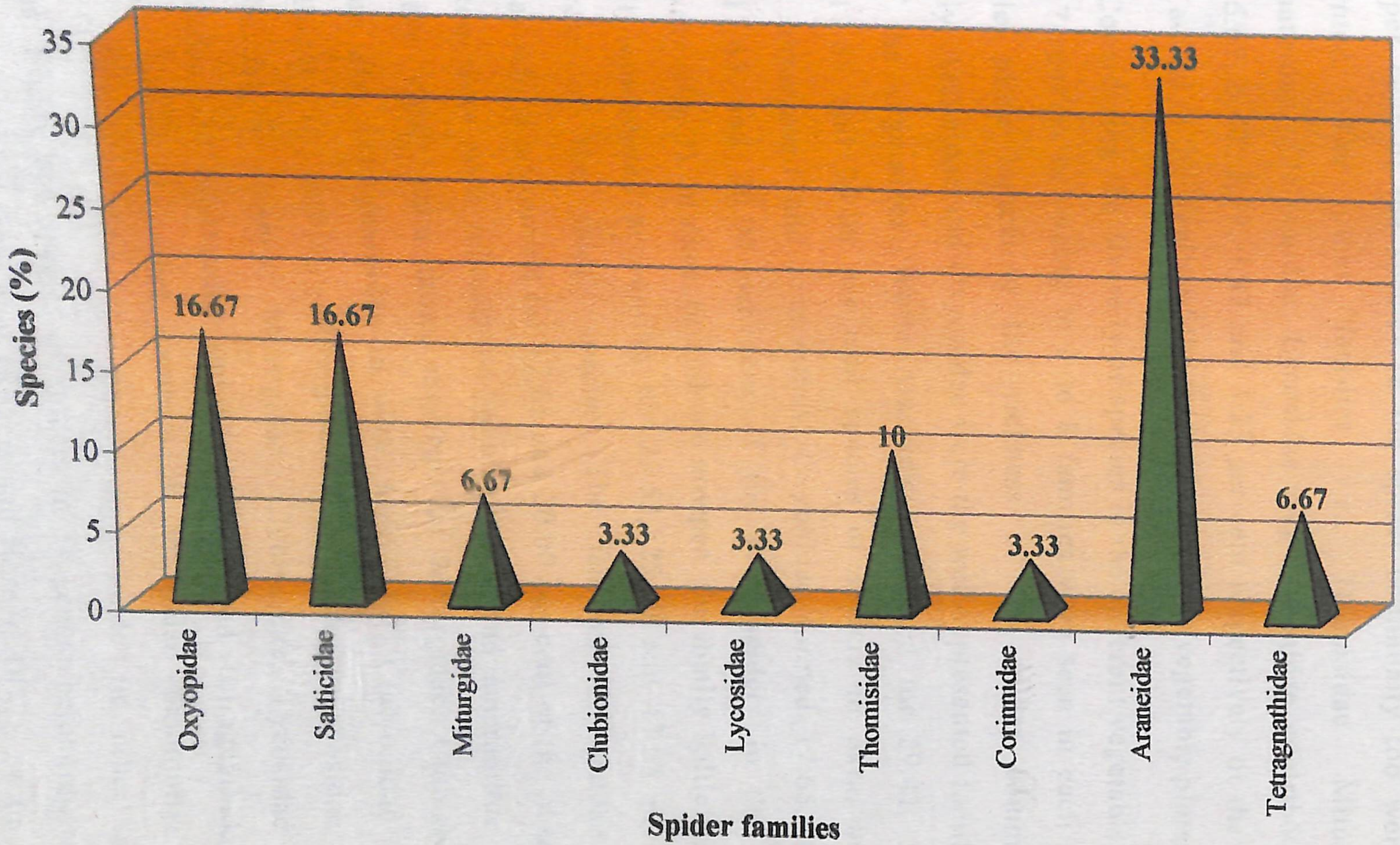


Fig. 2. Species richness of different spider families in vegetable ecosystem

consisting of *O. javanus*, *O. shweta*, *O. quadridentalus*, *Oxyopes* sp. and *P. viridana* and Salticidae comprising of *H. semicupreus*, *Hyllus* sp., *Carrhotus* sp., *T. dimidiata* and *Phidippus* sp. and each contributing to 16.67 per cent of the species in the spider community too were well represented. The other families *viz.*, Thomisidae, Miturgidae, Tetragnathidae, Clubionidae, Lycosidae and Corinnidae contributing to 10.00, 6.67, 6.67, 3.33, 3.33 and 3.33 per cent respectively of the spider species added to the wealth of the spider fauna in the vegetable plots.

Considering the diversity of species in the different vegetable plots, 11 to 17 species belonging to 5 to 8 families were seen in each of the vegetable plots indicating the richness of the spider community. Generally, Araneidae and Oxyopidae were the well-represented families in each of the vegetables. While Araneidae accounted for 29.41, 25.00, 29.41, 17.65 and 30.00 per cent species of spiders in okra, brinjal, cowpea, bittergourd and amaranthus, Oxyopidae formed 17.65, 18.50, 17.65, 17.65 and 20.00 per cent of the total spiders in the plots respectively (Fig 3). In okra, brinjal and cowpea, the family Salticidae too was well represented accounting for 23.53, 25.00 and 17.65 per cent respectively of the spider species. The families Thomisidae and Miturgidae which accounted for 17.65 and 20.00 per cent of the observed species too were well represented in bittergourd and amaranthus plots respectively. Apart from these, members of Miturgidae, Clubionidae, Corinnidae and Tetragnathidae in okra, Mitrugidae, Clubionidae and Tetragnathidae in brinjal, Miturgidae Clubionidae, Lycosidae and Tetragnathidae in cowepa, Mitrugidae, Clubionidae, Lycosidae and Tetragnathidae in bittergourd and Clubionidae and Tetragnathidae in amaranthus formed the other members of the spider community. The findings corroborate with the observations made in other agro-ecosystems. Eighty one species of spiders in 34 genera belonging to 13 families were recorded from guar (Rogers and Horner, 1977). A total of 31 species of spiders belonging to eight families were observed in cotton

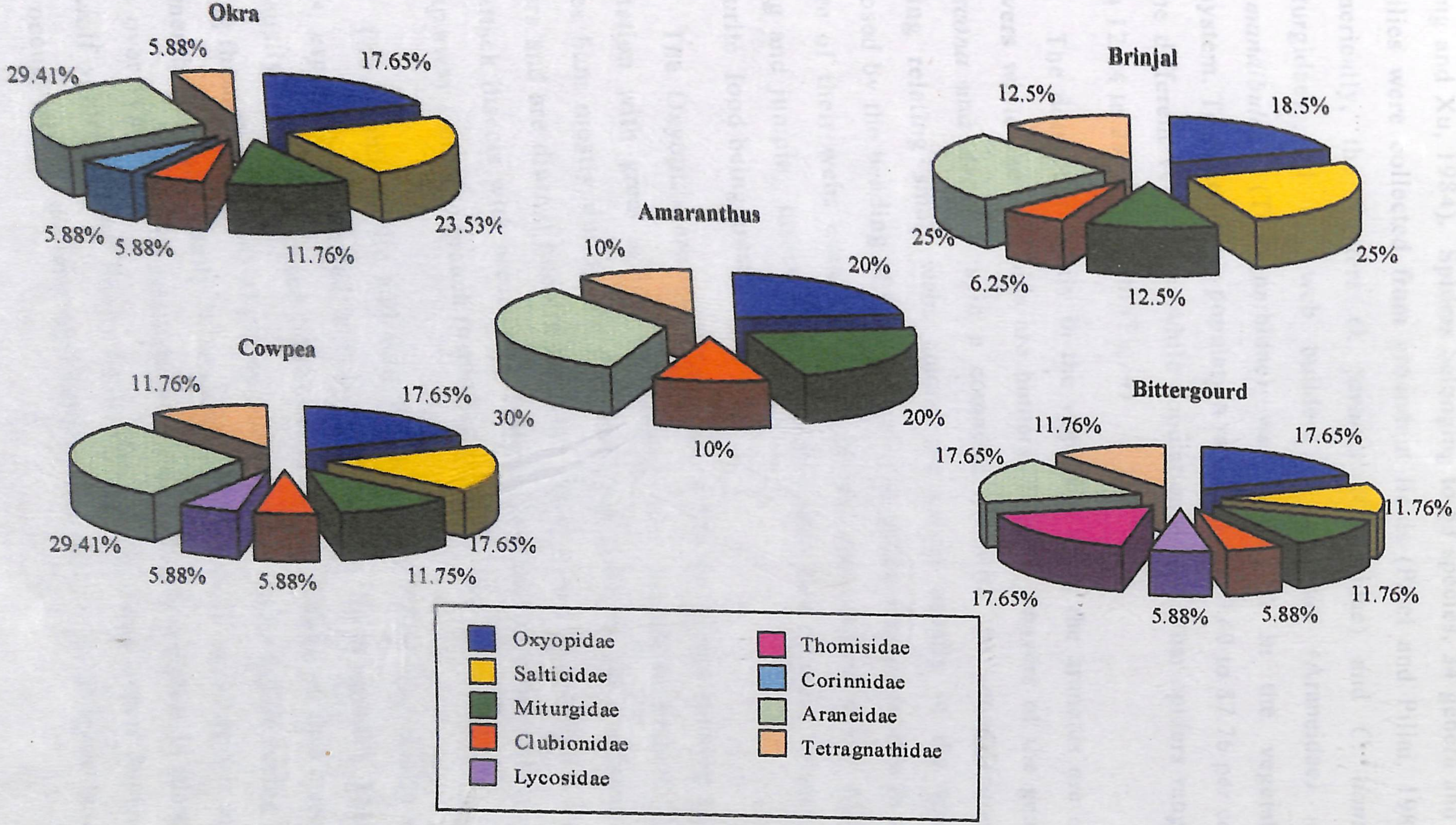


Fig. 3. Species richness of different spider families in various vegetable fields

(Dong and Xu, 1984). Spiders belonging to 53 species, 34 genera and 14 families were collected from groundnut fields (Patel and Pillai, 1988). Numerically, the hunters *O. javanus* (Oxyopidae) and *C. danieli* (Miturgidae) and the web builders *N. mukerjei* (Araneidae) and *T. mandibulata* (Tetragnathidae) were dominant in the vegetable ecosystem. Together, their population ranged from 70.40 to 87.76 per cent in the different vegetables, while population of the other spiders ranged from 12.24 to 29.60 per cent (Fig. 4)

The dominant family in the vegetable plots; the araneids are orb weavers while the oxyopids are hunters. The orb weavers of the genus *Neoscona* and *Araneus* spin a complete orb with the genus *Araneus* making relating small webs among the leaves usually in the space enclosed by the bending of a single leaf. The genus *Argiope* remain in the centre of their webs even during the hottest and sunniest days. Many flying and jumping insects are captured in the snare of these spiders, a favourite food being grasshoppers.

The Oxyopids are specialized for a life on plants running over vegetation with great agility and leaping from branch to branch. The lynxes hunt mostly during the day time. The Salticids are the jumping spiders and are diurnal hunters too. They spy the prey at a distance, sulk and attack insects with precision and alertness. They have been observed to leap away from one branch to another and catch insects in flight.

The Thomisids lie and wait for their prey. They live chiefly on plants, especially concealed in flowers where they lie in ambush. These are usually brightly coloured like the flowers they inhabit so that insects visiting these flowers may alight within reach of a spider before seeing it. The members of the family Miturgidae usually live in rolled leaves and climb over vegetation to catch the prey and make their retreat in plants. The wolf spiders of the family Lycosidae are rapacious expert hunters. They occupy almost all terrestrial habitats and seem to be at home in all

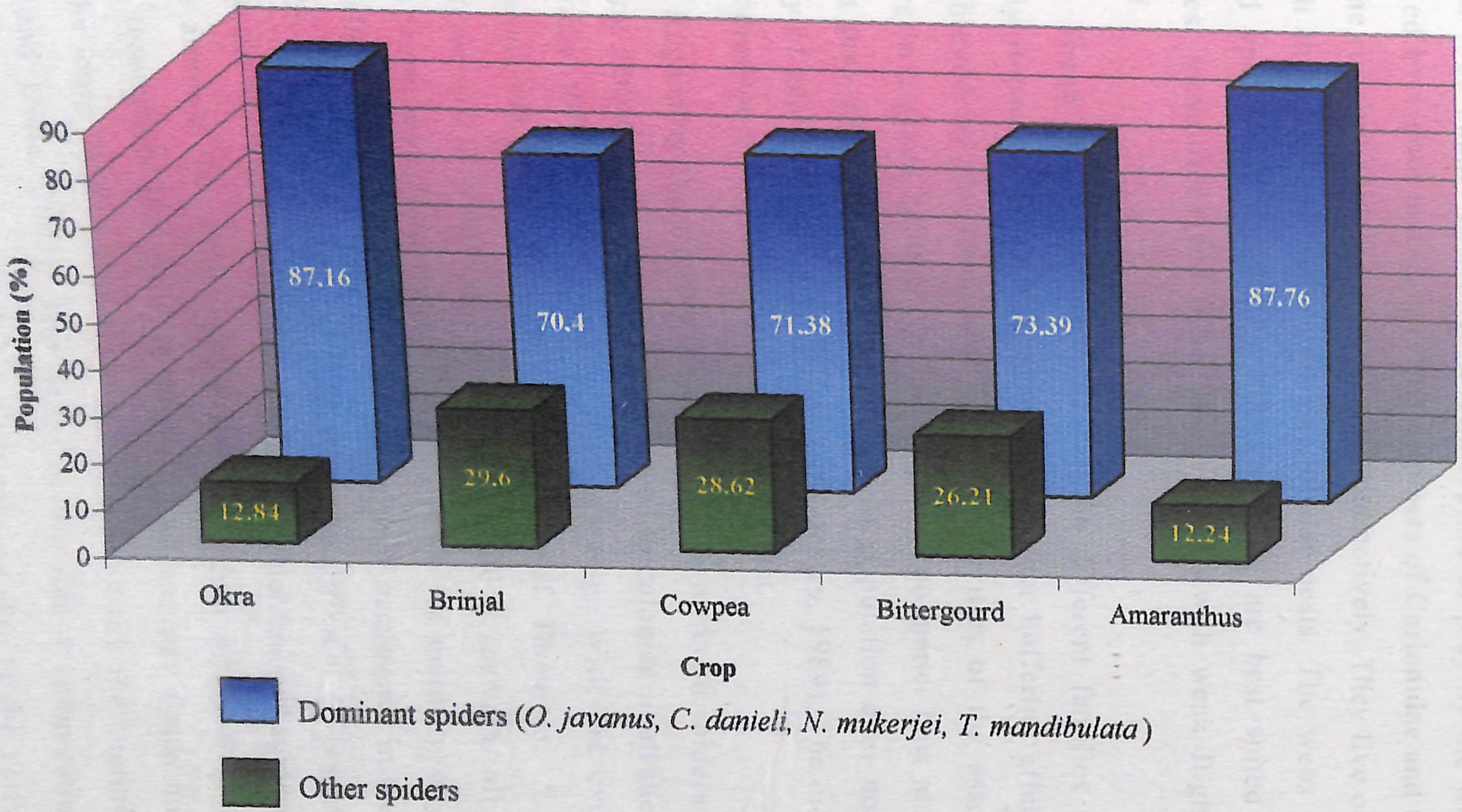


Fig. 4. Relative abundance of the four dominant spiders in vegetable fields in relation to other spiders

habitats and are dominant predators. They abound wherever a plentiful insect food supply is available. The capture of prey by the wolf spider is marked by vigour and power. The members of Corinnidae and Clubionidae are the running spiders which move about actively. They live on the leaves which they roll and make into flat tubular nests. The webs of the long jawed spiders of the family Tetragnathidae are best suited to capture midges, mosquitoes and other small insects with weak flight (Gertsch, 1979).

These varied characteristics of the different families make them equally important in agro-ecosystems as spider buffering effect can only be achieved by the composite foraging activities of the assemblage of spiders in a given habitat. No spider species no matter how abundant can hold a prey population in check, since its population does not track the density of pest population (Riechert and Lockley, 1984). The more diverse the species the better is its pest regulatory effect.

Regarding the relative prevalence of the different spiders during the cropping period, the spiders were observed to colonize in all the vegetable plots only three to four weeks after planting. With the exception of *O. shweta*, *O. quadridentatus*, a species of *Thomisus*, *N. vigilans*, *N. molemensis*, *Araneus* sp., *A. pulchella* and *A. aemula*, all the other spiders were seen from the late vegetative to the maturity stages of the crops, slight variations being observed in their occurrence in the different vegetables. The occurrence of spiders in the different stages of the crop noted in the study is in consonance with the occurrence of spiders reported in other annuals. The spiders *O. ratnae*, *O. shweta* and *Neoscona* sp. were present throughout the growing period in pigeon pea fields and peaked when the crop began flowering and remained till the maturity stage. (Borah and Dutta, 2003). The delay in the initial colonization of the spiders observed in the vegetable plots may be due to the early cultural operations like field preparation, weeding, earthing up, manuring etc., which disturb the ecosystem. Moreover, spider micro-habitat associations are linked with patches of abundant prey. In the vegetables, migration of the araneae might have occurred from the surrounding vegetations when the population of the insects in the plots showed an increasing trend towards the active vegetative stage.

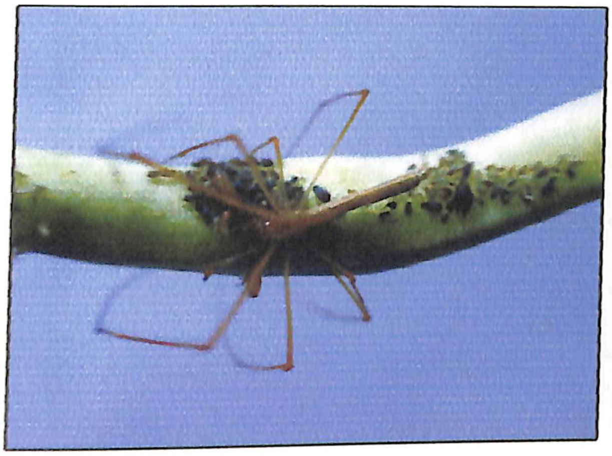
5.2 INFLUENCE OF SEASON

Season and stage of growth of plants greatly influence predator distribution. In the trial conducted on the seasonal abundance, occurrence of the spiders during summer and rainy seasons did not vary significantly. However, significant difference was observed in the population of the araneae in the vegetative and reproductive stages of the vegetables as indicated by the population of the spiders presented in para 4.2. Higher population was recorded during the reproductive stages of the different vegetables. Such trends in the population buildup have been reported in soybean where spiders were more abundant during pod fill stages contributing to heavy mortality of the prevailing pests (Bechinsk and Pedigo, 1981). Similarly, predatory spiders were seen in abundance when *H. armigera* appeared during flowering season in pigeon pea (Borah and Dutta, 2003). Abundance of spiders in the cotton fields of Peru was directly linked to the development of plants rather than the season (Aguilar, 1975). This correlation with the growth stages of crops may be due to increase in prey availability, which in turn supports more species to co-exist. Contrarily, peak activity and higher density of spiders were recorded in summer while the lowest were in winter in eight vegetable crop fields in Egypt. The high abundance of spiders in summer was attributed to the combination of three factors, dense vegetation cover, higher temperature and significant relative humidity (Hussein, 1999). Thus, the results of the study on seasonal abundance need further elucidation.

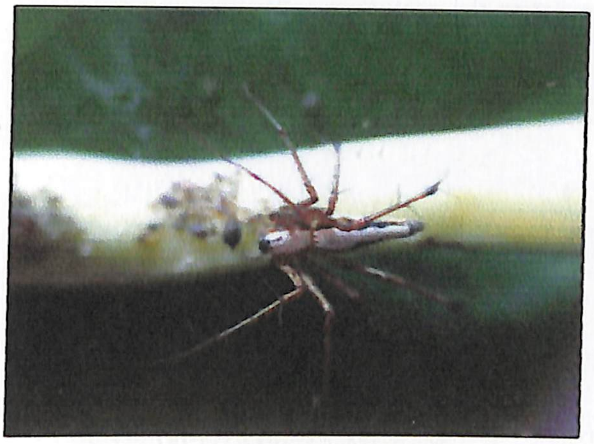
5.3 PREDATORY EFFICIENCY

Spiders often constitute a large part of the predatory fauna in agro-ecosystems and prey on many insect pests (Plates 7 and 8). Although incidence of predation on insect pests in vegetable fields have been reported, little effort has been made to evaluate their feeding potential on different kinds of insects. The studies on the prey range indicated that when offered with a choice the spiders do show preference for certain prey. Evidently, the four major spiders observed in the vegetable ecosystem preferred soft bodied pests, like the hemipterans, lepidopterans (caterpillars and moths), coleopterans (grubs and egg masses) and dipterans (Fig.5).

Among the pests of okra screened, three hemipterans and caterpillars of two lepidopterans were the preferred prey of the spiders. Between these the consumption rate of the hemipteran prey was high being 47.44 in seven days, while the feeding potential on the caterpillars was only 4.95 in seven days (Fig. 6). Similarly, among the pests of brinjal tested, three hemipterans (*A. gossypii, C. insolitus* and *U. hystricellus*), caterpillars of *A. olivaceae* and egg masses of *H. vigntioctopunctata*, comprised the preferred diet of the spiders. The feeding rate for the hemipterans was relatively high, the average consumption being 30.57 hemipterans in seven days. The average number of caterpillars and egg masses consumed were 8.74 and 5.09 respectively. Among the pests of cowpea, the preferred prey included hemipterans (*A. craccivora* and *A. pilosum*), caterpillars of *L. boeticus* and grubs and egg masses of leaf beetle, the average number consumed being 26.92, 6.93, 5.02 and 3.31 in seven days respectively. Again, the feeding potential of the spiders on pests of bittergourd was high for the hemipterans (40.96) followed by egg masses of *E. septima* (12.32), moths (12.25) and caterpillars of *D. indica* (11.03) and flies (10.75). The lepidopteran leaf feeders of amaranthus (10.37 moths and 9.53 caterpillars) constituted the preferred diet of the

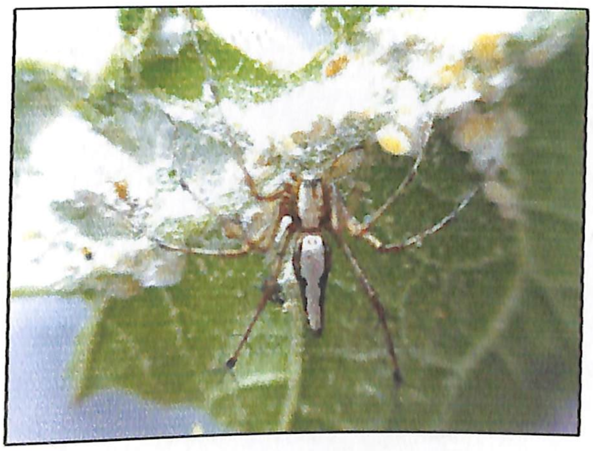


T. mandibulata on *Aphis craccivora*



O. shweta on *Aphis craccivora*

T. dimidiata on *Aphis craccivora*



O. shweta on *Urentius hystricellus*

Q. quadridentatus on *Urentius hystricellus*

Cheiracanthium sp. on *Urentius hystricellus*

Plate 7. Spiders predating on different pests

T. dimidiata on S. derogata **(Caterpillar)**

O. javanus on S. derogata **(Caterpillar)**

***Carrhotus* sp. on *S. derogata* (Caterpillar)**

O. javanus* on *Lampides boeticus

T. dimidiata* on *Epilachna septima

Plate 8. Spiders predating on different pests

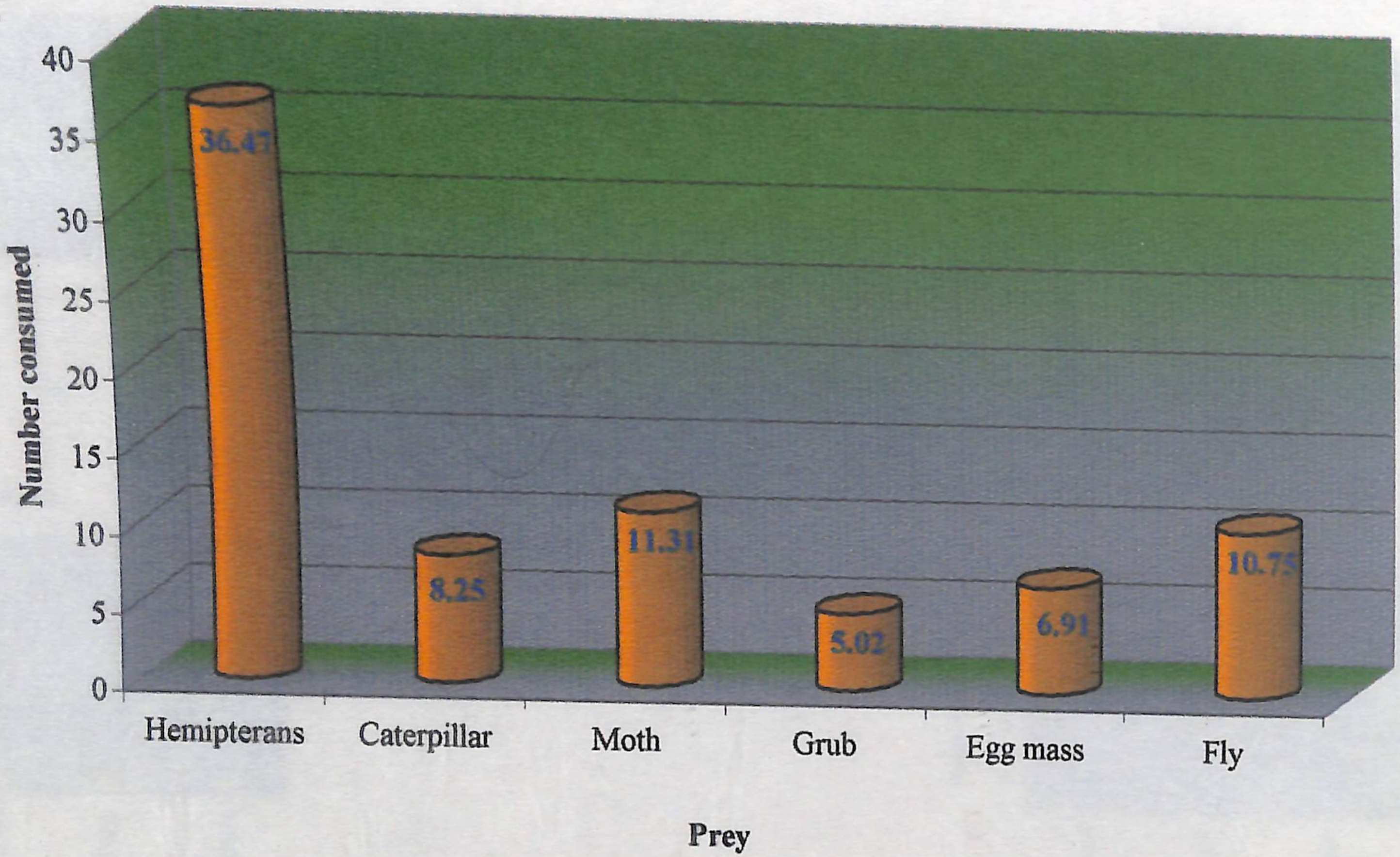


Fig. 5. Relative preference of spiders for different pests of vegetabels

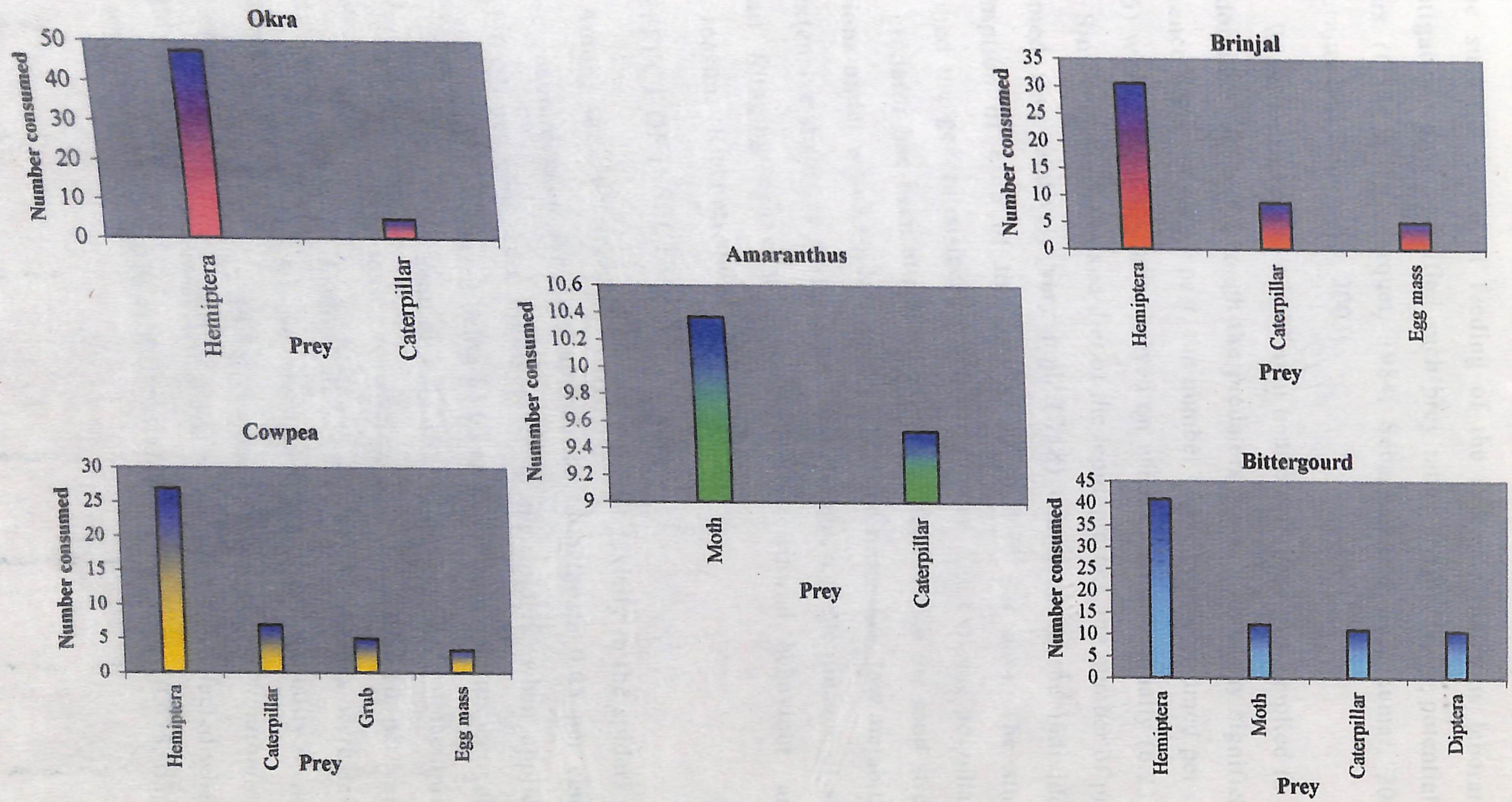


Fig. 6. Feeding potential of spiders on pests of different vegetables

spiders. The exclusive preference for soft bodied insects may be attributed to the suctorial mode of feeding of the spiders. Numerous laboratory investigations have identified such prey range and predatory potential of spiders (Chiu, 1979; Parquet, 1984; Sebastian and Sudhikumar, 2002; Mathirajan and Regupathy, 2003).

When a mixed diet of different hemipteran prey was supplied to the four dominant spiders, though the predators did not show any significant preference for a particular pest, the number of the pests consumed per day (16.45) was twice the number preyed on when given individually (6.23 to 7.08). Similarly, in the mixed diet of the lepidopterans, the number of prey consumed was relatively very high (7.18) compared to the individual consumption of each of the prey (1.42 to 1.75 per day). The study confirmed the generalist-feeding trait of spiders. The extreme polyphagy of the predator has been attributed to various factors like the food stress conditions under which spiders evolved, of food limitation, low metabolic rate, extensive digestive systems for food storage, a predominance of sit-and-wait foraging behaviour, energy based territorial behaviour, and dietary reasons (Riechert and Lockely, 1984).

5.4 EFFECT OF INSECTICIDES

Among the insecticides screened for their toxicity to the spiders at the dose recommended for field application, dimethoate 0.05 per cent, carbaryl 0.02 per cent were highly toxic to the spiders, when applied topically, the mortality caused being 85.00 and 87.75 per cent respectively (Fig. 7). Malathion 0.1 per cent, quinalphos 0.05 per cent and imidacloprid 0.02 per cent were less toxic, registering only less than 50 per cent mortality of the spiders. Comparatively, all the insecticides were less toxic to the predator when released on treated plants, the mortality of the spiders ranging from 7.31 to 46.56. Among the spiders, *T. mandibulata* was highly sensitive to the insecticides and *N. mukerjei* less affected when treated topically. When tested at different doses, dimethoate (0.025, 0.05

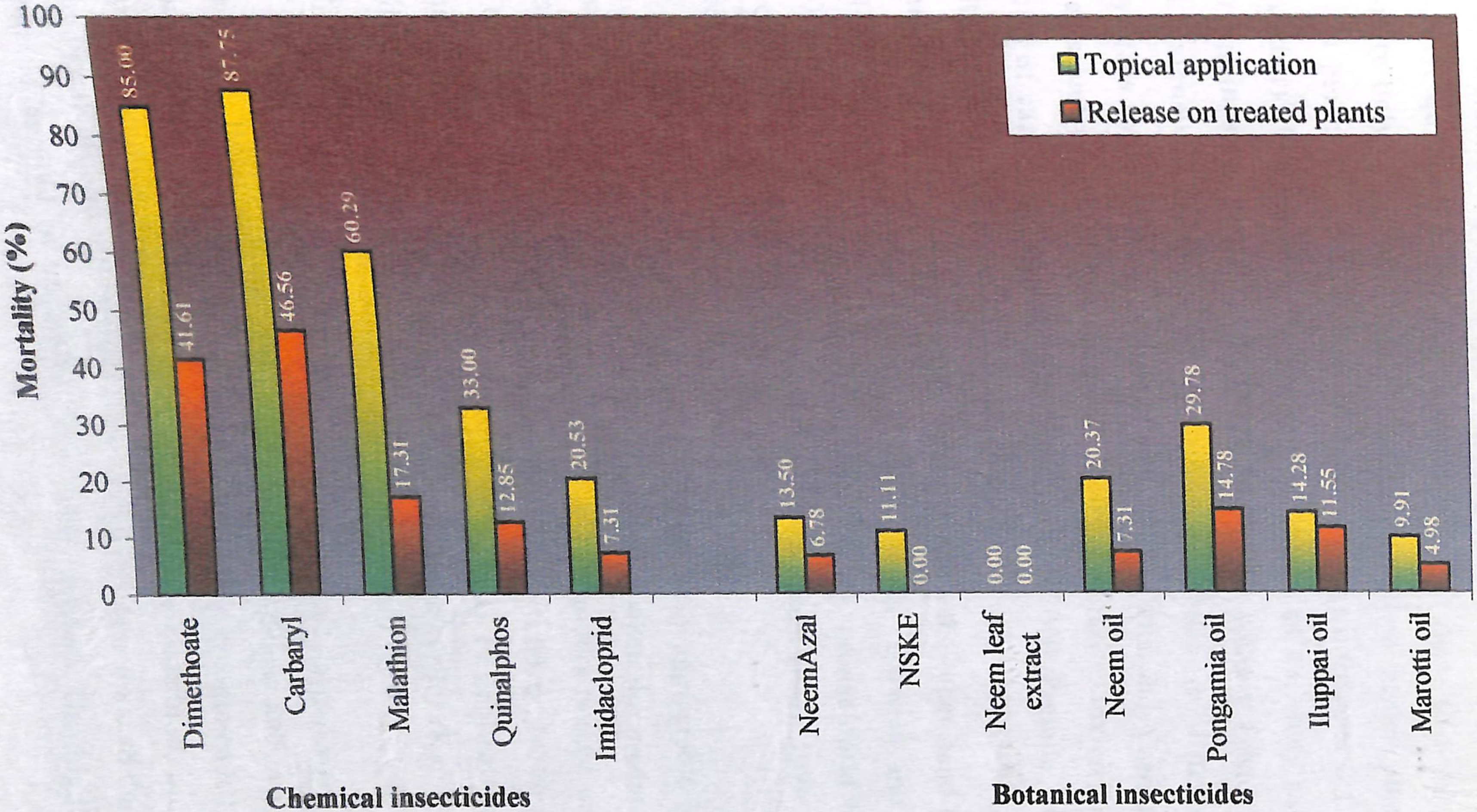


Fig. 7. Effect of chemical and botanical insecticides on spiders

and 0.1) and carbaryl (0.015, 0.2, 0.3) were equally toxic at all the doses (Fig.8). Malathion was toxic only at the higher doses (0.1 and 0.2 per cent). Similarly, quinalphos and imidacloprid recorded more than 50 per cent mortality only at the higher dose. When released on treated plants, more than 50 per cent mortality was recorded only in dimethoate 0.1 per cent and carbaryl 0.3 per cent treatments. The results of the study conform to other findings on the effect of the insecticides on spiders. Dimethoate has been extensively reported to be toxic to spiders in different agro-ecosystems (Vickerman and Sunderland, 1977; Culin and Yeargan, 1983; Casteels and Clercq, 1990; Huusela, 2000). Contrarily, toxicity and non-toxicity of carbaryl (Yabar, 1982; Tanaka *et al.*, 2000; Premila, 2003) and malathion (Fitzpatrik *et al.*, 1978; Mendes *et al.*, 1985; Mishra and Mishra, 2002) have been reported. Quinalphos on the other hand has been observed to be toxic to araneae in cotton fields (Darwish and Farghal 1990) and spiders in rice fields (Premila, 2003). Imidacloprid has been recorded to be relatively non- toxic to spiders (Kunel *et al.*, 1999; Mo and Philpot, 2003; Gopan, 2004).

None of the botanical insecticides caused any appreciable mortality of the spiders neither when applied topically nor when the predators were released on treated plants. The mortality of the spiders ranged only from 0.00 to 30.00 per cent (topical application) and 0.00 to 14.78 per cent (release on treated plants) in the different methods of application. Non-toxicity of botanicals to araneae has been observed earlier (Kareem *et al.*, 1998; Mishra and Mishra, 2002).

Evidently, susceptibility of spiders to insecticides varies enormously. Botanicals are certainly safe to the araneae and can be used for pest control. Among the chemical insecticides recommended for the control of vegetable pests, the contact insecticides malathion, quinalphos and the neonicotinoid imidacloprid were relatively less toxic to the spiders and can be applied in vegetable plots when needed. The highly toxic

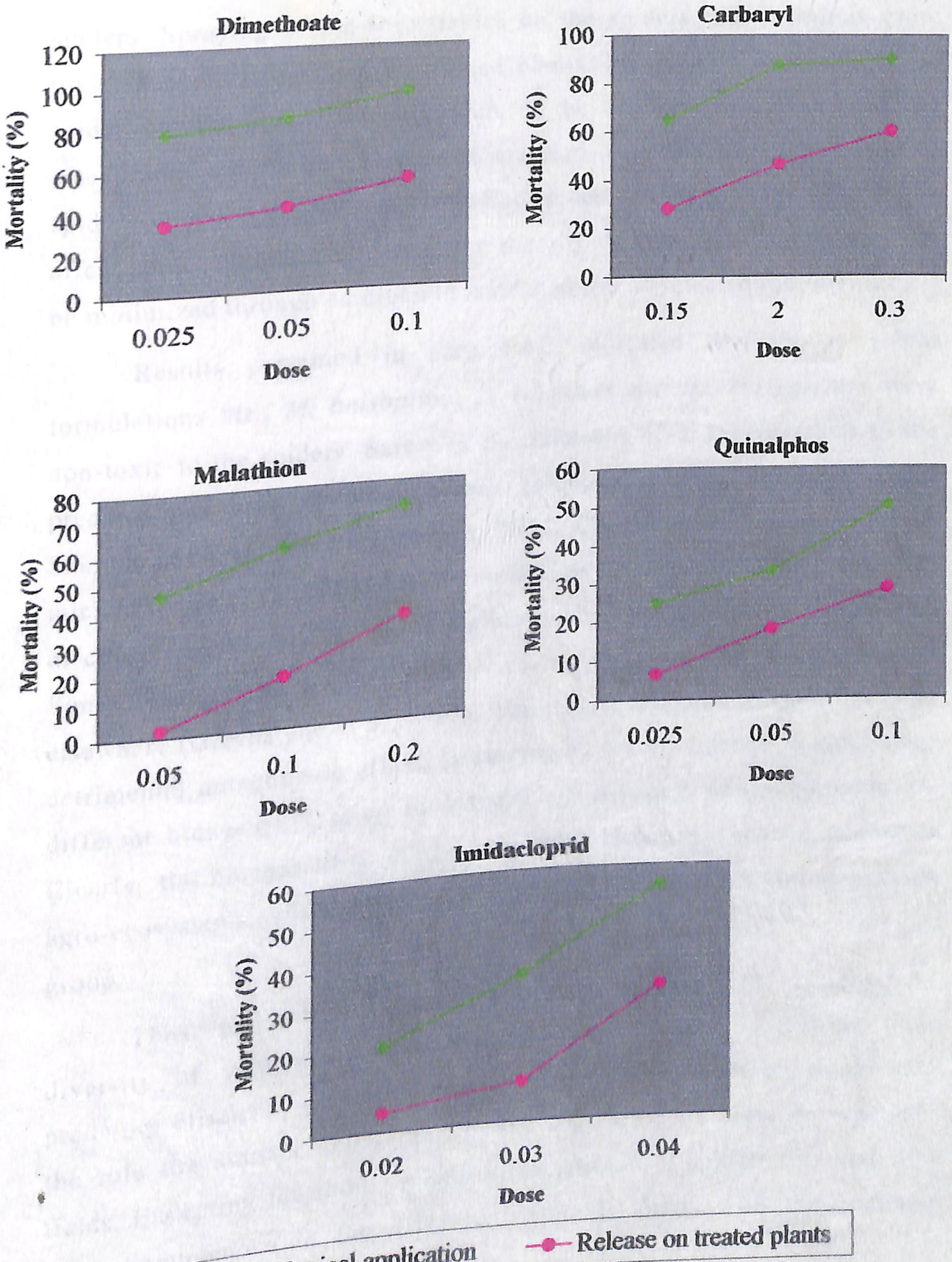


Fig. 8. Effect of different doses of chemical insecticides on spiders

dimethoate and carbaryl showed be avoided, especially when the population of spiders is high in vegetable fields. The mode of application of the insecticides too had a significant bearing on their toxicity to the spiders. Spraying of the insecticides on the spiders was definitely more toxic than releasing them on treated plants. Presumably, the build up of spider population in the field will not be affected significantly if the insecticides are applied before colonization. Contrarily, direct contact of spiders with insecticides applied after spider colonization may adversely affect spider population. Hence, the toxicity of insecticides to spiders can be minimized through careful and restricted use of sélécted insecticides.

Results presented in para 4.4.2 indicated that the microbial formulations *viz.*, *M. anisopliae*, *P. lilacinus* and *B. thuringiensis* were non-toxic to the spiders. Safety of formulations of *B. thuringiensis* to the predator has been observed earlier (Mendoza, 1972; Sklyarov, 1983; Sharma and Kashyap; 2002; Gopan, 2004). Contrarily, *F. pallidoroseum*, a microbial insecticide used for the control of *A. craccivora* the major pest of cowpea, *Fusarium* sp. and *B. bassiana* were pathogenic to the araneae. Similar toxicity of the fungus *N. atypicola* to spiders has been observed elsewhere (Greenstone et al, 1987). The results reflected the possibility of detrimental antagonistic effects occurring as a consequence to combining different bioagents, leading to reduced effectiveness of the components. Clearly, the compatibility of the important biological control agents in agro-ecosystems should be examined prior to the augmentation of a target group.

Thus, the tentative efforts made to document the density and diversity of spiders in vegetable ecosystem and to determine their predatory efficiency and susceptibility to insecticides, notably established the role the araneae could play in the regulation of pests in vegetable fields. Excepting for some variations, population of spiders was high and quite homogenous in the different vegetable fields with the common spiders being distributed evenly. Even though under field conditions spiders rarely show specificity to any prey and attack the prey relative to the rate of encounter with them, the observations made on the prey range, predatory potential and prey preference in the laboratory could act as a predictor of the biocontrol potential of the natural predator. Further more, the study revealed that need based and localized use of selective insecticides would help to offset their disruptive influence on the agro-ecosystems. Since unlike perennials, annual crop fields (like vegetable) usually support lower spider population at a time on account of the frequent mechanical disturbances (like tillering, manuring, weeding and harvesting), in addition to the disruptive influence of plant protection measures, steps should be taken to maintain the spider community to obtain their maximum control effect. Provision of refugia through planting / maintaining beneficial weeds and flowering plants in the plots, bunds and adjacent vacant lands and maintenance of compost traps are excellent practices for maintaining the spider community. Conservation rather than augmentation should be the motto in the exploitation of the natural bioagent.

In summary, preservation of the diverse assemblage of spiders characteristic of the vegetable ecosystem would be a practical and definitely more ecologically and economically viable approach for pest suppression in vegetables, particularly in organic farming. When there is a spurt in pest damage, the protection afforded by the predator can be supplemented with "spider friendly" insecticides like botanicals and the chemicals, quinalphos and imidacloprid applied judiciously.

Summary

6. SUMMARY

Inspite of their well defined role in the regulation of pest population in rice and several other crops, the spiders are the least studied natural enemies in the vegetable ecosystem. Information on the predator could lead to the formulation of a sustainable integrated pest management package for adoption in vegetable ecosystem. With this view, survey was conducted in okra, brinjal, cowpea, bittergourd and amaranthus plots in Kalliyoor panchayat of Thiruvananthapuram district to determine the abundance and diversity of spiders prevalent in vegetable fields. The seasonal abundance of the predator was assessed through a field trial laid out in the instructional farm Vellayani. The predatory efficiency of the major spiders identified in the survey and the relative toxicity/safety of chemical, botanical and microbial insecticides recommended for the control of pests of vegetables were determined in the laboratory. The major findings of the study are summarized below:

- High population of spiders was observed in the vegetable plots, the number of spiders ranging from 6.00 to 35 per 10 plants in okra, brinjal, cowpea, bittergourd and amaranthus in a cropping season. Maximum number of spiders was recorded from okra fields.
- Both hunting and web building spiders were prevalent in the vegetable fields. Between the two guilds, the hunting spiders were dominant in all the vegetable fields constituting 65.50 per cent of the spider population. The web builders comprised 34.50 per cent of the population. Among the vegetables, no significant difference was observed in the occurrence of hunters and web builders.

- Thirty species of spiders distributed in nine families were recorded from the vegetable plots. The spiders observed included the hunters *O. javanus, O. shweta, O. quadridentatus, Oxyopes* sp., *P. viridana, H. semicupreus, Hyllus* sp., *Lycosa* sp., *Phidippus* sp, *Clubiona* sp., *Carrhotus* sp, *T. dimidiata, Cheiracanthium* sp., *C. daniel, T. pugilis, T. sorajaii, Thomisus* sp. and *C. zetes* and the web builders *N. mukerjei, N. vigilans, N. molemensis, N. poonaensis, Neoscona* sp., *Neoscona* sp., *Araneus* sp., *A. anasuja, A. pulchella, A. aemula, T. mandibulata* and *Tetragnatha* sp. The number of species in each vegetable ranged from 10 to 17.

- Among the 30 species recorded, 16 species spiders were commonly seen in the different vegetable plots. The species *viz., Hyllus* sp., *C. zeks, N. vigilans* and *A. aemula* (okra), *H. semicuprens* and *H. pulchella* (brinjal), *A. anasuja* and *Argiope* sp. (cowpea), *N. molemensis, T. sorajai, T. pulgilis* and *Thomisus* sp. (bittergourd), *P. viridana* and *N. poonaensis* (amaranthus) were seen exclusively associated with a particular vegetable.

- Araneidae consisting of 10 species was the most represented family in the vegetable ecosystem. Oxyopidae and Salticidae each comprising of five species too were well represented. The other families observed were Miturgidae, Thomisidae, Tetragnathidae, Corinnidae, Lycosidae and Clubionidae.

- Most of the spiders appeared in the fields during the vegetative and flowering stages of the crop. Few spiders were recorded in the early stage of the crops

- Among the different genera of spiders recorded, the hunters *O. javanus* and *C. danieli* and the web weavers *N. mukerjei* and *T. mandibulata* were dominant in all the vegetable fields.

Among the four spiders, *O. javanus* and *C. danieli* were equally dominant in the vegetable ecosystem.

- No significant difference was observed in the abundance of spiders during summer and rainy seasons. But the abundance of spiders differed significantly between the growth stages *viz.*, vegetative and reproductive stages of the crops. The population of spiders was significantly higher during the reproductive phase.

- The four dominant spiders *viz.*, *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* preferred soft bodied insects like hemipterans, lepidopterans (caterpillars and moths), coleopterans, (eggs masses and grubs) and dipterans when tested for their prey range.

- Among the pests of okra, the spiders preferred *A. biguttula biguttula*, *A. malvae*, *B. tabaci* and caterpillars of *S. derogata* and *S. litura* for consumption, higher preference being shown for the hemipteran prey. Similarly, among the pests of brinjal, *A. gossypii*, *C. insolitus* and *U. hystricellus*, caterpillars of *A. olivaceae* and egg masses of *H. vigintioctopunctata* comprised the five relatively preferred diet of the spiders. Consumption of the hemipteran pests was relatively high.

- The five preferred prey among pests of cowpea included the hemipterans *A. craccivora* and *A. pilosum*, caterpillars of *L. boeticus* and grubs and egg masses of *A. misera*, maximum consumption being for the hemipteran prey. Feeding potential of the spiders on the pests of bittergourd was high for *A. gossypii* followed by the fruitfly, *B. cucurbitae*, moths and caterpillars of *D. indica* and egg masses of *E. septima*.

- Among the pests of amaranthus the spiders preferred moths and caterpillars of *H. recurvalis* and *P. basaslis* and caterpillars of *S. litura*

- The spiders equally preferred all the hemipteran pests for consumption when a mixed diet of hemipteran prey was offered. However, significant difference was seen in the preference for the lepidopteran pests. *O. javanus* had a higher preference for the lepidopteran pests followed by *T. mandibulata, N. mukerjei* and *C. danieli.*

- The chemical insecticides viz., dimethoate, carbaryl, malathion, quinalphos and imidacloprid were more toxic to the spiders than the botanical insecticides when tested at the doses recommended for the control of pests. Between the two methods of application topical treatment with the insecticides resulted in higher mortality (45.30 to 78.65 per cent) than when released on insecticide treated plants (13.95 to 33.55 per cent). Among the insecticides, dimethoate 0.05 per cent, carbaryl 0.02 per cent and malathion 0.1 per cent were toxic to the spiders when applied topically. Imidacloprid 0.02 per cent and quinalphos 0.05 per cent were less toxic.

- The botanical insecticides *viz.*, NeemAzal 1 per cent, NSKE 5 per cent, neem leaf extract 5 per cent, neem oil, pongamia oil, iluppai oil, and marotti oil (2 per cent each) were less toxic registering only less than 50 per cent mortality both when applied topically and when released on treated plants.

- The spiders differed in their susceptibility to the insecticides too. *T. mandibulata* was the most susceptible followed by *C. danieli. O. javanus* and *N. mukerjei* were less susceptible to the insecticides.

- Considering the effect of different doses of insecticides, the recommended dose and the higher dose resulted in higher mortalities than the lower dose.

- Among the microbial insecticides tested, *M. anisopliae* and Bt were safe to spiders. Contrarily, *F. pallidoroseum*, *Fusarium* sp. and *B. bassiana* were pathogenic to the predator.

Based on the results of the study, conservation of the spiders characteristic of the vegetable ecosystem would be a practical and ecologically and economically viable approach for pest suppression in vegetables. When there is a spurt in pest ravage, the protection afforded by the predator could be supplemented with judicious use of "spider friendly" insecticides like botanicals, quinalphos and imidacloprid.

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MAJOR SPIDERS IN VEGETABLE ECOSYSTEM AND THEIR PREDATORY POTENTIAL

MANU P. MANI

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Department of Agricultural Entomology
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM-695 522

ABSTRACT

Spider faunistic survey conducted in okra, brinjal, cowpea, bittergourd and amaranthus fields in Kalliyoor panchayat of Thiruvananthapuram district during the summer of 2004, revealed the prevalence of high density and diversity of spiders in the vegetable ecosystem. Hunting spiders were dominant in all the vegetable plots. Thirty species of spiders distributed in nine families were recorded with the number of species in each vegetable field ranging from 10 to17. Among the thirty species, 16 species were commonly seen in the different vegetable fields while 14 species were seen exclusively associated with a particular vegetable.

Araneidae with ten species was the most represented family in the vegetable fields followed by Oxyopidae and Salticidae. The other families observed were Miturgidae, Thomisidae, Tetragnathidae, Corinnidae, Lycosidae and Clubionidae. Most of the spiders appeared during the vegetative and flowering stages of the crop. Few spiders were recorded in the early stage of the crops.

Four spiders *viz*., *O. javanus*, *C. danieli*, *N. mukerjei* and *T. mandibulata* were dominant in all the vegetable plots among which *O. javanus* and *C. danieli* predominated.

Studies on the seasonal influence showed no significant difference in the abundance of the spiders during summer and rainy seasons. Rather, the growth stages of the crops significantly influenced the build up of the spider population with higher population being observed during the reproductive phase.

In general, the spiders preferred soft bodied insects like the hemipterans, lepidopterans, dipterans and coleopterans (eggs and grubs) for predation. While the spiders did not show any significant preference

for the different hemipteran prey in a mixed diet, significant difference was shown for the different lepidopteran pests. *O. javanus* had the maximum preference for the lepidopteran pests

Chemical insecticides were more toxic to the spiders than botanicals when tested at their recommended doses. Among the chemical insecticides, dimethoate 0.05 per cent, carbaryl 0.2 per cent and malathion 0.1 per cent were highly toxic. Even at different doses the insecticides were toxic to the spiders. Quinalphos 0.05 per cent and imidacloprid were less toxic. Between the two methods of application, topical application of insecticides was more detrimental to the spiders than release on treated plants. Among the spiders, *T. mandibulata* was more susceptible to the insecticides followed by *C. danieli*. *O. javanus* and *N. mukerjei* were less sensitive.

While the fungal pathogens, *M. anisopliae*, *P. lilacinus* and *Bt* were safe to the spiders. *F. pallidoroseum*, *Fusarium* sp. and *B. bassiana* were pathogenic.

Based on the results of the study, conservation of the spiders characteristic of the vegetable ecosystem would be a practical and ecologically and economically viable approach for pest suppression in vegetables. When there is a spurt in pest ravage, the protection afforded by the predator could be supplemented with judicious use of "spider friendly" insecticides.