

**EVALUATION OF PREDATORY POTENTIAL OF
PHYTOSEIID MITES ON MITE PESTS OF
LEAFY VEGETABLES AND
FRUIT CROPS**

*Thesis submitted to
the faculty of science, University of Calicut
for the award of the degree of*

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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2022

DECLARATION

I, Jyothis Devasia do hereby declare that this thesis entitled “**EVALUATION OF PREDATORY POTENTIAL OF PHYTOSEIID MITES ON MITE PESTS OF LEAFY VEGETABLES AND FRUIT CROPS**” is an authentic record of the research work carried out by me under the supervision and guidance of **Dr. N. Ramani**, Professor (Rtd.), Division of Acarology, Department of Zoology, University of Calicut and that no part of this thesis has been submitted before for the award of any other Degree or Diploma.

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CERTIFICATE

This is to certify that the thesis entitled “**EVALUATION OF PREDATORY POTENTIAL OF PHYTOSEIID MITES ON MITE PESTS OF LEAFY VEGETABLES AND FRUIT CROPS**” is an authentic record of the work carried out by **Mr. Jyothis Devasia** under my supervision and guidance in partial fulfilment of the requirements of the Degree of Doctor of Philosophy in Zoology in the Division of Acarology of this Department and that no part thereof has been presented before for any other degree or diploma.

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Dr.N. RAMANI
(Supervising Guide)

Dedicated
to
my most beloved mother
Sheelamma John

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CHAPTER I

INTRODUCTION

INTRODUCTION

The practice of agriculture has a long history of about 10000 years that revolutionised human history and radically transformed our civilisation from ‘hunter - gatherers’ to ‘agricultural societies’. In order to sustain the needs of the growing population, mankind continued to alter surrounding flora and fauna for their own benefit and adopted the practice of agriculture as a successful strategy for species survival. During the middle ages, human population continued to shoot up and eventually increased the land use. Through the ages, several improvisations and new technologies were introduced for the better productivity. Between the 17th and mid 19th centuries, new agricultural practices like enclosure, mechanization, crop rotation and selective breeding opened a new era of ‘modern agriculture’. Green revolution and organic farming gave momentum to the development of agricultural practices during the 20th century. The recent developments in the field of bio technology, molecular biology, agricultural engineering and artificial intelligence have been triggering portentous progress in the field of agriculture, turning it in to ‘smart farming’.

Even though the modernisation of agricultural practices increased the productivity to a considerable extend, we are facing a tremendous set back due to the climate changes and potential threats from phytophagous pests. Climate change like global warming facilitates the outbreak of agricultural pests in an alarming scale, and doubling the crop loss. Food and agriculture organization of the United Nations estimated that 20 - 40 per cent of global crop production is lost due to pests annually. Agricultural pests constitute insects, mites, weeds, rodents and plant pathogens like fungi, bacteria and viruses. Among which, mite pests alone cause substantial damage to several cultivars, especially both vegetables and fruit crops. Phytophagous mite species

belonging to the families, Tetranychidae, Eriophyidae, Tenuipalpidae and Tarsonemidae are considered as the most injurious pests in the acarine world.

Mites of the family Tetranychidae are popularly known as the spider mites and unique among Acari in having the ability to spin webs and sometimes form a web nest. Webs serve several functions like protection of entire colony, especially the vulnerable life stages like inactive egg and quiescent stages, facilitating group dispersal by wind or animal transport and often act as a physical support for locomotion. Among the members of Tetranychidae, the two spotted spider mite (*Tetranychus urticae*) is considered as the most notorious species worldwide with a host range of 1200 plant species including fruit crops and leafy vegetables. The important genera containing voracious spider mites include *Tetranychus*, *Eutetranychus*, *Eotetranychus*, *Schizotetranychus*, *Oligonychus* and *Panonychus*. They feed by piercing the plant tissue with their cheliceral stylets and suck out the cellular content along with chlorophyll creating white chlorotic spots at the sites of attack. Prolonged feeding imparts a stippled appearance to the foliage, leading to subsequent necrosis and leaf burn. Sometimes, damage could be more severe due to the transmission of plant pathogens like bacteria and viruses excreted on to the site of attack and facilitate their entry in to the plant tissues. Spider mites pass through egg, larva, protochrysalis, protonymph, deutochrysalis, deutonymph and teliochrysalis before attaining adulthood. It takes an average of 13 days to reach adult hood. Short life span, high fecundity and acaricide resistance enable spider mites to rapidly proliferate to reach Economic Injury Level (EIL) both in green houses and open fields.

Eriophyid mites are another kind of successful acarine pests which comes under the family Eriophyidae, superfamily Eriophyoidea of the order Prostigmata. There are more than 100 described species of eriophyids of which only a few are serious pests of agricultural crops. Unlike other mites they have vermiform body lacking last two pairs of

legs and nearly all body setae. They are entirely phytophagous and usually live, feed and reproduce in confined micro-environments. The disappearance of body parts are considered as an adaptation for the survival in their microhabitats. Eriophyid mites are well known for their high host specificity. Based on the variation in feeding habitat eriophyids are of different types. Eriophyid 'bud mite' invades bud tissue causing abnormal bud formation. On the other hand 'gall forming' eriophyids causes tissue pocketing leading to abnormal growth on the affected part of the foliage. 'Blister mites' invades mesophyll tissue of leaves and feed from inside causing substantial damage to the leaves leading to the development of discoloured blister appearance externally. 'Rust mite' feeds on leaf surface and are usually seen on the adaxial side. Some species have two adult form viz., normal feeding form called protogyne and the overwintering deutogyne form.

The false spider mites of the family Tenuipalpidae are also recognised as major pests of several economically important crops and feeds on stems, leaves, fruits and flowers. They belong to the superfamily Tetranychoidae of the order Prostigmata. Unlike true spider mites they never produce silk webbing on plants. They are also known as flat mites because most of the species are dorso-ventrally flattened in appearance. More than 600 species of false spider mites are described in about 30 genera, among which the most potent pest species comes under the genera *Brevipalpus* and *Tenuipalpus*.

The family Tarsonemidae includes more than 500 species of phytophagous mites in 40 genera. However the most injurious species belongs to the genera *Polyphagotarsonemus*, *Hemitarsonemus*, *Phytonemus* and *Steneotarsonemus*. Most of the species belong to the aforementioned genera have wide host range including many of the economically important food crops. The damage is inflicted either directly or through the transmission of plant pathogens.

The traditional strategies for the control of pest population include physical, cultural and mechanical methods. However, pest control by chemical pesticide is the most common and widely accepted control strategy across the globe. The actual revolution in chemical pesticides happened during the 18th and 19th centuries as part of the industrial revolution. Some estimates suggest that crop productivity shoot up to 50 per cent due to the leap in chemical pesticide usage and became an indispensable tool for the sustainable agriculture. However the extensive use of organophosphate and synthetic organic pesticides jeopardises both the aquatic and terrestrial ecosystems and the concern increases day by day. Moreover, the short life span of pest mites facilitates the rapid acquisition of pesticide resistance and subsequent pest resurgence. Furthermore, the deleterious effect of synthetic acaricides on non target/ beneficial organisms including predators, parasites and parasitoids creates unforeseen pest outbreaks.

Biological control has emerged as an alternative to the chemical pest control ensuring a long term action and minimum damage to the environment. It has been actively practiced for more than 100 years. Biological control method involves the use of beneficial organisms/ natural enemies of agricultural pests. Natural enemies can be predators, parasites, parasitoids or plant pathogens to suppress and maintain the pest population below economic injury level. The different strategies employed in bio control includes, Importation (Classical bio control), Augmentation and Conservation. Classical biocontrol involves the introduction of non native natural enemies into a new area for the permanent and long term pest control, while augmentation involves the supplemental release of biocontrol agents (exotic or endemic) in order to boost the existing natural enemy population. Conservation of existing natural enemy population in the pest infested area is the third strategy involved in biological pest control.

When it comes to acarine pest management using biocontrol agents, the most accepted and widely used natural enemies are the predatory mites of the family Phytoseiidae. They are free living, pro- active and fast moving predators inhabiting on plants and upper soil layers. They mostly feed on mites but some have developed a taste on nematodes, fungi and small insects like white flies, thrips, mealy bugs and aphids. They could be identified from all types of plants comprising herbs, shrubs, trees, grasses, fungi, mosses and from plant parts like inflorescence, leaves, flowers and under barks etc. Because of their usefulness as biocontrol agents, interest in phytoseiids has increased over the past 50 years.

Phytoseiidae is one of the important family under the order Mesostigmata. The family phytoseiidae contains more than 2400 described species, organized in 91 genera. (Demite *et al.*, 2018) They are reported from all continents, except Antartica. Phytoseiidae is further divided in to three major subfamilies viz., Amblyseiinae, Typhlodrominae and Phytoseiinae. These subfamilies differ in their morphological and biological attributes. The members of the family Phytoseiidae bear an entire dorsal plate with fewer than 23 pairs of setae (of a total of 28 possible pairs of setae). Their stigmata opens between leg III and leg IV and the metasternal plates are small. They lack leg grooves and the leg I bears an ambulacra, and the digits of the male spermatodactyls are distally free. Chelicerae chelate-dentate with both digits well developed. Anterior margin of tectum smooth or minutely denticulate, without processes. Peritremal shield in most species fused anteriorly with dorsal shield. Female genital shield is truncate posteriorly, with a straight posterior margin. Most adult females have a ventral and anal shield fused together to form a ventrianal shield, a few species with a separate ventral and anal shields, or with a simple anal shield. Males with separate sterno- genital shield and anal

shields; all legs with pretarsi and claw and with reduced setation. Spermatheca well developed, with atrium, calyx and major duct sclerotized.

In general, the sex determination in most of the phytoseiids take place by parahaploidy or pseudo-arrhenotoky, where mating is required for the production of both male and female embryo but the male become haploid by a genome loss during embryonic development. The life cycle of phytoseiid predatory mites comprises egg, larva, protonymph, deutonymph and adult stages with intermediary quiescent stages viz., proto chrysalis, deuto chrysalis and teliochrysalis. Several factors like type of diet, prey density, temperature, relative humidity etc. are known to exert significant effects on feeding and development of predatory mites. Other factors like prevailing light conditions, lunar periodicity and gravitational or geomagnetic influences of the moon were also found to impact the development and predation rates. Many phytoseiids develop within one week at suitable environmental conditions of 27°C and 60-90% relative humidity (RH). The healthy adult female phytoseiids usually lay 30-40 eggs in their oviposition period. All the active stages are voracious feeders except for the larval stage which is facultative feeder in some species. Phytoseiids use their pincer like chelicerae to cut the cuticle of the prey and suck the contents inside. However, they are exceptionally well adapted to sustain their population on varied alternative food sources like pollen, fungal spores and plant exudates. The ability of phytoseiid predators to feed and reproduce on alternative food items opens up the possibilities of mass rearing of predatory mites in the laboratories and commercialization of natural enemies for the control of agricultural pests.

Based on the diversity of feeding habits, phytoseiids are organised in to four categories viz, Type I, Type II, Type III and Type IV, where the first two types are the specialist feeders of the spider mite genus *Tetranychus* and the family Tetranychidae

respectively, whereas Type III and Type IV predators are considered as generalist species that can actively feed and reproduce on mites belonging to multiple families and also on different species of plant pollen (McMurtry and Croft, 1997). In general, the specialist feeders exhibit preference to feed on egg stage of the prey mite. But generalists prefer to feed active life stages of the prey mites rather than their inactive eggs. This preference in feeding habit can be exploited for the effective control of the target pest species in biological control programs.

Apart from the great diversity in feeding habits, phytoseiid predatory mites possess the essential adaptive features like, wide distribution, high abundance, short life cycle than that of their prey, equivalent reproductive potential, good searching capacity, good dispersal rate, ability to survive on a low prey density, and adaptability to different ecological niches etc. As a result, many countries have started extensive studies on different aspects of phytoseiid predatory mites and attempts were made to incorporate predatory mites in biocontrol programs as part of the Integrated Pest Management (IPM) through mass rearing, release and export of phytoseiid predators. At the same time, the phytoseiids are barely explored in India and little work is done on their biological aspects. In the light of the above, the present work was undertaken with an intention to locate the most common and widely distributed species of phytoseiid mites associated with the most injurious species of pest mites infesting selected species of vegetables and fruit crops by conducting extensive surveys. Simultaneously, attempts were also made to evaluate the predatory habit and rate of predation of phytoseiid mites belonging to Type II, Type III and Type IV categories viz, *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* respectively, against spider mite pests such as *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis*, as well as different life stages of the same species of pest mites. In addition, the functional response

parameters of the predator, *N. longispinosus* towards the egg stages of the potential spider mite pests viz, *T. urticae* and *T. macfarlanei* were also assessed. Attention was also focused to explore the mass rearing possibilities of the Type III phytoseiid predator, *A. paraaerialis* on various alternative diets like honey, pollen, combination of honey and pollen etc. The current research work would enrich the existing knowledge in biological control of acarine pests of economically important plants.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Mites of the family Phytoseiidae are generally considered as the predators of phytophagous mites, thrips, white flies, mealy bugs and aphids infesting many economically important plants. For this reason, they have been treated as biological control agents of the phytophagous pest species around the globe. Meticulous research works on several aspects of biological control of pests using phytoseiid predators have been carried out globally for the past seven decades. The present review includes a concise version of the findings made by various workers around the world on the food preference, predatory potential, functional response and the attributes related to the feeding characteristics of the predatory mites on the varying life stages of pest mites and alternative food items.

The potential of phytoseiid mites in controlling phytophagous mites was first tested by Parrot *et al* (1906) by evaluating the predatory efficacy of a representative species viz. *Seius pomi* upon the eriophyid species, *Eriophyes pyri*. The association of predatory mites with red spider mites in citrus orchards of California was studied by Quayle (1912). Ewing (1914) recorded *S. pomi* as a natural enemy of spider mites and the author also provided data on the different life stages of the predator. Observations made by Gilliatt (1935) confirmed predatory mites as important natural enemies of the European red mite, *Paratetranychus pilosus*. Studies made by Nesbitt (1951) proved the potential of the phytoseiid predator, *Typhlodromus fallacis* in controlling populations of spider mites like *Tetranychus canadensis* and *Tetranychus schoenei*. Ballard (1954) conducted biological studies of *T. fallacis* on its spider mite prey, *T. bimaculatus*, in a modified Huffaker cell and the author reported that the predator could successfully complete its life cycle and its oviposition period was recorded to be 22 days. Fleschner

(1958) noted that spider mite pests like *Oligonychus punicae* and *Panonychus citri* infesting avocado could be controlled by phytoseiid predators. While conducting a survey on the diversity of predatory mites on strawberry plants in Central California, Kennett (1958) provided information on nine species of phytoseiid predators belonging to three genera. The food range of six species of phytoseiids viz. *Typhlodromus tiliae*, *Typhlodromus rhenanus*, *Typhlodromus finlandicus*, *T. fallacis*, *Typhlodromus corticis* and *Phytoseius macropilis* was evaluated by Herbert (1959) on three species of Tetranychoid mite pests such as *Panonychus ulmi*, *Bryobia arborea* and *Typhlodromus telarius* and one species of eriophyoid pest mite, viz. *Vasates schlechtendali*. The results of his study revealed that *T. tiliae* had a broad feeding range from overwintered eggs to the adults of all species of the prey mites tested while the remaining species of predators failed to feed on the eggs of *B. arborea* and *P. ulmi*. Studies made by Chant (1959) revealed the ability of some species of phytoseiids to thrive on miscellaneous food items like fungi and the author (1961) further conducted experiments on biological control of the spider mite pest, *T. telarius* by releasing the phytoseiid predator, *P. persimilis* under green house conditions. The author observed that periodic release of the predator was successful in suppressing the pest mite population in green house conditions.

The rate of development of predatory mites in general was found enhanced by the honey dew excreted by coccids and mealy bugs as revealed through the studies of Chant and Fleschner (1960). Observations made by Putman (1962) on the life history and behaviour of the phytoseiid predator, *Typhlodromus (T.) caudiglans*, revealed its significant preference to the larval and protonymphal stages of pest mites infesting peach trees. The author also reported that the nymphal stages of the predator successfully reached maturity on leaf pieces when fed on pollen of plants like peach, weeds like *Chenopodium album* (L.) and *Ambrosia artemisiifolia* (L.), and the grass, *Setaria glauca*

(L.) Beauv. McMurtry and Scriven (1965) traced the life history of *Amblyseius limonicus* on test food items comprised of spider mite pest mites viz. *P. citri*, *Oligonychus punicae* and *Tetranychus cinnabarinus* infesting the foliage of avocado and castor bean. The authors noted that the predator survived and reached adulthood by feeding on both the adult and immature stages of the pest mites. An unusually high increase in the population density of *Amblyseius hibisci* was observed by McMurtry and Johnson (1965) in the avocado orchards of Southern California during the blossoming period and the authors could establish a positive correlation between the rate of egg production of the species and flowering intensity of avocado plants. The authors observed that the pollen of the host plant could exert a significant impact on the development of the mite species. The ability of another predatory species viz. *Euseius hibisci* to reproduce on avocado pollen grains when supplied in limited numbers on excised avocado leaves was also reported by the same authors (1965b). McMurtry and Scriven (1965) reared many species of phytoseiids on an artificial substrate and explained the details of insectary production of these mites. The authors reared species capable of reproducing readily on pollen of *Mesembryanthemum* without prey mites and species which required prey mites for extensive reproduction on the Pacific spider mite, *Tetranychus pacificus*. Kuchlein (1966) observed a decrease in the fecundity of *Typhlodromus longipilis* in response to an increase in its population density. A study on the influence of relative humidity on the behaviour and activity of the phytoseiid predator, *Phytoseiulus persimilis* was made by Mori and Chand (1966) and the authors concluded that relative humidity exerted an important role in limiting the number of prey consumed by the predator. The searching efficiency of phytoseiid mites showed a decreasing trend in response to an increase in their population density as recorded by Hassell and Varley (1969). The authors observed that the increased population density would result in mutual interference of the predators

which in turn would hinder their ability to undertake prey searching movements and often leading to completely stopping the prey search and departing from the area

The feeding preference of *Galendromus occidentalis* towards different species of prey mites was studied by Croft (1972) and the author recorded that the order of predator preference to prey stages showed variation as: eggs > larvae > protonymph towards *Tetranychus mcdanieli* and eggs = larvae > adult female towards *T. pacificus*. While studying the feeding preference of *Amblyseius andersoni* towards different life stages of the European red mite, *P. ulmi*, Van de vrie (1974) recorded that the predator showed more preference to the larvae than the adult female. El-Banhawy (1975) carried out studies on the feeding behaviour and biology of the predatory species, *Amblyseius brazili* and recorded high rate of prey consumption during its adult stage, with high rate of fecundity and shorter developmental duration when fed on pollen or mite with pollen. Through radioactive labelling studies, Poress *et al.*(1975) confirmed that even the plant sap from Avocado leaf formed an alternative food source for the predatory mite, *A. hibisci*. Muma (1975) carried out observations on the feeding habits of 11 species of phytoseiid mites distributed in citrus orchards of Florida.

Laboratory studies were undertaken by Swirski *et al.* (1976) on the feeding, development and oviposition strategies of the predatory mite, *Typhlodromus athiasae* by rearing the species on various sorts of food items. Eveleigh and Chant (1981) experimentally analysed the effect of the age as well as nutritional history on the functional response of two species of phytoseiid predators viz. *P. persimilis* and *Amblyseius degenerans* to their natural prey species, *T. pacificus*. Dhooria (1981) carried out studies on the feeding behaviour of predatory mites, thrips and beetles on the spider mite pest infesting citrus viz. *Euseius orientalis*. Seasonal fluctuations in the population

density of *Amblyseius delhiensis*, an efficient predator of the eggs of the cotton jassid were studied by Somchaudhuri (1981).

Observations made by Sabelis (1985a) revealed that the prey preference of *P. persimilis* decreased in the order: egg > larva > protonymph > deutonymph and 70 per cent of the ingested food was utilized for egg production. Sharma and Sadana (1987) hypothesized that an increase in the prey and predator densities would induce more disturbances on the predator, leading to a decrease in their fecundity. Akpokodje *et al.* (1990) tested the functional response of the larva and adult female of *Iphiseius degenerans* and the protonymph and adult female of *Neoseiulus idaeus* to different stages of the prey mite, like the cassava green mite, *Mononychellus tanajoa* and the results of their studies enabled to procure typical Holling type II curves. The authors further observed that *N. idaeus* could reduce the population of *M. tanajoa* in a faster rate than the other predator, *Iphiseius degenerans*, thereby recording the greater potential of *N. idaeus* as a biological control agent of the cassava green mite. To the existing 55 known species of phytoseiid mites collected from Latin America, Moraes *et al.* (1991) added nine new phytoseiid species viz. *Amblyseius neoperditus*, *Amblyseius vasiformis*, *Amblyseius curticervicalis*, *Amblyseius gonzalezi*, *Amblyseius pentagonalis*, *Amblyseius pentvianus*, *Amblyseius farallonicus*, *Amblyseius miconiae* and *P. curtisetus* collected mostly from cassava habitat in southern Mexico, and Central and South America. Studies carried out by Ferragut *et al.* (1992) clearly disclosed the preference of the adults of *Typhlodromus phialatus* and *Euseius stipulatus* to the adult females of the prey mite, *P. citri* rather than their eggs. Observations made by Flechtmann and McMurtry (1992) on five species of phytoseiid predators viz. *Galendromus occidentalis*, *Phytoseiulus fragariae*, *E. stipulatus*, *Amblyseius similoides* and *Iphiseius degenerans* enabled to confirm the first two species as "specialists" showing preference to tetranychid mites

and the latter three species as "generalists" feeding and reproducing on varied foods including tetranychids and pollen. Brodeur and Cloutier (1992) described a modified leaf disc method for rearing the predator, *Amblyseius cucumeris* and its thysanopteran prey, *Frankliniella occidentalis* on a nutrient solution solidified with agar. Evans (1992) mentioned that phytoseiid mites would cut the prey cuticle with their chelicerae and injected a proteolytic enzyme to liquefy the body contents of the prey, which in turn would be consumed by the predator. Clements and Harmsen (1992) compared the predatory behaviour and prey-stage preference of the stigmaeid species, *Zetzellia mali* and the phytoseiid species, *T. caudiglans* by making laboratory experiments and recorded a consumption rate of 38% on the eggs of *T. caudiglans* by *Z. mali*

Ibrahim and Palacio (1994) conducted studies on the life history and demography of *Amblyseius longispinosus* and recorded that the immature females consumed more number of prey eggs than the males. Momen (1995) evaluated the influence of different food types such as the spider mite pests, *T. urticae* and *Euseius dioscoridis*, pollen of *Ricinus communis* and *Phoenix dactylifera* on the development and reproduction of the phytoseiid predator, *Amblyseius barkeri*. The life style of phytoseiid mites was reviewed by McMurtry and Croft (1997) by focusing on their role in biological control programmes. Wei and Walde (1997) tested the effect of alternative food on the functional response of *T. pyri* to its prey *P. ulmi*, by providing pollen from *Typha latifolia*, and the results of their study showed a significant reduction in the rate of predation. Studies of Maeda *et al.* (1998) revealed that the residing time of the predators would be greatly influenced by the volatiles emitted from the prey patch. The authors observed that the volatiles emitted from the high density prey patch of *Tetranychus urticae* triggered the migration of its predator, *P. persimilis* from a low density prey patch of the species. Croft *et al.* (1998) recorded that the rate of egg production of the predator, *N.*

californicus was 3.45 eggs/day when it was fed on the prey, *T. urticae*. Momen and El-Borolossy (1999) evaluated the suitability of nine species of phytoseiid predators in reducing the population of the major citrus pest mite, *E. orientalis*. The authors observed that out of the nine phytoseiid species studied, only four species viz. *A. barkeri*, *T. athiasae*, *Amblyseius olivi* and *Typhlodromus transvaalensis* could successfully reach adulthood on the above prey, with respective survival rates of 100%, 100%, 84% and 70%. The remaining five species, viz. *T. talbii*, *T. balanites*, *A. badryi*, *A. cabonus* and *A. lindquisti* were not able to reach even the protonymphal stage. Nachman (1999) compared the functional responses between the predators, *I. degenerans* and *Neoseiulus teke* to the increasing density of three life stages of the prey mite, *M. tanajoa* and found that in all cases, the rate of predation of the former species was higher than that of the latter. The results of the study also revealed that for a given prey stage, the predator's attack coefficient increased and the handling time decreased as the predator stage got advanced. Pallini *et al.* (1999) observed that spider mites strongly avoided plants defended by the predator, *P. persimilis* by recognising the cues associated with the latter species. Castagnoli and Simoni (1999) evaluated the effect of long-term feeding history on the functional and numerical responses of *N. californicus* and reported that the predator could successfully develop and reproduce on the pest mite, *T. urticae* upto 28 annual generations.

Intraguild predation and cannibalism being very common features among the phytoseiid predators, Schauseberger and Croft (2000) carried out a detailed investigation on the nutritional benefits of these habits in different species of phytoseiids. While tracing the development of *A. cucumeris* on the prey mite, *Schizotetranychus nanjingensis* infesting the moso bamboo fields of Fujian, China, Zhang *et al.* (2000) observed that the female predators were able to invade, stay and lay eggs in the broken

nests. Ghosh *et al.* (2001) reported that the predatory efficacy of the facultative predator, *Amblyseius tetranychivorus* was greater at lower prey density. The authors further recorded that the application of the microbial acaricide, Vertimec caused 100 % mortality of *T. urticae* population and reinfestation was observed after 30 days. Blackwood *et al.* (2001) conducted a series of experiments to study the prey stage preference of 13 species of phytoseiid predatory mites viz. *P. macropilis*, *P. persimilis*, *N. longispinosus*, *N. fallacis*, *N. bakeri*, *N. californicus*, *N. cucumeris*, *Kampimodromus aberrans*, *G. occidentalis*, *T. pyri*, *E. finlandicus*, *E. hibisci* and *A. andersoni* towards the eggs and larval stages of the two spotted spider mite, *T. urticae*. They found that the oligophagous specialized spider mite feeders preferred to feed on the spider mite eggs, whereas the generalist predators showed no preference to any life stages of the prey mite. The feeding response of the generalist predator, *E. finlandicus* towards three different test food items such as eriophyid mites, pollen of *Tulipa gesnerana* and the spider mite, *T. urticae* was evaluated by Abdallah *et al.* (2001) and the authors observed that the total developmental time of immature stages of the predator was shortest when fed on eriophyid mites whereas, its fecundity was highest on pollen. Jung and Croft (2001a) recorded the walking speed of the predator, *N. fallacis* and it was found to range from 0.1 to 0.4 mm/s (2.7 h to move through 1m). The potential of five species of phytoseiid predators viz. *Typhlodromus athiasae*, *N. barkeri*, *Typhlodromips swirskii*, *Euseius scutalis* and *Phytoseius finitimus* was assessed by Nomikou *et al.*, (2001) against the white fly species like *Bemisia tabaci* in the Middle East.

Changes in the oviposition pattern of the phytoseiid predator, *I. degenerans* in response to its prey comprised of the Western flower thrips, *Frankliniella occidentalis*, on Sweet pepper plants were studied by Faraji *et al.* (2002). Further investigations proved that, the plants would ensure the protection of predatory mite's eggs by

developing spacially segregated domatia, the latter being the natural oviposition sites of the predator, rather than inducing the domatia near the flowers and thereby preventing the chances of destruction of predatory mite eggs by the prey thrips.

Magalhaes *et al.* (2002) reported that the vertical migration exhibited by the cassava green spider mite, *M. tanajoa* was an anti-predator behaviour in response to the body odour of three species of phytoseiid predators inhabiting different strata of cassava plants in Africa. Badii *et al.* (2004) conducted studies on the prey stage preference and functional response of the predator, *E. hibisci* towards varying stages of the prey mite, *T. urticae* and the results of their study indicated variations in the functional response parameters of the predator in the presence of the pollen of *Lingustrum ovalifolium*. The potential of four species of phytoseiid mites as biocontrol agents of the spruce spider mite, *Oligonychus ununguis* was evaluated by Shrewsbury and Hardin (2004) through laboratory experiments. Zhang *et al.* (2004) established the potential of *A. cucumeris* as a biocontrol agent against the spider mite pest infesting Moso bamboo in Fujian, China by conducting feeding experiments on the basis of daily consumption and daily egg production of the predator, when presented with increasing number of prey eggs. Mori and Saito (2004) provided information on the inverse relationship between the nest size of four social spider mite species belonging to the genus *Stigmaeopsis* and their natural phytoseiid predators on the bamboo plants in Japan. The authors further revealed that the nest size of the social spider mites could act as a factor, mediating the antipredator behaviour in their natural habitat.

Extensive surveys undertaken by Kongchuensis *et al.* (2005) in different regions of Thailand, revealed the wide distribution pattern of *N. longispinosus* over the country throughout the year and its common association with the spider mites which produced heavy webbing on the abaxial surface of leaves of 33 species of plants ranging from the

perennials like the fruit trees to annual crops like vegetables and ornamentals. Escudero and Ferragut (2005) conducted studies on the life history of two species of phytoseiid predators viz. *N. californicus* and *P. persimilis* by offering four species of spider mites as prey, with particular reference to the species, *T. evansi*.

Canlas *et al.* (2006) conducted studies on the predatory habit and life history traits of the Japanese strain of *N. californicus* on a diet comprised of the two spotted spider mite, *T. urticae* under laboratory conditions. The results of their study proved the potential of the predator as an efficient control agent of the two spotted spider mite. Studies undertaken by Furtado *et al.* (2007) proved that the predatory mite, *P. longipes* could very successfully control the populations of the spider mite pest, *T. evansi*. Studies of Collier *et al.* (2007) could not reveal any significant differences in the predatory characteristics, including the duration of immature stages, pre-oviposition and oviposition periods and female longevity of *N. idaeus* when it was fed on different stages of the pest mite, *T. urticae* infesting papaya or snap bean leaves under laboratory conditions.

Observations made by Ragusa *et al.* (2009) revealed that 84% of the eggs laid by *N. californicus* developed in to adult mites when reared on a diet comprised of the pollen of *Carpobrotus edulis* and *Scrophularia peregrine*. Walzer and Schausberger (2010) conducted experiments to unravel the intricacies in the anti-intraguild predator competition and argued that interspecific threat sensitive anti- predation response promoted the co -existence of intra-guild predators and prey. Lemos *et al.* (2010) observed that the spider mite pest, *T. evansi* laid more eggs suspended in the web, rather than producing denser webs in response to the cues from the phytoseiid predator, *P. longipes*. Nguyen and Shih, (2010) evaluated the biocontrol potency of two species of phytoseiid predators viz. *N. womersleyi* and *E. ovalis* by tracing their development in the

laboratory at 25 °C on test food items such as four species of spider mites viz. *T. urticae*, *T. kanzawai*, *O. mangiferus* and *P. citri* as well as the maize pollen. Maanen *et al.* (2010) conducted experiments on the population-dynamics of *A. swirskii* in relation to the biological control of the broad mite, *Polyphagotarsonemus latus* on greenhouse pepper in South-eastern Spain. Momen and Abdelkhader (2010) tested the suitability of fungi as an alternative food for the successful development of *N.barkeri*, by comparing its developmental times, survival and oviposition rates on the primary food (*T. urticae*) and also the mycelium and spores of fungal species like *Aspergillus niger*, *Alternaria solani*, *Penicillium digitatum* and *P. italicum*. Results of their studies indicated that the former three fungal species viz. *A. niger*, *A. solani* and *P. digitatum* could serve as adequate food sources for the survival and development of the generalist predator, *N. barkeri*. Studies conducted by Fernando *et al.* (2010) enabled to confirm two species of Type III predators belonging to the genus *Neoseiulus* viz. *N. baraki* and *Neoseiulus paspalivorus* as highly promising agents against the coconut mite, *Aceria guerreronis*. Momen (2010) observed cannibalism and interspecific predation among the adult females and immatures stages of two species of generalist predators viz. *N. barkeri* and *T. negevi* under laboratory conditions. It was observed that the rates of predation of the adult females of both species were relatively greater on the larval stages than on the eggs and protonymphs. Xiao and Fadamiro (2010) conducted studies on the functional responses and prey-stage preferences of three species of phytoseiid predators viz. *P. persimilis*, *G. occidentalis* and *N. californicus* on the citrus red mite, *P. citri*. Logistic regression analysis made by the authors enabled to record a Type II (convex) functional response for all the three species of predators, with the consumption rate showing an increase with the availability of prey mites up to a maximum point after which it slowly decreased. Hinomoto *et al.* (2011) developed ten microsatellite DNA markers for *N.*

womersleyi collected from four sites within 200 meters of tea field and then evaluated the population structure of the predator and provided valuable information in conservation biological control. Sznajder *et al.* (2011) hypothesised that the response of the predatory mite, *P. persimilis* to herbivore induced plant volatiles was partially genetically determined. Laboratory experiments on the field collected base population of the predator showed a significant variation in response towards methyl salicylate (MeSa), a specific herbivore induced plant volatile, among the iso-female lines of predator, thereby confirming the involvement of a genetic component for this behaviour. Kasap and Atlihan (2011) established the potential of *K. aberrans* to control the population of *T. urticae* by testing the prey stage, type and parameters of functional response at 25 ± 1 °C, 65 ± 10 % RH and 16:8 (L:D) photoperiod.

Ali *et al.* (2011) evaluated the biological control potential of *N. womersleyi* against the pest mite, *T. macfarlanei* under laboratory conditions and recorded the rate of consumption rate of the predator on the different life stages of the prey such as the egg, larvae, protonymph, and deutonymph as well as the functional responses at different prey densities. The authors suggested that the predator could be a potential biocontrol agent of *T. macfarlanei* at low prey densities and approximated the Type II functional response of the predator through logistic regression analysis. Studies made by Onzo *et al.* (2012) on the predation rate and life table parameters of *A. swirskii* disclosed that the predator was very effective in suppressing the population of the broad mite, *P. latus*, a key pest of a leafy vegetable, viz. the egg plant, *Solanum macrocarpon* and on other solanaceous crops in Benin. Farazmand *et al.* (2012) determined the functional response and mutual interference of two predatory species, *N. californicus*, an introduced species in Iran and the native species, *Typhlodromus bagdasarjani* on *T. urticae*. The authors further compared the functional response parameters and finally concluded that *N. californicus*

was the more efficient biocontrol agent than *T. bagdasarjani*. The experimental results recorded by Fantinou *et al.* (2012) on the functional response and prey stage preference of the female of *I. degenerans* towards the increasing densities of females of the prey mites, *T. urticae* and *E. orientalis* proved that the predator followed a Type II functional response curve and which enabled to suggest it as a suitable biological control candidate for *E. orientalis* in the Mediterranean region. According to Jafari *et al.* (2012), foraging behaviour of the mated females of *N. barkeri* was greatly influenced by the change in temperature and exhibited the maximum feeding rate at 30°C. Any deviation in temperature caused a reduction in the feeding activity of the predator. The constant association of the Type III predator, *Amblyseius largoensis* with the red palm mite, *Raoiella indica* on coconut was observed by Moraes *et al.* (2012) and the authors reported that the above predator was a potential control agent of the pest mite. Carrillo and Pena (2012) demonstrated the functional response and prey stage preference of *A. largoensis* in controlling the population of the red palm mite, *R. indica*, particularly when the population density of the latter was low. . The potential of *N. longispinosus* in controlling the population of the red spider mite *O. coffeae*, a major pest of tea in India was tested and verified under laboratory and green house conditions by Rahman *et al.* (2012a) through a series of experiments, by evaluating the prey stage preference, predatory potential and optimum predator- prey ratio. The same authors (2013) further evaluated the successful biocontrol candidature of *N. longispinosus* by elucidating its life table parameters on the same species of spider mite prey.

As part of the survey conducted to study the diversity of mite fauna, Binisha and Bhaskar (2013) discovered a close association of phytoseiid predatory mites on spider mite pest population infesting vegetable crops cultivated in Kerala, India. The feeding response of *N. californicus* on varied developmental stages of the spider mite prey, *T.*

urticae was studied by Landeros *et al.* (2013) and they identified type II functional response curve through Holling's disc equation. Santoso and Iswella (2013) observed variations in the prey stage preference of the different life stages of the predator, *N. californicus* to the Kanzawa spider mite, *T. kanzawai* in Indonesia. The authors also noted the cannibalistic behaviour of the predator under low prey density. Studies of Moghadasi *et al.* (2013) revealed the significant preference of *T. bagdasarjani* to the eggs of the prey mite, *T.urticae* than the other stages, as revealed through their studies on both nutritional benefit and handling time. Xiao *et al.* (2013) tested the functional response and prey stage preference of two species of predatory mites viz. *N. californicus* and *A. swirskii* to understand their efficacy in suppressing the population of *T.urticae*. The results of their study revealed a type II functional response curve with no significant preference towards any of the life stage. Howell and Daugovish (2013) conducted laboratory studies on four species of phytoseiid predators viz. *P. persimilis*, *N. californicus*, *N. fallacis* and *A. andersoni*, to find out the best predatory species in controlling the population of the prey mite, *Eotetranychus lewisi* in the strawberry fields in California. While conducting studies on the anti- predator behaviour of predatory mites, Almeida and Janssen (2013) reported that the adult female of *A.swirskii* killed thrips to protect their offsprings from the attack of the latter and concluded that the predator displayed a complex anti-predator behaviour in response to the presence of counter-attacking prey. Based on their life styles, McMurtry *et al.* (2013) categorized phytoseiid mites into distinct groups like specialized predators of *Tetranychus* species (subtype I-a); specialized predators of web-nest producing mites (subtype I-b); specialized predators of tydeoids (subtype I-c); selective predators of tetranychid mites(type II); generalist predators inhabiting on pubescent leaves (subtype III-a); generalist predators harbouring on glabrous leaves (subtype III-b); generalist predators

found in confined spaces on dicotyledonous plants (subtype III-c); generalist predators inhabiting in confined spaces on monocotyledonous plants (subtype III-d); generalist predators from soil/litter habitats (subtype III-e); and pollen-feeding generalist predators (type IV). Besides, two additional lifestyles, viz. phytoseiids living on aquatic plants and phytoseiids capable of piercing leaf cells, were also proposed.

Demite *et al.* (2014) published an updated version of online database on the taxonomy and distribution of mites of the family Phytoseiidae which included 2,709 described species of phytoseiids (2,436 valid species), under 91 genera and three subfamilies (Amblyseiinae, Phytoseiinae and Typhlodrominae). Studies made on the functional response of *E. concordis* by Costa *et al.* (2014) revealed a type III functional response curve, which suggested that the predator increased its rate of consumption when the prey density got increased. Rasmy *et al.* (2014) conducted laboratory experiments and followed the non linear least-squares regression as well as random predator equation for evaluating the functional response parameters such as attack rate (a) and handling time (T_h) of protonymph, deutonymph and female of the predator *T. negevi* towards the nymphal stages of its prey, *T. urticae*. Zhang *et al.* (2015) observed that *A. orientalis*, a native predatory mite in China showed adequate preference towards the protonymph of its prey, *T. cinnabarinus*. Ganjisaffar and perring (2015) observed a significant preference of *G. flumenis* to the egg stages of the prey mite, *O. pratensis*. The authors suggested that the predator had to be released in the early stage of pest infestation in the field as it showed highest attack rate and lowest handling time towards immature stages of the prey mite, thereby proving very efficient in suppressing the population of *O. pratensis* in date fields. Lima *et al.* (2015) recorded a reduction in the attack rate (a) and consumption rate of the predatory mite, *N. baraki* due to the application of acaricides like abamectin and fenpyroximate against the coconut pest, *A. guerreronis*.

Maheswary *et al.* (2015) surveyed phytoseiid mite fauna associated with vegetable crops viz. amaranthus, brinjal, bhindi, bittergourd, chilli, cowpea, coccinia, cucumber, snakegourd and snap melon cultivated in Thrissur District of Kerala, India and identified *N. longispinosus* as the predominant species among the nine species of phytoseiids recovered. Calvo (2015) analyzed the major factors behind the successful candidature of *A. swirskii* as a most efficient biocontrol agent in Spain and also more than 50 other countries. The author concluded that the polyphagous nature of the predator, ease of rearing on factitious prey, and the external factors promoting the use of this predator like, export ban on vegetables with pesticide residue gave momentum for the use of *A. swirskii* by farmers. Goleva *et al.* (2015) assessed the body weight of adults of generalist predators like *A. swirskii*, *Amblydromalus limonicus* and *N. cucumeris*, by rearing them on pollen of 22, 12 and 6 plant species, respectively. Based on the maximum weight gained through feeding on pollen of different species of plants, it was concluded that the nutritional quality of pollen was neither consistent among the mite species nor among sex. It was also reported that the pollen of *Quercus macranthera* was suitable for females of *A. swirskii* and *T. gesneriana* pollen for males, *Alnusincana* pollen for females of *A. limonicus* and *Aesculus hippocastanum* pollen for males, and *Ae. hippocastanum* pollen for both sexes of *N. cucumeris*. Some phytoseiid predatory species like *N. fallacis* and *P. persimilis* were known to cut silken threads woven by spider mites with their chelicerae to enter into their colonies, as reported by McMurtry *et al.* (2015).

While conducting studies on the fitness parameters such as survival, development, sex ratio and fecundity of two species of phytoseiid mites viz. *A. swirskii* and *N. cucumeris* on two types of dietary supplements (cattail pollen, maize pollen, apple pollen and eggs of the Mediterranean flour moth, *Ephestia kuehniella*), Delisle *et al.* (2015) reported that pollen diet significantly improved the survival rate and shortened

the development time and thereby greatly affected their potential to control the prey viz. the western flower thrips, *F. occidentalis*. Ottaviano *et al.* (2015) studied the effect of pollen from different plant species on the survival, developmental time, and fecundity of the females of *N. californicus* and recorded more than 90 % survival on pollen from *Lamium amplexicaule*. The study also revealed the ability of *N. californicus* to sustain its population on pollen during low prey density seasons. Rahmani *et al.* (2015) evaluated the impact of biological control of *T. urticae* when three predatory species viz *N. californicus*, *T. bagdasarjani* and *P. plumifer* were present simultaneously. Result of their study revealed the intraguild predation among the three predatory mite (Predation of one predatory species over other) was very low in the presence of their prey, *T. urticae*.

Soleymani *et al.* (2016) evaluated the food preference of the polyphagous predator, *A. swirskii* among the egg, protonymphal and deutonymphal stages of *T. urticae* through Manly's preference index (β), which revealed the adequate preference of the predator towards the egg stage of the prey mite. Rahmani *et al.* (2016) observed that the generalist predator, *N. californicus* preferred to prey up on the immature stages of *T. urticae* when it was given a choice to feed on the first instar larvae of *Thrips tabaci* and different life stages of *T. urticae* simultaneously. Studies carried out by Doker *et al.* (2016) revealed a constant Type II functional response of *N. californicus* on its prey, *T. urticae* when exposed to extreme humidity conditions ($30 \pm 2\%$, $50 \pm 2\%$ and $90 \pm 2\%$ RH). *T. pyri* and *E. finlandicus* were tested for their ability to control the population of *T. urticae* on willows through feeding experiment conducted by Puchalska and Kozak (2016). The authors further observed that *E. finlandicus* could be mass reared by providing rape pollen (*Brassica napus*) as an alternative food. Seiedy *et al.* (2016) analysed the life table parameters of *A. swirskii* feeding on *T. urticae* and recorded the

developmental times of egg, larva, protonymph and deutonymph stages of *A. swirskii* as 1.36 ± 0.07 , 1.23 ± 0.07 , 1.43 ± 0.08 and 2.49 ± 0.14 days, respectively. Reichert *et al.* (2016) conducted studies on the feeding preference and rate of predation of *N. idaeus* on different prey species such as *Mononychellus planki*, *T. ludeni* and *T. urticae* and the authors recorded a strong preference to *T. urticae* followed by *T. ludeni* and *M. planki* by the predator. While studying the effect of five different photoperiods (Light:Dark = 4:20, 8:16; 12:12, 16:8, 20:4) on the development, survival and reproduction of *N. barkeri* on a diet comprised of the storage mite, *Tyrophagus putrescentiae*, Zou *et al.* (2018) reported that the predator fed and reproduced more efficiently at the photoperiod, 12:12. The authors also suggested that all the demographic parameters displayed a parabolic relationship with photoperiods. Tsolakis *et al* (2016) reported that pollen of *Oxalis pes-caprae* shortened the duration of embryonic development and increased the oviposition rate of *I. degenerans*, whereas the pollen was unable to induce any effect on these parameters in the life cycle of the other predator studied viz. *T. laurentii*. However, it was also reported that the pollen could positively affect the survivorship of *I. degenerans*. While conducting observations on prey consumption and functional response of two species of *Neoseiulus* viz. *N. californicus* and *N. longispinosus* on two species of tetranychid pest mites viz. *T. urticae* and *T. kanzawai*, Song *et al.* (2016) recorded a type II response on three immature stages (egg, larva and protonymph) of the pest mites. The value of attack rate coefficients (α) of *N. californicus* to each stage of *Tetranychus* was greater than that of *N. longispinosus*, and the shortest handling time (T_h) on larvae followed by the nymphs and eggs.

Differences in mite susceptibility of rose cultivars were studied by Golizadeh *et al.* (2017) through comparative life table analysis of *T. urticae* on ten rose cultivars in the laboratory condition at 24 ± 1 °C, $65 \pm 5\%$ relative humidity and a photoperiod of 16:8

(L:D) h. Functional response of *Cydnodromus picanus* on different egg densities of *T. urticae* was evaluated by Tello-Mercado *et al.* (2017) and they suggested a type II response with varying attack rate (a) and handling time (T_h) with respect to the age of the egg. Rao *et al.* (2017) evaluated the feeding preference and the potency of *N. longispinosus* on the prey, *T. urticae* infesting on okra plants. The authors observed that the predator showed the maximum preference to the larval stage of the prey and its potency followed a sequence in the order: adult female > deutonymph > protonymph > adult male and an increase in consumption rate with a rise in temperature, with the higher predation rate at 30 and 35 °C. Li *et al.* (2017a) analyzed the functional response and stage specific predation rate of *N. barkeri* against *Eotetranychus kankitus* on citrus orchards in China. Shen *et al.* (2017) compared the toxic effect of three different acaricides on the functional response of different life stages of *N. bicaudus* to the prey mite, *T. turkestanii* and found that all the acaricides could significantly affect the survivability of the predator with the highest toxicity exerted by Pyridaben. The authors also suggested that the less toxic acaricides, bifenthrin and azocyclotin could be used along with *N. bicaudus* for strategic control of *Tetranychus turkestanii*. Fathipour *et al.* (2017) studied the age specific functional response of *P. persimilis* on *T. urticae*, and the results of their studies revealed a progressive change in feeding and the functional response pattern from type II to type III as the predator developed. The combined effect of two species of *Neoseiulus* viz. *N. californicus* and *N. cucumeris* for the control of *T. urticae* was assessed by Zheng *et al.* (2017) by comparing their functional response parameters and the results indicated the potential of mixed release of both species of predatory mites in the infested field. Rezaie (2017) recorded the effects of pollen of three species of plants like corn, dates and walnut as well as the prey mite, *T. urticae* on the life history parameters and intrinsic population growth of the predator, *N. californicus*.

The author observed that 71%, 74% and 76% of eggs of the predator could develop successfully to reach adulthood on corn pollen, date pollen and walnut pollen, respectively.

Rezaie (2017) tested and compared the life table parameters of *N. californicus* on pollen from corn, walnut and date, along with the eggs of the two spotted spider mite, *T. urticae* on the detached leaves of strawberry and the results revealed a higher intrinsic rate of increase ($r = 0.201 \pm 0.032 \text{ day}^{-1}$) and higher fecundity rate (14.21 ± 2.91 eggs) when fed with date pollen. Rezaie *et al.* (2017) provided information on the effect of host plant on the functional response and prey stage preference of the adult female of *N. californicus* to varying life stages of *T. urticae* on seven varieties of strawberry plants. Mendes *et al.* (2017) conducted experiments to study the cannibalistic behaviour of the generalist predator, *A. largoensis* feeding on the red palm mite, *R. indica* and the coconut mite, *A. guerreronis* in coconut fields. The authors observed cannibalism in *A. largoensis* population, as an adaptive survival strategy when hetero-specific prey was absent or scarce.

Ullah *et al.* (2017) compared the durations of copulation, sperm transfer and reproduction of two closely related species of predatory mites viz. *N. womersleyi* and *N. longispinosus* and concluded that the longer copulation duration would lead to increased sperm transfer, and which resulted in more egg production by the female. Afshar and Latifi (2017) investigated the change in functional response and predation rate of the phytoseiid predator, *A. swirskii* towards the egg stage of *T. urticae* under three constant temperatures, like 25, 30, and 35 °C. Li *et al.* (2017b) tested the unchanged prey specificity of predatory mites even after long term feeding on alternative prey, through a series of experiments to study the prey preference, life table, and population parameters of *N. barkeri* between alternative preys like *T. putrescentiae* and three species of spider

mites, *T. urticae*, *P. citri* and *E. kankitus*. Alatawi *et al.* (2018b) compared the predation efficiency and preference of lab-reared and field-collected populations of *Cydnoseius negevi* on prey species like *O. afrasiaticus* and *T. urticae*. The authors further assessed the development and life table parameters of the phytoseiid predator, *Cydnoseius negevi* on date palm pollen at 35% and 60% relative humidity levels and proved its suitability as an alternative food source for the mass rearing of the predatory species. Atalay and Schausberger (2018) tested the fitness consequence of genetic relatedness between mates in the predatory mite, *P. persimilis* and provided information on in- and out- breeding depression in a haplo-diploid arthropod, supporting the optimal out breeding theory. Singh and Singh (2018) compared the feeding potential of two species of phytoseiid predators viz. *Amblyseius indicus* and *A. tetranychivorus* on different densities of all life stages of the pest mite, *T. neocaledonicus* on the host plant, brinjal in India. Both the predators were found effective in suppressing the pest mite population with a greater preference to the egg stage. The most effective predator-prey ratio was 1:20 and 1:25 for both predatory species and a linear increase was observed till the ratio reached to 1:25 and subsequently the predation rate subsided at 1:30 ratio.

Alatawi *et al.* (2018a) further compared the functional response of the predator, *C. negevi* to *Oligonychus afrasiaticus* and *T. urticae* and confirmed the ability of *C. negevi* in controlling prey population with a type II functional response to both species of spider mites. Kamel *et al.* (2018) evaluated the efficacy of four species of phytoseiid predators, *P. persimilis*, *N. californicus*, *E. scutalis* and *C. negevi* in suppressing population of the cosmopolitan pest, *T. urticae*. Li *et al.* (2018) identified all the three functional response types when the predatory mite, *N. barkeri* was fed on both the active and quiescent stages of *Tarsonemus confusus*, a tarsonemid mite causing 'black dot' symptom on bagged apple fruit in North China. Riahi *et al.* (2018) tested the mass

rearing possibilities of *T. bagdasarjani* on three different factitious prey types and nine artificial diets and found that only the pollen diet was suitable as an alternative food. Moya *et al.* (2018) tested the performance of *A. largoensis* at different relative humidity levels (20%, 36%, 56%, 65%, 72%, 80%, 89%, and 95%) in the laboratory and recorded a failure in completing the life cycle below 72% RH and a maximum growth rate and reproduction above 90% RH. During an extensive survey undertaken from 1980 to 2016 to study the mite population inhabiting on 10 species of *Prunus*, Stojnic *et al.* (2018) reported that *E. finlandicus* was present in high number (58%) among the 16 species of phytoseiids observed.

During a survey carried out on *T. urticae* and its associated predators, for the period of 2014-2015 in the major jasmine growing districts of Tamil Nadu, Isaac and Kennedy (2018) observed the presence of a phytoseiid predator, *N. longispinosus* in the majority of sampling localities. Fadaei *et al.* (2018) noted that, pollen significantly enhanced the feeding efficiency of the predatory mite *A. swirskii* in suppressing the population of *T. urticae* when offered with the prey eggs mixed with pollen of apricot, soybean, sesame, walnut and dates.

While conducting a survey to find out the diversity of mites inhabiting on cultivated vegetable plants such as the bean (*Phaseolus vulgaris*), corn (*Zea mays*), cucumber (*Cucumis sativus*), eggplant (*Solanum melongena*), leek (*Allium porrum*), lettuce (*Lactuca sativa*), onion (*Allium cepa*), pepper (*Capsicum annuum*), potato (*Solanum tuberosum*), radish (*Raphanus sativus*), tomato (*Solanum lycopersicum*), watermelon (*Citrullus lanatus* and zucchini (*Cucurbita* sp.) during 2013-2015 in Ordu province of Turkey, Soysal and Akyazi (2018) identified 15 species of Phytoseiidae, of which *A. swirskii* was the most abundant. Rezaie and Montazerie (2018) evaluated the prey stage preference of *N. californicus* towards four strains of *T. urticae* and the

influence of pollen of corn, walnut and dates on the predation rate under laboratory conditions. Kasap (2019) conducted a laboratory experiment to find out the effective predator: prey ratio for the release of *K. aberrans* as a biocontrol agent of *T. urticae* in the presence of birch pollen (*Betula pendula*). The study demonstrated the potential of *K. aberrans* to effectively suppress the population of *T. urticae* at ratios of 1:5 and 1:15 within three weeks, especially at a ratio of 1:5 in the presence of pollen. Su *et al.* (2019) examined the change in body size, locomotion and dispersal of the predatory mite *Neoseiulus bicaudus*, in response to the long term feeding on the alternative diet comprising *T. putrescentiae*. The authors observed a significant reduction in body size and locomotion of the predator even though the dispersal rate remained the same. Tsolakis *et al.* (2019) conducted studies to evaluate the biological and demographic parameters of the predator, *Neoseiulus longilaterus*, fed on life stages of *T. urticae* mixed with the pollen of *Oxalis pescaprae*. Results of the study revealed a positive impact on the demographic parameters, thereby confirming its potential in suppressing pest population in the presence of an alternative diet.

Akyazi *et al.* (2019) made observations on the prey stage preferences of *A. swirskii* and *N. californicus* between egg and nymph of *T. urticae* at 15:15, 10:20, and 20:10 egg: nymph ratios under laboratory condition. According to Neto *et al.* (2019), *N. idaeus* showed a type III functional response while *N. californicus* displayed a type II functional response towards the egg stage of the two spotted spider mite, *T. urticae*. It was also reported that, there was no significant difference in the numerical response of both the predators. Bazgir *et al.* (2019) traced the development of *T. bagdasarjani* on the nymphal stages of *E. frosti* at $25 \pm 1^{\circ}\text{C}$, $60 \pm 10\%$ relative humidity (RH), and a photoperiod of 16:8 h (light:dark) on apple leaves. The developmental durations of egg, larva, protonymph, deutonymph, and all immature stages were 2.27, 1.08, 2.31, 2.19, and

7.85 days for females, respectively. Goncalves *et al.* (2019) assessed the biological features of *N. californicus* which fed on the rice pest, *Sitophilus oryzae* in flooded rice fields of Brazil and the results of their study revealed the intrinsic rate of increase (rm) of the species as 0.21 female/female/day, thereby proving the ability of the predator in suppressing the pest population in a short time. Yang *et al.* (2019) conducted laboratory experiment to investigate the prey preference and life table parameters of *A. tsugawai*, an indigenous phytoseiid species of China which was fed on *T. urticae* and found that the predator significantly preferred larval stages. Akyazi *et al.* (2019) reported that *A. swirskii* and *N. californicus* were effective in controlling the population of the tarsonemid pest, *P. latus* when released at the initial predator: prey ratios of 1:10 and 1:20 on tea plants in Turkey

Jyothis and Ramani (2019, 2020) evaluated the prey stage preference of the phytoseiid predator, *N. longispinosus* on the varying stages of the spider mite pest viz. *T. neocaledonicus* and *O. biharensis* thus proved its potential in suppressing pest population. Li and Zhang (2020) investigated the effect of the pollen of *T. orientalis* on the rate of predation and functional response of the generalist predator, *N. cucumeris* to immature stages of *T. urticae*. During a study conducted to analyse the modulations by the supplementary food source to the functional response parameters of a generalist phytoseiid predator, Li and Zhang (2020) suggested that *N. cucumeris* was efficient in regulating the population of *T. urticae*, even in the presence of the pollen of *Typha orientalis*, as it was negatively affected by the attack rate and handling time of the predator while maintaining a type II functional response. Da-Silveira *et al.* (2020) conducted observations on the functional response of the predator, *E. concordis* towards the southern red mite, *O. ilicic* in coffee plantations and suggested that it could be used in augmentative bio control of the pest mite. Ahmadi *et al.* (2020) compared the

predatory potential of three different phytoseiid species with regard to their ability to reduce the population of *T. urticae* on four varieties of commercial green house roses. The results of the study revealed that the feeding potency of the predators followed a decreasing order of *P. persimilis*>*N. californicus*>*A. swirskii*. While assessing the impact of alternative food quality in reducing cannibalism among phytoseiid predators, Marcossi *et al.* (2020) suggested that the high quality cattail pollen significantly reduced cannibalism among *A. herbicolus* population than the low quality cotton pollen.

Tixier *et al.* (2020) carried out extensive surveys on the phytoseiid mites associated with solanaceous plants in South France and based on the results of their survey, the authors made a review on the world-wide biodiversity of phytoseiids associated with solanaceae. Among the 81 plants belonging to 20 species surveyed, 76 were found inhabited by Phytoseiidae representing three subfamilies, 143 species and 26 genera of Amblyseiinae, 45 species and 10 genera of Typhlodrominae, and 27 species and one genus of Phytoseiinae. Soltaniyan *et al.* (2020) reported the positive impact of four pollen species (cedar, pear, apricot, and pistachio) mixed with *T. urticae*, on the life table parameters of the predator, *N. californicus*. The authors also suggested that the intrinsic (r) and finite rates of increase (λ) as well as the net (R_0) and gross (GRR) reproductive rates were highest when fed with pistachio pollen mixed with *T. urticae*. McGregor *et al.* (2020) conducted laboratory feeding trials to find out the most promising factitious preys among three astigmatid mite species for the conduct of mass rearing of *N. californicus* and the results of their study revealed that the glycyphagid member, *Lepidoglyphus destructor* was preferred by the predator over the acarid members like *Aleuroglyphus ovatus* and *Thyreophagus entomophagus*. Fathipour *et al.* (2020) investigated the potential of *A. swirskii* in controlling the population of *T. urticae* by evaluating the functional response, numerical response, mutual interference, and prey

switching behaviour of the predator in the presence or absence of maize pollen under laboratory conditions. The authors reported a type II functional response of the predator in the absence of pollen whereas a type III response in its presence. Bazgir et al. (2020) evaluated the functional response of *A. swirskii* on two major pest mite species infesting apple orchards in Iran, viz. *E. frosti* and *Cenopalpus irani* at 25 ± 1 °C, with 16:8 h L: D, and a relative humidity of $60 \pm 10\%$ on host leaves. The authors observed a type II functional response of the predator to the immature stages of both species of the prey mites with the attack rate coefficient (a) following a decreasing trend in the order : eggs> larve> protonymph> duetonymph.

Amaral *et al.* (2020) studied the biological parameters of *A. chiapensis* when fed exclusively on *T. urticae*. Apart from the lower longevity (19.16 ± 1.84 days) all the other parameters like net reproductive rate ($R_0 = 8.61 \pm 1.59$), mean generation time ($T = 12.90 \pm 0.44$), intrinsic rate of natural increase ($r = 0.167 \pm 0.015$) and finite rate of increase ($\lambda = 1.181 \pm 0.018$) were found suitable to use it as an effective biocontrol candidate. The predation and oviposition potential of the predator were also assessed on the protonymphs of *T. urticae* in the presence of their web and the results revealed no significant reduction in predation as well as oviposition rate of the predator even in the presence of the web of the prey mite. Pascua *et al* (2020) tested the influence of *T. angustifolia* pollen on the population parameters of the specialized predator *N. californicus* feeding on *T. urticae*, and it was observed that, aside from sustaining population in the absence of primary prey, the supplementary diet, *T. angustifolia* pollen did not improve any of the population parameter. Wang *et al.* (2020) provided information on the positive influence of the supplementary food, *Camellia oleifera* pollen, boosting the expression of *Vg* genes (*AeVg1* and *AeVg2*) and *AeVgR* genes responsible for the production of vitellogenin and Vitellogenin receptor proteins, which

would play key roles in the reproductive process and development of *A. eharai*, a dominant natural enemy of spider mites.

Marcossi *et al.* (2020) reported that the high nutritional quality of alternative food items like cattail pollen significantly reduced the egg cannibalism among the phytoseiid predator, *A. herbicolus* when compared to the low quality cotton pollen. Prakash *et al.* (2021) conducted a comprehensive survey on the incidence of pest attack on the ornamental plants grown in Thrissur and Ernakulam districts of Kerala, India. The authors revealed eight dominant species of spider mites viz. *T. truncatus*, *Tetranychus okinawanus*, *T. urticae*, *T. fijiensis*, *T. neocaledonicus*, *Tetranychus marianae*, *E. orientalis* and *O. biharensis*. Ersin *et al.* (2021) compared the biology and life table parameters of *T. recki* at different temperatures (15, 20, 25, 30 and 35 °C) and found that the net reproductive rate of the predator was highest at 20, 25 and 30 °C. Fathipour *et al.* (2021) evaluated the functional and numerical response of the phytoseiid predator, *N. barkeri* on its prey mite, *T. urticae* and recorded a type II functional response curve. The efficiency of conversion of ingested food (ECI) was found decreasing with an increase in prey density. Momen and Khalek (2021) made observations on intraguild predation in three species of generalist phytoseiid predators viz. *N. californicus*, *N. barkeri* and *A. swirskii*. The results of their study established *A. swirskii* as the strongest intraguild predator, when compared to the other two species. Studies of Fu *et al.* (2021) on functional response of *A. andersoni* and *Neoseiulus neoreticuloides* (Acari: Phytoseiidae) to adults of the wolfberry gall mite *Aceria pallida* with seven prey densities (5, 10, 20, 40, 60, 80 and 100 adults of *A. pallida*) on a wolfberry leaf enabled to record a type II functional response by both species of predators, with the females of *A. andersoni* having a higher attack rate (5.961) and a shorter handling time (0.014 d) than the males (1.619; 0.019 d) of *A. andersoni* and females of *N. neoreticuloides* (0.719; 0.023 d). The

maximum attack rates (T/Th) of female and male of *A. andersoni*, were 71.43 and 52.63, respectively, while it was recorded to be 43.48 for females of *N. neoreticuloides*. Jafarian *et al.* (2022) revealed type II functional response in *T. bagdasarjani* to the protonymphs of *Eutetranychus frosti* on four apple cultivars.

CHAPTER III

MATERIAL AND METHODS

MATERIAL AND METHODS

During the present investigation, attention was focussed to procure data on the predatory potential of selected species of phytoseiid predatory mites on test prey items comprised of spider mite pests infesting leafy vegetables and fruit crops. Data were collected on the qualitative and quantitative aspects of predation such as prey searching behaviour, mode of attack, prey preference, functional response of individual species of predator to different prey species, as well as the prey stage preference of the different life stages of the individual predator species on the pest mite species which were selected as the test prey items. In order to explore the possibilities of mass rearing of predator mites in the laboratory, attempts were also made to evaluate the feeding response of the various life stages of the selected species of predatory mites to alternative food items such as honey, Pollen and Honey-Pollen mixture. Further, data were also collected on the postembryonic development of a species of predatory mite representing the Type III category of Phytoseiidae, among the three species of phytoseiid mites considered for evaluation of predatory potential, by rearing it on varied food items mentioned above. Details of the materials selected and the methods followed for fulfilling the objectives of the present study have been presented below.

I. STUDIES ON THE DISTRIBUTION AND DIVERSITY OF PEST MITES AND ASSOCIATED PHYTOSEIID PREDATORS

❖ Sampling localities (PLATE 1)

Field surveys were carried out during the period of 2016 - 2017, in order to locate the occurrence, distribution and diversity of phytoseiid predators associated with the spider mite pests infesting leafy vegetables and fruit crops, cultivated/grown over five districts of North Kerala viz. Malappuram, Kozhikode, Wayanad, Kannur and

Kasaragod. A total of 29 collection sites distributed over the above five districts were surveyed to record the fauna of pest mites and associated phytoseiid predatory mites (PLATE 1). Sampling of pest and predatory mites was carried out from leafy vegetables and fruit crops grown/cultivated in both the open fields and polyhouses, selected at different localities of the five districts as shown in plate-1.

In the Malappuram District, collections were made from agricultural fields and vegetable gardens located at places such as Vazhayur, Ariyallur, Moonniyur, Vazikkadavu, Nilambur, Oorakam, Angadippuram, Kuttippuram and Ponnani. Besides, vegetable crops grown in polyhouses and open fields of the Kerala Agriculture Office (Agricultural Service Supply Agency), Chiramangalam and the Agricultural Research Station at Anakkayam were also surveyed during the study.

The major sampling sites selected in the Kozhikode district were the agricultural fields and kitchen gardens located at places like Kuttyadi Maniyur, Koorachund, Kakkodi and Mukkom. In the Wayanad district, collections were mainly taken from the fruit and vegetable crops grown in open fields, backyards and terrace gardens maintained in selected houses and apartments located at Sultan Bathery, Meenangadi and the Regional Agricultural Research Station at Ambalavayal. Collection of mites from the Kannur District was done from the cultivated fruit crops maintained in the farmers' fields. In addition, different vegetable growing tracts situated at Payyannur, Pariyaram, Malur and Pinarayi, were also considered for sampling. In the Kasaragode district, agricultural fields located at Manjeswaram, Kanhangadu, Nileswaram and Alanthatta were considered for the survey. Apart from these, agriculture farms located in the campus of the College of Agriculture, Padannakkad were also screened for collection of pest mites and associated species of phytoseiid predators.

❖ **Host plants surveyed** (Table 1; PLATES 2-5)

Leafy vegetables and fruit crops represented by 16 species of plants were screened from the various sampling localities mentioned above, in order to probe the incidence of the common species of pest mites as well as their associated phytoseiid predatory mites. Table -1 illustrates the details of the diverse plant species surveyed during the study, with respect to pest infestation. As presented in the table, nine out of the 16 species of host plants constituted fruit crops while the remaining seven species were leafy vegetables. The leafy vegetables selected for the study were *Vigna unguiculata*, *Amaranthus viridis*, *Amaranthus tricolour*, *Moringa oleifera*, *Murraya koenigii*, *Cucurbita maxima* and *Colocasia esculenta*. The fruit trees screened for collection of mites included species viz. *Psidium guajava*, *Carica papaya*, *Achras sapota*, *Mangifera indica*, *Artocarpus heterophyllus*, *Artocarpus hirsutus*, *Syzigium aquem*, *Morus alba* and *Citrus limon*.

❖ **Collection of pest mites and associated predatory mites**

Under field conditions, the mite infested host plants were identified based on the visual symptoms such as yellowing, crinkling, chlorotic spots, white patches etc. induced by pest mites. Random samples of mite infested plant parts like the leaves, twigs, inflorescence etc. were collected from selected species of leafy vegetables and fruit crops mentioned above by cutting with the help of a scissors/ blade. The collected plant parts were kept in zip locked polythene bags and transported to the laboratory for further examination. In the laboratory, each plant sample was thoroughly examined under a stereomicroscope (Labovision KSz085) to locate the species of phytophagous mites and associated predatory mites. The pest mites as well as the predatory mites were segregated species-wise by adopting varied procedures such as hand sorting with the help of camel

Table- 1**Host plants screened for collection of pest and predatory mites**

Leafy Vegetables				
Sl No.	Plant species	Common name	Family	Economic utilities
1	<i>Vigna unguiculata</i> (L.) Walp.,1842	Cow Pea	Fabaceae	❖ Nutritional value- Grains are a good source of protein and the haulms used as animal feed. Leaves are also edible and rich in vitamins. ❖ Agricultural importance - Improves soil fertility through the symbiotic association with the nitrogen fixing bacteria, present in the root nodules of the plant. (Rahman et al., 2018)
2	<i>Amaranthus blitum</i> L.,1753	Amaranthus	Amaranthaceae	❖ Nutritional value: important leafy vegetable, rich in protein and vitamins. Leaves and seeds of the plant are edible. Seeds are also used for preparation of porridge and biscuits. ❖ Medicinal use: is a medicinal herb with multiple utility in Ayurveda. (Lowtim, 1985)

3	<i>Amaranthus cruentus</i> L.,1759	Purple Amaranth/ Red Amaranth	Amaranthaceae	❖ Nutrient value: Dried leaf powder is used in sauces during the dry season. ❖ Medicinal property: It has got very important medicinal properties. ❖ Other uses: Grown as ornamental plant in some countries. ❖ Also used as fodder, and for making dye. ❖ The dried plant is burnt for preparation of potash. (Yadav and Mina, 2019)
4	<i>Moringa oleifera</i> Lam., 1783	Moringa	Moringaceae	❖ Nutritional value: Leaves are edible and rich in vitamin E. Pods, seeds and roots are also edible. ❖ Medicinal properties –Roots are used for treating skin diseases. ❖ Other Uses: Traditionally used as a means to purify water. ❖ Used in production of lubricating oil, lamp oil and paper. (Ajayi et al., 2013)
5	<i>Murraya koenigii</i> (L)Spreng., 1825	Curry leaves	Rutaceae	❖ Nutritional value: Leaves are a fair source of Vitamin A, Vitamin C calcium, protein, carbohydrate. Curry leaves are a popular leaf-spice, widely used in Indian cookery for flavouring foodstuffs. The leaves are used for making tea.

				❖ Medicinal value: Used as medicinal ingredient in Ayurveda and Unani prescriptions. In traditional medicine, it is used for the treatment of dysentery, diarrhoea, vomiting, cataracts, renal diseases, piles, inflammation, itching, leucoderma, blood disorders and diabetes. ❖ Industrial use: Oil extracted from leaves is used in soap and perfume industry. (Dey and Lepcha, 2017).
6	<i>Cucurbita maxima</i> Lam., 1786	Pumpkin	Cucurbitaceae	❖ Nutritional value: Leaves, fruits, seeds and flowers are edible. Leaves contain 5 % protein. ❖ Medicinal uses – Seeds are used as a vermifuge. Pumpkin seed oil can also be used as a nerve tonic. Both the fruit pulp and flowers are used as a soothing on burns, boils, and inflammation. ❖ Other uses: Seeds contain 35 to 40 % oil which can be extracted and used for lighting. ❖ Nourishing face mask is made from the fruit which is effective for dry skins.

				❖ Bowls can be made from dried fruit shell. (Tropical Plants Database, 2021)
7	<i>Colocasia esculenta</i> (L.) Schott., 1832	Colocasia	Araceae	❖ Nutritional value: Leaves and corms are edible. Leaves contain a total of 72% nutrients including 15 % digestible true protein and 10% fiber. ❖ Other uses: Corms are processed into more consumable and value added products like beverage powders, flour, cereal base, chips, sun-dried slices, grits, and drum-dried flakes. ❖ Leaves are also used as animal feed. (Wang, 1983)
Fruit Crops				
Sl. No.	Plant Species	Common name	Family	Economic utilities
1	<i>Psidium guajava</i> L.,1753	Guava	Myrtaceae	❖ Food industry–Fruit pulp is used for preparation of juice, nectar, pulp, jam, jelly, slices in syrup, fruit bar.

				❖ Medicinal properties – used for treatment of gastrointestinal infections, malaria, respiratory infections, oral/dental infections, skin infections, diabetes, cardiovascular/hypertension, cancer, malnutrition, pain, fever, liver problems, kidney problems ❖ Nutritional value - rich in vitamin c, vitamin a and b, pectic substances, proteins and mineral salts, mainly iron, calcium and phosphorus ❖ Other uses - It is known to possess antioxidant property (Kadam et al., 2012; Birdi et al. 2017)
2	<i>Carica papaya</i> L.,1753	Pappaya	Caricaceae	❖ Therapeutic value - known to possess antioxidant, antimicrobial, anticarminative, anticancerous, hepato-protectiveand immunological properties ❖ Nutritional value –Rich in vitamin A, C, B₁, and B₂, thiamine, folate, riboflavin, niacin, calcium, potassium, iron and fiber contents ❖ Pharmacological importance (Saeed <i>et al.</i>, 2014)

3	<i>Achras sapota</i> L., 1762	Sapota	Sapotaceae	❖ Food industry – used for preparation of sweets and halwas, milky latex from unripe sapota known as chuckle is used to make chicklet and chewing gum. ❖ Nutritional value – rich in digestible sugar (15 -20 %), protein, fat, fiber, ascorbic acid, phenolics, carotenoids and minerals like iron, copper, zinc, calcium and potassium ❖ Other uses - possess antioxidant activity against 1,1-diphenyl-2-picrylhydrazyl free radicals and superoxide radicals (National Horticulture Board, 2021)
4	<i>Mangifera indica</i> L., 1753	Mango	Anacardiaceae	❖ Food industry - processed pulp is used in the preparation of juices, squashes and jams. ❖ Tannins extracted from premature fruits are used for production of astringents. ❖ Industrial uses- kernel is a rich source of carbohydrates, calcium, fat and starch. ❖ Wood is used as fuel and timber. (Sing <i>et al.</i>, 2011)

5	<i>Artocarpus heterophyllus</i> Lam.,1789	Jackfruit	Moraceae	❖ Food industry – used for production of various value added products such as jam, pickle, squash, chips, nutritional value-Seed chips and the ripened pulp are edible in the raw form. ❖ Other uses- used for the production of alcoholic beverage. The pulp is also used as flavouring agent in ice creams and beverages. The leaves, as well as the waste from the fruit after removal of bulbs and seeds, are useful as fodder. ❖ Medicinal uses – ash from jackfruit leaves is commonly used for healing ulcers. The root extract is used in treating skin disorders, asthma and diarrhoea. It is also useful against various ailments including leprosy, ulcers, constipation, heart disease, rheumatism, anaemia, asthma, dermatitis and cough. The latex produced by the tree is used as a chewing gum, and is also known to have bactericidal properties. ❖ Heated latex is employed as glue in chinaware and pottery. The bark of the tree has a high content of tannins, and when boiled with alum, it yields a clothing dye.
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				❖ Hard wood of jackfruit tree is widely used for making furniture, masts, oars and musical instruments. ❖ Also used as a shade tree in agriculture (Saxena et al., 2013)
6	<i>Artocarpus hirsutus</i> Lam., 1789	Wildjack	Moraceae	❖ Nutritional value- fruits are edible ❖ Medicinal properties- Leaf, stem, bark and seeds are known to possess varied medicinal properties. ❖ Used as timber (Ankitha et al., 2017)
7	<i>Syzygium aqueum</i> (Burm.f.) Alston., 1929	Rose apple	Myrtaceae	❖ Nutritional value: Fruits are edible. ❖ Wood is used to make tools ❖ Leaves and bark are used in traditional medicines to treat anaemia, diabetes, dysentery, bleeding gums etc. ❖ Also considered as an ornamental plant. (Singh, 2007)

8	<i>Morus alba</i> L., 1753	Mulberry	Moraceae	❖ Leaves are extensively used in sericulture to feed silk worm. It is also used as feed for livestock. ❖ Fruits are edible and used for preparing wine, ice cream and tea. ❖ Nutritional value – edible fruits contain nutrients including iron, riboflavin, vitamin C, vitamin K, potassium, phosphorous, and calcium. They also contain dietary fibers and organic compounds, including phytonutrients, zeaxanthin, resveratrol, anthocyanins, lutein etc. ❖ Medicinal properties –contain chemical compounds used for treatment of neurological disorders, gastrointestinal disorders and cardiovascular diseases. Fruits contain bioactive components such as flavonoids, polyphenols, alkaloids, terpenoids and steroids, which help to lower serum glucose and blood cholesterol levels. Furthermore, it has antioxidative potential, hepatoprotective potential, anticancer effectand antimicrobial effects. (Kadam et al., 2019; Scrivastava et al., 2003; Andallu and Varadacharyulu, 2003)
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9	<i>Citrus limon</i> (L.) Osbeck., 1765	Citrus	Rutaceae	❖ Food industry – fruits are edible and also used as drinks and flavouring. Also used for preparation of various kinds of food items like jam, jelly, pickle and salads. ❖ Medicinal property - it contains organic compounds of medicinal importance, which act as antidepressant, anti oxidant and works against asthma, colds, flu, fever, nosebleeds, mouth ulcers, throat infection and boils. (Sarker, 2017).
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hair brush, beating over a white enamel tray and by applying suction force using an aspirator. A fraction of the sampled mite specimens was transferred to vials using a moistened camel hair brush and preserved in 70% ethanol for taxonomic studies. The live mite specimens were transferred to culture arena prepared of respective host plant leaves for subsequent rearing and further biological studies.

I.A TAXONOMIC STUDIES

a. Clearing and mounting of specimens

The mite specimens preserved in 70% ethanol were subsequently dehydrated alcohol series (80%, 90% and absolute alcohol) contained in cavity blocks. Properly dehydrated specimens were slide mounted in Hoyer's medium, prepared as per the procedure given below.

b. Preparation of Hoyer's medium

Hoyer's medium was prepared by mixing the following ingredients in a beaker. The ingredients were weighed as per the specifications mentioned below:

Gum-Arabic crystals – 30 gms

Chloral hydrate -200 gms

Glycerine -20 ml.

Distilled water - 50 ml

The above chemicals were put in a 500 ml. beaker. The solution was slightly warmed and by using a glass rod, the ingredients were stirred properly, until the mixture turned into a clear, weakly amber coloured viscous liquid. The medium was then filtered through two folds of thin cloth or glass wool and stored in an amber coloured bottle.

c. Preparation of permanent slides

Slide mounting of cleared mite specimens was carried out in the Hoyer's medium prepared as described above. Properly cleared and intact specimens representing the adult male and females of each species were carefully picked up using a camel hair brush and placed in a drop of the mountant taken at the centre of a microslide. The specimens were oriented along their antero-posterior axis, with the appendages spread out properly in order to get a detailed view of the diagnostic features. Specimens of each species were mounted along their lateral position also to get a better view of the details of the male genitalia for confirmation of species. The chelicerae of predatory mite species were segregated by strongly pressing the specimens to spread out both of the cheliceral digits, to get a precise view of the dentition on these digits, the latter being one of the major criteria for generic and specific identification. After proper spreading and correct orientation, the specimens were slide mounted by carefully placing a round coverslip of 0.17mm thickness, without trapping any air bubbles. After mounting, the slides were kept in an oven at 40-45°C to facilitate adequate clearing and drying of the specimen. The slides were then labelled by providing the collection details such as the names of respective hostplants of each species, collection locality, date of collection and collector's name. Scientific names of the specimens were also added on the labels immediately after identification. The cover slips were then sealed peripherally with nail polish in order to prevent the damage of specimens due to exposure to excessive moisture/drying/mold.

d. Identification of mite specimens

Identification of slide mounted specimens was made under the high power objective of a Zeiss Axio Scope A.1 phase contrast microscope. Major taxonomic

characters considered for species identification of phytoseiid predatory mites were: the shape, number and nature of setae on the dorsal and ventral shields; cheliceral structure and dentition on the movable and fixed digits; shape and nature of spermatheca in females, nature of spermatophoral processes in males, features of the peritreme, ventrianal shield, leg chaetotaxy etc. For taxonomic identification of pest (tetranychid) mites, morphological characters including the number and nature of setae on the dorsal and ventral shields, leg chaetotaxy and nature and shape of male genitalia were carefully studied. The specimens were photographed and the morphological characters were drawn using a Carl Zeiss Axiocam 305 colour camera (ZEN 2 core imaging software) attached to Zeiss Axio Scope A.1 phase contrast microscope. Measurements of the various diagnostic structures were taken using the stage and ocular micrometers and presented in micrometers (μm). Species identity and systematic position of the individual species of phytoseiid mites were assessed following the books of Gupta (1985, 1986), Smiley (1992), Zhang (2007) and other relevant literature. The setal nomenclature and chaetotaxy adopted for phytoseiid mites were based on those of Evans (1963), Rowel *et al.* (1978) and Chant and Yoshida-Shaul (1989, 1991 & 1992). The nomenclature used for dorsal solenostomes was followed from Athias-Henriot (1975). The identification of tetranychid species which were selected as the prey mites during the current study was made following Gupta (1985, 1986), Smiley (1992) and Zhang (2007) and other recent literature. Confirmation of the mite species involved in the study was made in consultation with Dr. S. K. Gupta, Principal Investigator, USERS Project, Department of Science and Technology (Former Joint Director and Emeritus Scientist ZSI and Ex-National Co-ordinator, ICAR, Acarology Project).

I.B. PEST MITES SELECTED AS TEST PREY SPECIES

Spider mites of the family Tetranychidae, were selected as the test prey mites during the present study for qualitative and quantitative evaluation of the predatory potential of the three species of owing to the prevalence and regular infestation in relatively high numbers of these mites on the leafy vegetables and fruit crops in most of the sampling localities surveyed in North Kerala. Of the total 11 species of spider mites recovered from the leafy vegetables and fruit crops, three species of spider mites viz. *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* were selected as the test prey mites for the conduct of feeding experiments. The species selection was done duly considering their dominance on the host plants and the common availability for making regular observation. Details of the prey mites selected for feeding studies have been discussed below.

I.B.i. *Tetranychus urticae* Koch 1835 (PLATE 6)

This species is commonly known as the two-spotted spider mite. It is widely distributed in 124 countries (Migeon and Dorkeld, 2021) across the Afrotropical, Australasian, Nearctic, Neotropical, Oriental and Palearctic regions and is an extremely polyphagous species, enjoying a very vast host range of 1169 species of host plants belonging to 127 families (Migeon and Dorkeld, 2021). It is rated as a notorious pest of at least 30 species of economically important crops (Helle and Sabelis, 1985) representing field, greenhouse and horticultural crops, leafy vegetables, ornamentals and fruit-bearing trees. Like all other species of spider mites, *T. urticae* also feeds on its host plants by piercing the leaf epidermal and mesophyll cells with its cheliceral stylets and sucking up the released cellular content along with chlorophyll, thereby inducing considerable levels of damage. Apart from inducing direct feeding damages on respective host plants, *T. urticae* helps in the transmission of several phytopathogenic

viruses also into the host plant tissue, thereby intensifying the yield loss. Excellent examples for virus transmission include that of the potato virus Y, tobacco mosaic virus, tobacco ringspot virus etc. by the species. The species has very low economic threshold at 1–2 mites/tomato leaflet, making it responsible for 10–50% of yield loss in an average tomato production season (Meck, 2010). In the present study, infestation of the species was evident on both leafy vegetables and fruit crops such as *V. unguiculata*, *A. viridis*, *M. oleifera*, *C. esculenta*, *C. papaya* and *A. Sapota* leading to visible damage symptoms.

I.B.ii. *Tetranychus macfarlanei* Baker and Pritchard, 1960 (PLATE 7)

The red spider mite, *T. macfarlanei* was first described from Mauritius and Africa based on the specimens collected from beans, pumpkin and *Hibiscus* sp. Afterwards, it was recorded from Gwalior and Madhya Pradesh in India showing infestation and serious damage to crops like okra and cucurbits (smooth gourd, bottle gourd, pumpkin & cucumber). Occurrence of the species has been reported in nine countries viz. China, India, Malaysia, Bangladesh, Philippines, Thailand, Spain, Madagascar and Mauritius, distributed over Afro tropical, Oriental and Palearctic regions. Till date, the species has been recorded from 46 species of host plants belonging to 15 families viz. Amaranthaceae, Caricaceae, Caryophyllaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Lamiaceae, Leguminosae, Malvaceae, Menispermaceae, Moraceae, Musaceae, Rutaceae, Solanaceae and Zingiberaceae. In the present study, heavy infestation of the species was observed on the vegetable crops like *V. unguiculata*, *A. viridis*, *M. oleifera* and *C. esculenta*.

I.B.iii. *Oligonychus biharens* Hirst, 1924. (PLATE 8)

O. biharens is a sporadic pest of many species of highly important crops, such as vegetables, rose, camphor, litchi, etc causing heavy yield loss every year. It was originally described from *Rosa* sp. in India and later, it was recorded from 78 species of host plants belonging to 25 families Viz Anacardiaceae, Annonaceae, Apocynaceae, Araceae, Arecaceae, Betulaceae, Dipterocarpaceae, Ebenaceae, Euphorbiaceae, Lauraceae, Leguminosae, Malvaceae, Moraceae, Musaceae, Myrtaceae, Phyllanthaceae, Polygonaceae, Proteaceae, Rhamnaceae, Rosaceae, Rutaceae, Sapindaceae, Sapotaceae, Solanaceae and Vitaceae. The species was collected from 26 countries distributed over Afrotropical, Australian, Nearctic, Neotropical, Indomalayan and Palearctic biogeographic realms. In the present study, the species was found to show severe infestation on the leaves of the vegetable crop, *V. unguiculata* and fruit crops like *S. aqueum* and *M. indica*. Visible symptoms of damage were evident in the form of crinkling, bronzing, drying and subsequent defoliation of affected leaves, leading to reduced growth and vigor of the host plant.

I.C. PREDATORY MITES SELECTED FOR THE STUDY

In the present study, three species of phytoseiid mites out of the total 17 species collected from the various sampling localities surveyed from North Kerala were considered for making detailed observations on feeding biology. Among the 17 species of phytoseiid mites collected from different localities of North Kerala, three major phytoseiid predatory species were selected for the experimental studies. The species selection was done mainly based on variations in their feeding habits and inclusion in the feeding categories like the Type II, Type III and Type IV predators (Mc Murtry *et al.* 2013). Accordingly, three species of phytoseiids viz. *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* were selected as the test species,

representing the respective feeding categories type II, type III and type IV predators, for making detailed studies on predatory potential.

I.C.i. *Neoseiulus longispinosus* (Evans, 1952). (PLATE 9)

This species of phytoseiid predator was originally described from Indonesia on *Manihot utilissima*. There after the species was recorded from more than 27 countries around the globe. It was also recorded from the Union Territories viz. Andaman Islands, Puducherry and six other states of India such as Andhra Pradesh, Himachal Pradesh, Odisha, Uttar Pradesh, Tamil Nadu Karnataka and Kerala. The species was included in the category of Type II predator, based on its feeding specificity on spider mites infesting leafy vegetables and fruit crops, both in poly houses and in open fields. *N. longispinosus* possesses all the essential characteristics required for an efficient bio-control agent, such as short generation time, high fecundity, voracious feeding habit, higher searching ability, dispersal rate and adaptability to different ecological niches. The species was selected for making detailed biological observation during the present study, based on its frequent association with the spider mite pests viz. the vegetable spider mite, *Tetranychus neocaledonicus*, the two spotted spider mite, *T. urticae*, the red spider mite, *T. macfarlanei* and the bean spider mite/European red mite *Tetranychus ludeni* infesting vegetable crops like *Vigna unguiculata*, *Amaranthus viridis*, *Moringa oleifera* and the fruit crop, *Achras sapota* cultivated in various localities of all the five districts of North Kerala. Its association with another species of spider mite pest viz. *Eutetranychus orientalis* was also recorded on *Moringa oleifera*, in the sampling locality at Maniyur, Kozhikode Dt.

I.C.ii. *Amblyseius paraaerialis* Muma, 1967 (PLATE 10)

This species of phytoseiid predator was originally described from the Palghat district of Kerala, India from Citrus plant. Subsequently, it was reported from several localities of Kerala and also from other states of India viz. Arunachal Pradesh, West Bengal, Assam and Meghalaya. Distribution of the species was also reported from several other countries like China, Thailand and Malaysia. Based on its predatory habit, the species was included in the Type III category of phytoseiidae. During the field surveys carried out in the present study, a very close association of the species was recorded with spider mite pests like *T. neocaledonicus*, *T. urticae* and *T. macfarlanei*, infesting vegetable crops like *V. unguiculata* and *A. viridis*. It was also found associated with the tenuipalpid mite pest like *Brevipalpus phoenicis* infesting the fruit crop, *Psidium guajava* growing at Alanthatta area of the Kannur Districts of Kerala.

I.C.iii. *Euseius rhododendronis* (Gupta, 1970) (PLATE 11)

This species was first described from Sukna, Darjeeling of West Bengal district. North India from the plant, *Rhododendron* sp. and *Shorea robusta*. Later, it was reported from other states like Karnataka, Tripura and Kerala also. Presently, the species was collected from the leaves of the vegetable crop, *A. viridis* and the fruit crop, *Mangifera indica* infested with *T. urticae* and *O. biharensis*, respectively. The species was included under the Type IV category of phytoseiid predators. In the present study, the species was selected for detailed biological studies, considering the lacuna of knowledge on its predatory potential and also to gather information on its possible use in biological control of spider mite pests.

II. STUDIES ON THE PREDATORY POTENTIAL OF SELECTED SPECIES OF PHYTOSEIID MITES

Studies on the predatory potential of each of the three selected species of phytoseiid mites viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* were initiated by raising sufficient stock cultures of the predatory as well as the test prey mites through laboratory rearing of the species. Details of the culturing processes and the procedures adopted for raising their stock cultures have been discussed in details below:

a. Raising of stock cultures of prey mites (PLATE 12, Figs. c & f)

Live specimens of the three species of spider mites which were selected as the test prey items were reared separately in the laboratory in rectangular plastic trays (35cm length, 25cm width and 8cm depth). For the preparation of culture trays, sponge pads of 2.5cm thickness were cut in suitable dimension and were placed inside the plastic basins. The sponge pads were kept moistened by soaking in water to maintain adequate moisture conditions required for the culturing purposes. The leaves of respective host plants of the three species of spider mite pests mentioned above were cleaned thoroughly and were cut in to square pieces. Such leaf discs were uniformly spread over the wet sponge pads kept in the culture trays with their abaxial surface facing upwards. Gravid females of each species of prey mites were transferred carefully on to the leaf discs with the help of a moistened camel hair brush and were reared for sufficient time so as to lay eggs on the leaf discs, for subsequent establishment of colonies. Daily observation was made to ensure adequate moisture condition in the culture trays during the entire period of rearing. Chances of cross culture contamination were prevented by covering the upper surface of culture trays with a nylon mesh (Mesh size .25 cm) fixed on acrylic frame. The culture trays were subjected to routine microscopic examination in order to check

aerial contamination with fungal growth. When the leaf discs in the culture trays showed symptoms of drying, they were replaced with new leaf discs prepared out of fresh leaves of respective host plants so as to avoid food deprivation and fungal growth.

b. Raising of stock cultures of predatory mites (PLATE 12 , Fig. e)

Pure cultures of the three species of phytoseiid predators mentioned earlier were raised on leaf discs prepared from the leaves excised from mulberry (*Morus alba*). Circular leaf discs (2cm diameter) were cut from mulberry leaves and different life stages of the prey mite were transferred separately species-wise on to the leaf discs. The leaf discs were then placed on moistened cotton pads which were kept as inner lining of a petridish (70 mm diameter). A single mated adult female of each species of phytoseiid predator was introduced separately, species wise on to the leaf discs harbouring the varied life stages of individual prey mite species, using a camel hair brush. More water was added to make the cotton pads fully saturated with water, in order to prevent the escape of both the prey and the predatory mites. Each species of predatory mite was allowed to lay eggs and undergo further development by feeding on the life stages of the individual species of the prey mite. Chances of starvation and cannibalism were prevented among the phytoseiid species in the cultures by supplying sufficient numbers of the prey mite life stages frequently onto the culture discs.

II.A. QUALITATIVE EVALUATION OF THE PREDATORY POTENTIAL OF PHYTOSEIID MITES

The mated healthy adult females of each of the selected predatory species of the F₁ generation raised through pure culturing were carefully introduced separately on to the surface of respective host leaves containing mixed life stages of individual species of

spider mite in high numbers. The culture trays containing the leaves harbouring the predator as well as prey mite life stages were regularly examined under a stereomicroscope so as to record data on the predatory behaviour of the three species of predatory mites such as their prey capturing habit, mode of attack, mode of consumption, dispersal and colonization due to starvation etc. Appropriate photographs were taken using a Camera (EOS 6D Mark II Canon) and presented appropriately.

II.B. QUANTITATIVE EVALUATION OF PREDATORY POTENTIAL OF PHYTOSEIID MITES

II.B.i. Preparation of experimental arena

a. Experimental Arena I (Open) (PLATE 12, Fig. a)

The experimental arena I consisted of leaf discs placed over 2% semi solidified agarose medium. For the preparation of agarose medium, 2 gm agarose was weighed and it was mixed with 100 ml of distilled water taken in a beaker. This mixture was warmed for 2 minutes by constant stirring. When the agarose was completely dissolved in water, the medium was poured in to a Petridish (7 cm diameter) and allowed to cool until it was semi solidified. The leaf discs were cut in to an appropriate size of 2 cm² and were carefully placed over the agarose medium without trapping any air bubbles. The fluid surface of the agarose medium served successfully to prevent the escape of mites as well as to keep the leaf afresh for a long period.

b. Experimental Arena II (Closed) (PLATE 12, Figs. b & d)

The experimental arena II consisted of three rectangular plates (4 cm x 7.5 cm x 0.4 cm) of acrylic sheets placed over one another and both ends of which were clipped together with paper clips. Leaf discs cut appropriately of 2 cm² size were carefully spread

on a thin layer of wet cotton placed over the first plate. The second plate with a centre cavity (2 cm x 3 cm x 0.4 cm) was sandwiched in between the first and third plates so as to maintain the central cavity closed to prevent the escape of both the predatory and pest mites. Drops of water were added periodically using a syringe to the thin cotton layer in between the plates to maintain the leaf afresh.

II.B.ii. Evaluation of predatory potential of adult females of *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis*.

Gravid females (4-6 numbers) of each species of the spider mite mentioned above were picked up from their respective stock cultures and transferred on to the mulberry leaf discs of 2 cm² diameter placed over 2% semi solidified agar medium contained inside the petridish (Experimental arena I). Females were allowed to lay eggs for the next 24 hours and were transferred back to the stock culture soon after the mentioned time frame. Eggs were counted and only 15 numbers of eggs were retained on the leaf disc by removing the excess eggs. Prior to the start of feeding experiment, 15 numbers of active life stages of spider mites viz, larvae, nymphs (Protonymph and deutonymph) and adult females in their pre-oviposition period were also introduced on to the leaf disc. The feeding experiment was initiated by carefully introducing an active adult female predator on to the leaf arena harbouring all the life stages of the spider mite prey. Adult males of the predators were not considered for feeding experiments during the study, duly considering the female biased sex ratio with significantly higher number of females than the males in the population density of the predators. Further, the predatory potential and longevity of the males of the selected species of phytoseiids were observed to be comparatively lower than that of the females. The experimental duration was fixed as 24 hours and observations were made carefully by counting the number of shrivelled carcasses of the life stages of the prey mite left over the leaf discs. The rate of

Table 2 **Details of the predatory mites (Adult) vs prey mites considered for the laboratory feeding experiment**

<i>Neoseiulus longispinosus</i> (Adult female)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>
<i>Amblyseius paraaerialis</i> (Adult female)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>
<i>Euseius rhododendronis</i> (Adult female)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>

egg consumption by the predator was evaluated by subtracting the number of intact eggs on the leaf discs from the initial number of eggs offered. Each experiment was replicated 10 times and the data collected were subjected to statistical analysis through ANOVA, following SPSS (IBM SPSS Statistics 20). The results were presented in tables and graphs. Necessary photographs were taken with a camera (EOS 6D Mark II Canon) attached to a LYNX LM-52-3621 Trinocular Stereo Zoom Microscope (Table. 2).

III. COMPARATIVE EVALUATION OF PREDATORY POTENTIAL OF PHYTOSEIID MITES

In the present study, feeding experiments were carried out to evaluate the biocontrol potential of immature stages of the three selected species of phytoseiid mites mentioned above, in order to find out the most efficient predator/predatory life stage as well as the most preferred life stage of the spider mite pests of leafy vegetables and fruit crops viz. *T. urticae*, *T. macfarlanei* and *O. biharensis*, which were offered as the test prey items. Evaluation of the predatory preference of the immature stages of the three predators, *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* towards the varying life stages of the spider mite pests was made in the open experimental arena I under laboratory conditions of 30 ± 2 °C and $70 \pm 5\%$ RH

Gravid females of respective species of spider mites (4-6 Nos.) were picked up from the stock cultures using a camel hair brush and were transferred on to the mulberry leafdiscs of 2 cm² placed over the semi-solidified agar medium, contained inside the Petridish. The adult females were allowed to lay eggs on the leaf discs in the experimental arena for one day. The number of eggs on each leaf discs were counted and 15 numbers were retained by removing the excess eggs from the arena. Then all the female mites were transferred back to the stock culture. Prior to the introduction of the predatory life stage of each species, 15Nos. of the spider mite life stages such as the

Table 3. Details of the predatory mites (Immature stages) vs prey mites considered for the laboratory feeding experiment

<i>Neoseiulus longispinosus</i> (Nymph)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>
<i>Amblyseius paraaerialis</i> (Larva and Nymph)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>
<i>Euseius rhododendronis</i> (Larva and Nymph)	Vs	<i>Tetranychus urticae</i>
		<i>Tetranychus macfarlanei</i>
		<i>Oligonychus biharensis</i>

larvae, nymphs (Protonymph and deutonymph) and the adult females in their pre-oviposition period were transferred on to the leaf arena. The feeding experiment was initiated by carefully introducing an actively feeding immature life stage, either larva or nymph of the selected predatory species onto the experimental arena with extreme care to avoid any mechanical damage to the pest mite life stages while transferring them on to the leaf disc. Regular observations were made on the feeding rate of the individual predatory species at every 24 hours by counting the number of shrivelled carcasses of the life stages of the prey mite left over the leaf discs. However, the rate of egg consumption by each species of predator was calculated by subtracting the number of eggs left intact on the leaf discs from the initial count after 24 hours. Each experiment was repeated 10 times and the data collected were subjected to statistical analysis through ANOVA, following SPSS (IBM SPSS Statistics 20). The results were presented in tables and graphs. Necessary photographs were taken using a camera (EOS 6D Mark II Canon) attached to a LYNX LM-52-3621 Trinocular Stereo Zoom Microscope (Table 3).

IV. STUDIES ON THE FUNCTIONAL RESPONSE OF THE PHYTOSEIID REPRESENTATIVE, *Neoseiulus longispinosus*.

Based on the significant feeding preference as well as the unique ability to exert effective control of pest mites in their egg stage itself, *N. longispinosus* was selected to undertake detailed studies on its functional response towards the egg stages of two species of the spider mite pests viz., *T. urticae* and *T. macfarlanei* under laboratory conditions at a temperature of $30 \pm 2^{\circ}\text{C}$ and $70 \pm 5\%$ RH.

Feeding experiments were carried out in the open experimental arena I prepared by placing mulberry leaf discs of 2 cm^2 over semi-solidified agar medium in a Petridish. Seven experimental set ups were prepared with varying densities of prey mite eggs such as 2, 4, 8, 16, 32, 64 and 128, by allowing the gravid females of the spider mite species

to lay eggs in the respective experimental arena. After oviposition, the females were removed and the eggs were counted and maintained at the required density, with the help of a fine needle under a stereo binocular microscope. The mated females of *N. longispinosus* which were kept in the starved conditions for eight hours in empty Eppendorf tubes were carefully introduced separately on to each leaf disc containing the prey mite eggs in the experimental set ups and were allowed to stay on the leaf discs so as to feed freely on the prey eggs for a period of 24 hours. After the prescribed period of time, the number of intact eggs was counted to find out the total number of eggs consumed by the predator in order to calculate the functional response of the predator towards the prey eggs. For each experiment, ten replicates were maintained for confirmation of data.

Data analysis was done in Microsoft Excel (<http://www.microsoft.com/>). Data gathered on the functional response of *N. longispinosus* on the egg stages of spider mites were approximated based on the Holling type II model by a cyrtoid curve rising at a decreasing rate to a plateau and was determined by fitting data to the Holling's disc equation (Holling 1959) as follows.

$$N_a / P = aNT / (1 + aT_h N)$$

Where N_a is the number of successful attacks per predator (P) during a specific time period (T), N is the initial density of the prey, and a and T_h are the rate of successful attacks and the time required to handle the prey respectively. Handling time (T_h) includes the time required for the predator to pursue, kill, and digest the prey (Holling, 1961).

In the present study, the method of Livdahl and Stiven (1983) was followed and the data were simply plotted as reciprocals and a linear transformation was obtained by

reciprocating both sides of Holling's disc equation to yield a straight line equation as given below:

$$P/N_a = 1/aTN + T_h/T$$

The parameters a and T_h were calculated using a linear regression technique where $1/N_a$ was regressed on $1/N$. ' a ' is the reciprocal of the slope and the y-intercept multiplied by the time of exposure give rise to handling time (T_h). The a/T_h value indicates the effectiveness of predation. Maximum predation rate (K) was calculated as T/T_h .

V. EXPLORATION OF MASS REARING POSSIBILITIES OF THE TYPE III PHYTOSEIID PREDATOR, *Amblyseius paraaerialis* UNDER LABORATORY CONDITIONS

Being a representative of the type III category of phytoseiid predators, having the ability to complete life cycle on both prey mites and alternative food items, *A. paraaerialis* was selected for further studies to explore possibilities of mass rearing of the species for future studies on its exploitation in biological control. The remaining two species of predators included in the study viz. *N. longispinosus* and *E. rhododendronis* were excluded from the study owing to the obligate spider mite feeding habit (Type II) of the former and the comparatively low feeding potential on spider mite pests (Type IV) by the latter.

❖ Alternative test food items used for the rearing of *Neoseiulus longispinosus* (PLATE 13)

i. Honey

Commercially available honey, purchased from an apiary farm, produced in the hives of *Apis cerana indica* of the Maliyekkal bee farm, Parappanangadi, Malappuram

district. was also offered as an alternative test food item to the predatory mites studied, to assess its suitability for subsequent mass rearing possibilities of the species. The original consistency of the test honey was maintained in the laboratory by storing it in Eppendorf tubes at room temperature.

ii. Pollen

The pollen grains from the flowers of a medicinal shrub, *Ricinus communis* (Castor) were collected from plants grown in the Botanical garden of the Calicut University Campus and were used as an alternative test food item to rear the predatory mite and record its suitability for mass rearing the predator. The collected pollen grains were transferred to a watch glass (50 mm diameter) and examined under a stereomicroscope (Labovision KSz0850) to remove the impurities and were stored in the refrigerator at 4 °C.

iii. Honey-Pollen Mixture

A mixture of castor pollen and commercial honey procured from the apiary mentioned above was prepared in a paste like consistency and offered as an alternative test food item to the predatory mites studied. For preparing the mixture, the pollen grains were carefully removed from the flowers of castor using a camel hair brush and sprinkled over a leafdisc. Subsequently, small droplets of honey were added with the help of a needle to the pollen and mixed into a paste and which was offered as an alternative food source in order to test its suitability for mass rearing of the selected species of phytoseiid predatory mites in the laboratory.

V.A. DEVELOPMENTAL STUDIES ON THE TYPE III PREDATOR, *Amblyseius paraaerialis*

A comparative study was made on the postembryonic development of the type III phytoseiid predator viz. *A. paraaerialis* by offering alternative food items like castor pollen, honey, honey – pollen mixture and the natural prey species comprised of the spider mite pest, *T. urticae* under laboratory conditions of $30 \pm 2^{\circ}\text{C}$ and $70 \pm 5\%$ RH. The experiment was conducted with an intention to record the durations of the various developmental stages of the predator as well as those of pre-oviposition, oviposition and post-oviposition periods. Experimental arena II was used for tracing the postembryonic development and two separate sets of experiments were performed, using the leaf discs (2 cm^2) of the *A. blitum* as the substratum. Four sets of experiments were carried out in the laboratory, in total. In the first experimental set up, pollen from the flowers of *R. communis* sprinkled over the leafdisc with a fine brush was used as the food source for the immature stages of the predator. In the second set of experiment, the immature stages were provided with a few drops of honey, transferred on to the surface of the leaf disc placed in the experimental arena using a camel hair brush. In the third set of experiment, a combination of honey and pollen (honey-pollen mixture) was placed over the leaf disc, as the food source for the immature stages of the predator. In the fourth experimental set up, mixed life stages of the pest mite, *T. urticae*, were offered as the food source for the life stages of the predator.

The experiment was initiated by carefully introducing a single mated female from the stock culture of *A. paraaerialis* on to the experimental arena with a camel hair brush and then it was left free to lay eggs. As soon as the adult female predator laid a single egg on the leaf disc, the predator was removed from the arena by transferring it again to the stock culture. The egg laid on the leaf disc was allowed to complete the incubation

period and subsequent developmental processes in the closed experimental arena. The moisture content inside the arena was maintained by adding a few drops of water to the thin cotton layer kept beneath the leaf disc. Regular observation was made at every two hours under a stereomicroscope to follow the progressive developmental processes of the predator. Data were recorded on the durations of incubation, larval and nymphal stages, quiescent stages, total duration of life cycle etc. as well as those on hatching, moulting etc. Relevant photographs were also taken using a camera (EOS 6D Mark II Canon) attached to LYNX LM-52-3621Trinocular Stereo Zoom Microscope. When the female predator reached the adulthood, a male predatory mite from the stock culture was transferred onto the leaf disc and kept it there for 48 hours without disturbance so as to provide sufficient time for mating. After mating the male was removed from the leaf disc of the experimental arena and the experiment was repeated. Five replicates were maintained for each experimental set up for confirmation of data and the results were subjected to statistical analysis through ANOVA, following SPSS (IBM SPSS Statistics 20).

CHAPTER IV
OBSERVATION

OBSERVATION

I. DISTRIBUTION AND DIVERSITY OF PHYTOPHAGOUS MITES AND ASSOCIATED PHYTOSEIID PREDATORS

a. Distribution and diversity of phytophagous mites

During the present study, 26 collection sites distributed over five districts of North Kerala viz. Kasaragod, Kannur, Kozhikode, Wayanad and Malappuram (PLATE 1) were screened to record the fauna of the common pest mites and associated phytoseiid predators. The results of the survey revealed the presence of 20 species of phytophagous mites (Table 4) belonging to three superfamilies viz. Tetranychoidae, Tarsonemoidea and Eriophyoidea and five families viz. Tetranychidae, Tenuipalpidae, Tarsonemidae, Eriophyidae and Diptilomiopidae. The superfamily Tetranychoidae was the dominant taxon, comprising 15 species belonging to two families viz. Tetranychidae and Tenuipalpidae. Of these, 11 species were identified as members of the family Tetranychidae while four species could be assigned to the family Tenuipalpidae. Eriophyoidea was the second larger superfamily in terms of family diversity as it included two families viz. Eriophyidae and Diptilomiopidae, the former comprising two species and latter included a single species. As presented in Table-3, Tarsonemoidea was recognized as the superfamily with lowest family diversity as it supported a single family viz. Tarsonemidae, with two species.

Tetranychidae was the dominant family of phytophagous mites with the maximum number of species (Table 4), infesting the leafy vegetables and fruit crops. It supported 11 species, thereby representing 55% of the total number of species collected during the study (Fig. 1). The second position in terms of species diversity was achieved by Tenuipalpidae (20%), supporting four species. The third position was shared by two

families viz. Eriophyidae and Tarsonemidae (10% each), supporting two species each. The family Diptilomiopidae with a single species reached the last position with respect to species diversity (5%). Thus the species diversity of the various families of phytophagous mites recovered during the study could be presented in the sequence as Tetranychidae > Tenuipalpidae > Tarsonemidae = Eriophyidae > Diptilomiopidae. The generic diversity was also found maximum in Tetranychidae, as it comprised members of four genera viz. *Tetranychus*, *Oligonychus*, *Schizotetranychus* and *Eutetranychus*, thereby comprising 40% of the total genera collected. The second position with respect to generic diversity was shared by two families viz. Tenuipalpidae and Eriophyidae comprising two genera each, thereby constituting 20% of the total genera. The genera recognized under the former family were *Brevipalpus* and *Tenuipalpus* while those of the latter family were *Aceria* and *Cisaberoptus* (Table 4). A comparatively low generic diversity of 10% was evident under each of the remaining two families viz. Tarsonemidae and Diptilomiopidae, both comprised of a single species each. The genus collected under Tarsonemidae was *Polyphagotarsonemus*, while Diptilomiopidae was represented by the genus *Diptilomiopus*. Thus the five families collected during the study were found to follow the sequence: Tetranychidae > Tenuipalpidae = Eriophyidae > Tarsonemidae = Diptilomiopidae, based on the number of genera assigned to each taxon (Fig. 2).

Results of the study enabled to record varied species diversity among the various genera of phytophagous mites collected during the study. Accordingly, the genus *Tetranychus* was found to exhibit the maximum species diversity, by revealing six species, out of the total 20 species of mites collected, thereby reaching 30% of the total number of species (Fig. 3; Table 4). The second position in species diversity was shared by two genera viz. *Eutetranychus* and *Tenuipalpus*, both comprising three species each, thereby representing 15% each of the total number of species. The genus

Polyphagotarsonemus reached the third position, in having two species each, thereby representing 10% of the total number of species. The remaining six genera viz. *Oligonychus*, *Schizotetranychus*, *Brevipalpus*, *Aceria*, *Cisaberoptus* and *Diptilomiopus* were represented by a single species each, thereby sharing 5% each of the total number of species collected during the study. The various genera of phytophagous mites recovered during the study could be arranged in the sequence of: *Tetranychus*>*Eutetranychus*=*Tenuipalpus*>*Polyphagotarsonemus*>*Oligonychus*=*Schizotetranychus*=*Brevipalpus*=*Aceria*=*Cisaberoptus*=*Diptilomiopus* based on their species diversity.

The results of the survey also revealed the co-occurrence of two or more species of phytophagous mites on the same species of crop plant. Accordingly, the seven species of leafy vegetables viz. *V. unguiculata*, *A. blitum*, *M. oleifera*, and *A. cruentus* disclosed infestation by two or more species of spider mites like *T. macfarlanei*, *T. neocaledonicus*, *T. truncatus* and *T. urticae* as presented in Table 4. Multiple infestation by spider mites, false spider mites (*Tenuipalpidae*), and eriophyoid mites was also observed on vegetable crops like *A. cruentus*. Similarly, leafy vegetables like *M. koenigii* showed infestation by spider mites like *Schizotetranychus hindustanicus* as well as the tarsonemid, *Polyphagotarsonemus* sp. Despite this, leafy vegetables like *M. oleifera* showed infestation by spider mites alone. Fruit crops like *M. alba* showed infestation by a single species of spider mite like, *E. africanus*. Multiple infestation by spider mites and false spider mites was evident on fruit crops like *C. papaya* and *A. sapota* whereas, crops like *P. guajava*, and *A. heterophyllus* displayed infestation by tenuipalpid mites alone. As shown in Table 3, the fruit crop, *A. hirsutus* showed single infestation by the eriophyid species of the genus *Diptilomiopus*.

The level of infestation of the various species of phytophagous mites showed variation on individual species of host plant examined, as presented in table-3. The

study enabled to record the prevalence, species diversity, wide distribution and relatively higher population density of spider mites on most species of host plants screened. Their dominance was particularly high, reaching 55%, thereby constituting over 50% of the total phytophagous mite fauna collected during the study (Fig. 1). In general, moderate populations of spider mites could be noted on the fruit crops screened during the study in contrast to the high infestation tendency of these mites to colonise the leafy vegetables. Infestation by the two spotted spider mite, *T. urticae* was very high on the vegetable plants like *V. unguiculata*, *A. blitum*, *A. cruentus* and *M. oleifera*, whereas, it was at a moderate level on fruit crops like *C. papaya*, *A. sapota* and the vegetable, *C. maxima*. However, it showed a low level of infestation on the vegetable crop, *C. esculenta*. As presented in table 3, species like *T. macfarlanei*, *T. neocaledonicus* and *T. truncates* showed infestation on vegetable crops like *V. unguiculata*, *A. blitum*, *A. cruentus* and *M. oleifera*. High infestation of *T. ludeni* was also evident on *V. unguiculata* and *A. sapota*. Infestation of *T. udaipurensis* was found restricted to a single host plant viz. *M. oleifera*. Low infestation of *S. hindustanicus* and *E. africanus* was observed on curry leaves (*M. koenigii*) on mulberry leaves (*M. alba*). Distribution of *O. biharensis* was visible on the fruit crop, *M. indica* and the vegetable host, *V. unguiculata*. Low population density of *E. orientalis* was observed on the abaxial leaf surface of *V. unguiculata* and *M. oleifera*.

The percentage distribution of Tenuipalpidae could be accounted to 20%, as shown in Fig. 1 and the infestation level of these mites on all host plants appeared to be relatively lower than that of the spider mites (Tetranychidae). Among the tenuipalpid mites recorded during the study, a well known and widely distributed pest viz. *B. phoenicis* was found to infest both the leafy vegetables and fruit crops screened such as *V. unguiculata*, *A. blitum*, *A. cruentus*, *C. papaya* and *P. guajava*. Moderate levels of

infestation by three species belonging to the genus *Tenuipalpus* were also observed on leaves of fruit crops like *A. sapota*, *P. guajava* and *A. heterophyllus* as presented in table 3.

The percentage distribution of two families viz. Tarsonemidae and Eriophyidae was the same, by accounting 10% each (Fig. 1). As indicated in Table 3, both the families contained members representing two species each, assigned to genera such as *Polyphagotarsonemus*, *Aceria* and *Cisaberoptus* respectively. Of the two species of *Polyphagotarsonemus* recovered during the study, one species viz. *P. latus* represented a notorious pest on various species of economic crops and it showed heavy infestation on the leaves of the leafy vegetable, *V. unguiculata*. The other species of *Polyphagotarsonemus* was found to occur in moderate density on curry leaves, *M. koenigii* during the study. The family Eriophyidae, though shared an equal percentage distribution of 10% with Tarsonemidae, showed a higher generic diversity (20%) than that of the latter (10%) (Fig. 2). As shown in Table 3, Eriophyidae contained two species belonging to two genera viz. *Aceria* and *Cisaberoptus*, both exhibiting heavy infestation on their respective host plants. Of these, the species of the former genus, viz. *Aceria* showed heavy infestation on the abaxial surface of the leaves of the fruit crop, *A. cruentus*, leading to considerable leaf damage. Similarly, heavy infestation of the species belonging to the latter genus, *Cisaberoptus* viz. *C. kenyae* the so called leaf coating mite, was found to induce pronounced waxy coating on the abaxial leaf surface of the fruit crop, *M. indica*.

The percentage distribution was recorded to be the lowest (5%) for the family Diptilomiopidae, belonging to the superfamily of Eriophyoidea (Fig.1). Under Diptilomiopidae, a single species could be recovered belonging to the genus, *Diptilomiopus*, thereby presenting 10% of generic diversity (Fig. 2). However, as

Table 4

Distribution and infestation level of pest mites collected from the host vegetable/fruit crops screened during the study.

Super family	Family	Genus		Species		Host Vegetable / Fruit Crops	Abundance
TETRANYCHOIDEA DONNADIEU, 1876.	Tetranychidae Donnadieu, 1875.	1	<i>Eutetranychus</i> Banks, 1917.	1	<i>E. africanus</i> (Tucker), 1926.	<i>Morus alba</i>	++
				2	<i>E. orientalis</i> (Klein), 1936.	<i>Vigna unguiculata</i>	++
						<i>Moringa oleifera</i>	++
				3	<i>Eutetranychus</i> sp.	<i>Carica papaya</i>	++
		2	<i>Oligonychus</i> Berlese, 1886.	4	<i>O. biharensis</i> (Hirst), 1924.	<i>V. unguiculata</i>	+++
						<i>Mangifera indica</i>	++
		3	<i>Schizotetranychus</i> Tragardh, 1915.	5	<i>S. hindustanicus</i> (Hirst), 1924.	<i>Murraya koenigii</i>	+++
		4	<i>Tetranychus</i> Dufour, 1832.	6	<i>T. ludeni</i> Zacher, 1913.	<i>V. unguiculata</i>	+++
						<i>A. sapota</i>	++
				7	<i>T. neocaledonicus</i> Andre, 1933.	<i>V. unguiculata</i>	+++
						<i>A. blitum</i>	++
						<i>A. cruentus</i>	+++
				8	<i>T. macfarlanei</i> Baker and Pritchard, 1960.	<i>V. unguiculata</i>	+++

						<i>A.blitum</i>	++
						<i>A. cruentus</i>	+++
						<i>M. oleifera</i>	+++
				9	<i>T. truncatus</i> Eharai, 1956.	<i>V. unguiculata</i>	+++
						<i>A.blitum</i>	++
						<i>A. cruentus</i>	+++
				10	<i>T. udaipurensis</i> Gupta and Gupta, 1994.	<i>M. oleifera</i>	+++
				11	<i>T. urticae</i> Koch, 1836.	<i>V. unguiculata</i>	+++
						<i>A.blitum</i>	+++
						<i>A. cruentus</i>	+++
						<i>M. oleifera</i>	+++
						<i>C.papaya</i>	++
						<i>A. sapota</i>	++
						<i>Colocasia esculenta</i>	++
						<i>Cucurbita maxima</i>	++
	Tenuipalpidae Berlese, 1913	5	<i>Brevipalpus</i> Donnadieu, 1875.	12	<i>B. phoenicis</i> (Geij), 1939.	<i>V. unguiculata</i>	++
						<i>A.blitum</i>	++
						<i>A.cruentus</i>	++

		6	<i>Tenuipalpus</i> Donnadieu, 1875.	13	<i>T. chichlorum</i> De Leon, 1957.	<i>C. papaya</i>	++
				14	<i>Tenuipalpus</i> sp.1	<i>Psidium guajava</i>	++
				15	<i>Tenuipalpus</i> sp.2	<i>Artocarpus heterophyllus</i>	++
	TARSONEMOI DEA KRAMER, 1877.	7	<i>Polyphagotarsonemus</i> Beer and Nucifora, 1965.	16	<i>P. latus</i> (Banks), 1904.	<i>V. unguiculata</i>	+++
				17	<i>Polyphagotarsonemus</i> sp.	<i>M. koenigii</i>	++
	ERIOPHYOIDEA NALEPA, 1891.	8	<i>Diptilomiopus</i> Nalepa, 1917.	18	<i>Diptilomiopus</i> sp.	<i>A. hirsutus</i>	+
	Diptilomiopi dae Keifer, 1944.	9	<i>Aceria</i> Keifer, 1944.	19	<i>Aceria</i> sp.	<i>A. cruentus</i>	+++
	Eriophyidae Nalepa, 1898.	10	<i>Cisaberoptus</i> Keifer, 1966.	20	<i>C. kenya</i> Keifer, 1966.	<i>M. indica</i>	+++

+++ : High infestation (>10 mites/leaf)

++ : Moderate infestation (5-10 mites / leaf)

+ : Low infestation (< 5 mites/leaf)

indicated in table 3, a single species could be collected under the genus *Diptilomiopus*, from the leaves of the fruit crop, *A. hirsutus* and its infestation appeared to be very low.

b. Distribution and diversity of phytoseiid predators

The results of the survey elucidated the presence of predatory mites of the family Phytoseiidae on all species of host plants examined from various localities of North Kerala. The species - wise distribution and host range of the phytoseiid mites collected from the various host plants screened during sampling, from the various localities of North Kerala along with details of the associated pest mites have been presented in Table 4. As indicated in Table 4, a total of 17 species belonging to 6 genera of predatory mites were collected under the family Phytoseiidae, from the leafy vegetables and fruit crops screened during the study.

Among the various genera of Phytoseiidae collected during the study, *Amblyseius* was recognized as the most dominant genus showing high species diversity, comprising nine species, followed by *Euseius*, *Typhlodromips*, *Neoseiulus*, *Typhlodromus* and *Paraphytoseius*. As shown in fig. 4 *Amblyseius* occupied the first position with respect to species diversity, comprising 52.9% of the total number of phytoseiid species collected. *Euseius* was the second largest genus as it revealed the presence of three species, thereby disclosing 17.6% of the total number of species collected under Phytoseiidae. *Typhlodromips* was the third largest genus by disclosing two species and thereby contributing 11.7% of the total species composition. The remaining three genera viz. *Neoseiulus*, *Paraphytoseius* and *Typhlodromus* showed the lowest species diversity, by revealing representation by a single species each, and thereby reaching 5.8% of the total number of predatory species collected during the study.

Of the nine species of *Amblyseius* collected during the study, *A. largoensis* was identified as the most widely distributed species enjoying the maximum host range, as it could be collected from seven species of host plants representing both leafy vegetables and fruit crops (Table 5). The species showed its distribution on host plants grown/cultivated in four sampling localities extended over three districts, out of the 5 districts surveyed during the study. Its association was evident with pest mites like *T. urticae*, *T. neocaledonicus*, *T. ludeni*, *O. biharensis* and *B. phoenicis*. *A. channabasavannai* was collected from four major crops viz., *V. unguiculata*, *A. blitum*, *A. cruentus* and *P. guajava* which were found infested by pest mites like *T. macfarlanei*, *T. urticae*, *B. phoenicis* and *E. orientalis*. Similarly *A. diosoreae* was found inhabiting on both fruit crops and vegetable crops including *V. unguiculata*, *P. guajava*, *S. aqueum* and *A. sapota*, which showed infestation by several species of pest mites viz., *T. macfarlanei*, *T. urticae*, *T. ludeni*, *B. phoenicis* and *O. biharensis*. However, the direct feeding by the predator could be observed only on the larval stages of *T. macfarlanei* and nymph of *T. urticae*. The only phytoseiid that could be collected from the curry leaves was *A. kulini* and its population density was found low, despite the high population density of the pest mite, *S. hindustanicus* on the above host plant. The predatory species viz. *A. indirae*, *A. orientalis*, *A. kundurukae* and *A. aeralis* were recovered exclusively from fruit crops. *Amblyseius indirae* was collected from guava plants infested with *T. urticae*. Likewise, *A. kundurukae* was seen in association with pest mites like *T. ludeni*, *Tenuipalpus* sp. and *Eotetranychus* sp. infesting fruit crops like Mulberry and Sapota. Predators like *A. aeralis* and *A. orientalis* were collected from *C. limon* and *C. Papaya* respectively and their presence could be traced on the host plants infested with populations of the pest mite, *T. urticae*.

Amblyseius paraaerialis was observed as a common predatory mite dwelling on leafy vegetables like *V. unguiculata*, *A. blitum* and *A. cruentus* and the fruit crop, *P. guajava* along with populations of *T. urticae*, *T. neocaledonicus*, *T. ludeni*, *T. macfarlanei*, *B. phoenicis* and *P. latus*. But its population density in the field appeared to comparatively lower than that of another phytoseiid member viz. *Neoseiulus longispinosus*. However, all the prey patches were found colonised by the adult predator, thereby supporting its outstanding dispersal ability in the field. Apart from mite pests, *A. paraaerialis* was also found in association with insect pests like whiteflies, feeding on their younger stages and thereby proving its potential as a broad spectrum biocontrol agent in the agricultural fields. The species was also observed to feed on the pearl bodies, a lustrous transparent high energy secretion rich in amino acids, lipids and carbohydrate produced from the epidermal cells of plants as a reward in exchange of active protection offered by the predator.

The second species rich genus under Phytoseiidae was *Euseius* as recognized during the study and it included three species viz. *E. alstoniae*, *E. finlandicus* and *E. rhododendronis*. Of these, *E. alstoniae* was found to occur in moderate density on both the leaves and fruits of *A. hirsutus* in association with the eriophyid mite of the family Diptilomiopidae viz. *Diptilomiopus* sp. Despite of the high density of both the pest and predator, direct feeding could not be observed during the study. Interestingly, the predator was observed to feed on the fruit sap (fluid from the fruit pulp) of Wild jack. Good populations of *E. finlandicus* could be recovered from the leaves of single host viz. *A. blitum* infested with pest mites viz. *T. urticae* and *B. phoenicis*. The predator was found to devour all the life stages of *T. urticae* as well as the pollen of *A. blitum* in the field. *E. rhododendronis* showed distribution on three host plants such as *V. unguiculata*, *A. blitum* and *M. indica*. Optimum population density (5-10 adult mites per leaf) of *E.*

rhododendronis was observed in association with pest mites viz. *T. urticae*, *T. macfarlanei*, *O. biharensis* and *B. phoenicis* on the above species of host plants. In the field, *E. rhododendronis* was observed to consume different life stages of pest mites, especially the adult stages of spider mites. Presence of *E. rhododendronis* could be noted on mango leaves infested with the mango leaf coating eriophyid mite, *C. kenya*, though no direct feeding of the predator on the life stages of *C. kenya* was observed in the field.

Typhlodromips was the third largest genus under Phytoseiidae recovered during the study and it included two species viz. *T. officianaria* and *T. syzygii*. Presence of these two species could be traced in association with the pest mite species, *B. phoenicis* infesting on host plants viz. *V. unguiculata* and *A. blitum* respectively.

The remaining three genera of phytoseiid predators collected during the study viz. *Neoseiulus*, *Paraphytoseius* and *Typhlodromus* were found represented by a single species each viz. *N. longispinosus*, *P. orientalis* and *Typhlodromus* sp. respectively. Of these, *N. longispinosus* could be recovered from 5 species of host plants representing both vegetables and fruit crops viz. *V. unguiculata*, *A. blitum*, *A. cruentus*, *C. papaya* and *M. oleifera* collected from nine sampling localities. *N. longispinosus* was found distributed on 4 species of leafy vegetables and 2 species of fruit crops in the field viz. *V. unguiculata*, *A. blitum*, *A. cruentus*, *M. oleifera*, *Psidium guajava* and *C. papaya* (Table 5). Being the efficient feeders of spider mites, the species was found to occur in high populations in the field, in association with spider mite pests such as *T. urticae*, *T. neocaledonicus*, *T. ludeni*, *T. udaipurensis*, *T. macfarlanei*, *O. biharensis* and *T. truncatus*. In the laboratory, the species was found actively feeding on all life stages of spider mites, with significant preference towards the egg stages, in laboratory studies. *P. orientalis* was found to occur in moderate density on *A. cruentus* and *C. esculenta* infested with the two spotted spider mite, *T. urticae*.

Table 5

Species diversity, geographic distribution and host range of the Phytoseiid predators associated with the pest mites collected during the study

Superfamily	Family	Genera	Species		Range of Host Plants	Locality	District	Associated pest mite species
PHYTOSEIOIDEAKARG, 1965	PHYTOSEIDAEERLESE, 1916.	1. AmblyseiusBerlese, 1914	1	<i>A. aerialis</i> (Muma), 1955.	<i>Citrus limon</i>	Meenangadi, Payyannur	Wayanad, Kannur	<i>Tetranychus urticae.</i>
			2	<i>A. channabasavannai</i> Gupta and Daniel, 1978.	<i>Vigna unguiculata</i> , <i>Amaranthus blitum</i> , <i>A. cruentus</i> , <i>C. limon</i>	Moonniyur, Koorachund, Kuttiady	Malappuram, Kozhikode	<i>T. macfarlanei</i> , <i>T. urticae</i> , <i>Brevipalpus</i> , <i>phoenicis</i> , <i>Eutetranychus orientalis</i>
			3	<i>A. dioscoreae</i> Rahul <i>et al.</i> 2016.	<i>V. unguiculata</i> , <i>Psidium guajava</i> , <i>Syzigium aqueum</i> , <i>Achras sapota</i>	Ponnani, Kuttippuram, Oorakam, Vazhayur, Kakkodi,	Malappuram, Kozhikode	<i>T. macfarlanei</i> , <i>T. urticae</i> , <i>T. ludeni</i> , <i>B. phoenicis</i> , <i>Oligonychus biharensis</i> .

			4	<i>A. indirae</i> Gupta, 1985.	<i>P.guajava</i>	Vazhayur	Malappuram	<i>T. urticae</i>
			5	<i>A. kulini</i> Gupta, 1978.	<i>Murraya koenigii</i>	Meenangadi, Ambalavayal, Malur,	Wayanad, Kannur	<i>Schizotetranychus hindustanicus</i>
			6	<i>A.kundurukkae</i> Mary Anitha and Ramani, 2004.	<i>Morus alba</i> , <i>A. sapota</i>	Ambalavayal, Nilambur	Wayanad, Malappuram	<i>T.ludeni</i> , <i>Tenuipalpus</i> sp., <i>Eotetranychus</i> sp.
			7	<i>A. largoensis</i> Muma, 1955.	<i>V. unguiculata</i> , <i>A.blitum</i> , <i>A.cruentus</i> , <i>Carica papaya</i> , <i>Moringa oleifera</i> , <i>Mangifera indica</i> , <i>Citrus limon</i>	Nileswaram, Kanhangad, Ambalavayal, Vazhikkadavu,	Kasaragod, Malappuram, Wayanad.	<i>T.urticae</i> , <i>T.neocaledonicus</i> , <i>T.ludeni</i> , <i>O.biharensis</i> , <i>B. phoenicis</i>
			8	<i>A. orientalis</i> Ehara, 1959.	<i>C. papaya</i>	Pariyaram, Payyannur, Malur, Kanhangad	Kannur, Kasaragod	<i>T. urticae</i> .

			9	<i>A. paraaerialis</i> Muma, 1967.	<i>V. unguiculata</i> , <i>A. blitum</i> , <i>A. cruentus</i> , <i>P.</i> <i>guajava</i> .	Anakkayam, Ariyallur, Alanthatta, Mukkom	Malappuram, Kozhikkode, Kasaragod	<i>T. urticae</i> , <i>T.</i> <i>neocaledonicus</i> , <i>T. ludeni</i> , <i>T. macfarlanei</i> , <i>B.</i> <i>phoenicis</i> , <i>Polyphogotarsonemus</i> <i>latus</i>
	2. <i>Euseius</i> Wainstein, 1962		10	<i>Euseius</i> <i>alstoniae</i> (Gupta 1975).	<i>Artocarpus</i> <i>hirsutus</i>	Angadippuram	Malappuram	<i>Diptilomiopus</i> sp.
			11	<i>E. finlandicus</i> (Oudemans, 1915).	<i>A. blitum</i>	Kuttippuram, Mukkom,	Malappuram, Kozhikkode.	<i>T. urticae</i> , <i>B. phoenicis</i>
			12	<i>E. rhododendronis</i> (Gupta, 1970).	<i>V. unguiculata</i> , <i>A. blitum</i> , <i>M.</i> <i>indica</i>	Kuttippuram, Ariyallur, Kakkodi	Malappuram, Kozhikkode.	<i>T. urticae</i> , <i>T. macfarlanei</i> , <i>O. biharensis</i> , <i>B. phoenicis</i> , <i>Cisaberoptus kenyae</i>
		3. <i>Neoseiulus</i> Hughes, 1948	13	<i>Neoseiulus</i> <i>longispinosus</i> (Evans, 1952).	<i>V. unguiculata</i> , <i>A. blitum</i> , <i>A.</i> <i>cruentus</i> , <i>P.</i>	Moonniyur, Ariyallur, Kakkodi, Maniyur,	Malappuram, Kozhikkode Kasaragod,	<i>T. urticae</i> , <i>T.</i> <i>neocaledonicus</i> ,

					<i>Guajava,</i> <i>C.papaya,</i> <i>M.oleifera</i>	Nileswaram, Manjeswaram, Pinarayi, Sulthan bathery	Kannur, Wayanadu	<i>T.ludeni,</i> <i>T.udaipurensis,</i> <i>T.macfarlanei,</i> <i>O.biharensis,</i> <i>T.truncatus.</i>
		4. Paraphytoseius Swirski and Schechter, 1961.	14	<i>P. orientalis</i> (Narayanan <i>et</i> <i>al.</i> 1960.	<i>A.cruentus,</i> <i>Colocasia</i> <i>esculenta</i>	Nileswaram, Pariyaram, Kanhanged	Kasaragod, Kannur	<i>T. urticae.</i>
		5. Typhlodromips De Leon, 1965.	15	<i>T. officianaria</i> <i>Gupta, 1975.</i>	<i>V.unguiculata</i>	Moonniyur, Ponnani, Payyannur, Pariyaram	Malappuram, Kannur.	<i>B. phoenicis</i>
			16	<i>T. syzygii</i> (Gupta), 1975.	<i>A.blitum</i>	Ariyallur, Vazhayur, Pariyaram	Malappuram, Kannur	<i>B. phoenicis</i>
		6. <i>Typhlodromus</i>Scheuten, 1857.	17	<i>Typhlodromus</i> sp.	<i>C. papaya</i>	Ariyallur	Malappuram	<i>T. urticae, B. phoenicis</i>

Considering the very common occurrence in relatively high numbers of phytoseiid mites in association with the common pest mites on the leafy vegetables and fruit crops in agricultural fields and other ecosystems, extensive studies were undertaken to evaluate the predatory potential of three selected species viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* representing the Type II, Type III and Type IV feeding categories on different life stages of three species of spider mite pests. Further, developmental studies of a type III predator species viz. *A. paraaerialis* were also carried out to record the durations of individual life stages as well as total duration of development of the species. Taxonomic studies of the three species and their individual life stages were also performed and the morphological features were illustrated based on drawings and relevant photographs.

I.A. TAXONOMIC STUDIES

I.A.i. MORPHOLOGICAL STUDIES OF PHYTOSEIID MITES

❖ General morphology and terminology of phytoseiid mites

The various terminologies included in the taxonomic description part were briefly summarised to impart a better understanding of the morphological features of the respective species of phytoseiid predatory mites included in the study (Plate 16). In general, body of phytoseiid mites is divided in to two distinctive parts called Gnathosoma and Idiosoma.

i. Gnathosoma

Gnathosoma of phytoseiid mites bears major components of mouth parts including a pair of Chelicerae and pedipalp. The dorsal side of the gnathosoma is covered by a cuticular plate known as tectum or epistome.

- a. **Chelicera** – Generally, the chelicerae of phytoseiid mites are chelate - dentate type with a pair of terminal digits. The dorsal fixed digit and ventral movable digit may or may not contain tooth. The number of teeth and the pattern of dentition show variation depending upon species. The fixed digit carries a needle like structure called *pilus dentilis*. Phytoseiid male possesses a spermatophoral process on the movable digit. The shape of the spermatoporal process varies with species.
- b. **Pedipalp** – The pedipalps of phytoseiid predators are usually segmented and the segmentation is similar to that of legs and each distinctive segment named as coxa, trochanter, femur, genu, tibia and tarsus. Coxae of palpi are fused together to form basis capituli.

ii. **Idiosoma**

Idiosoma of phytoseiid mites are covered with a dorsal shield which in majority of the case is entire or transversely divided. It may be ornamented with reticulations and usually bears the following sets of setae.

- a. **Vertical setae (J₁):** One pair of setae, anterior in position on the dorsal shield.
- b. **Clunal setae (J₅):** One pair, posterior in position on the dorsal shield.
- c. **Dorsocentral setae (j-J):** Paired setae present on the central position of dorsal shield. j - J series includes j₁, j₃, j₄, j₅ and j₆ on the prodorsum and J₁, J₂, J₃, J₄ & J₅ on opisthodorsum.
- d. **Mediolateral setae (z-Z):** Paired setae present on the mediolateral position of dorsal shield. z – Z series includes z₂, z₃, z₄, z₅ and z₆ on the prodorsum and Z₁, Z₂, Z₃, Z₄ & Z₅ on opisthodorsum.

- e. **Dorsolateral setae (s-S):** A maximum number of five pairs of setae may be present on dorsolateral position of dorsal shield. In majority species s – S series includes s₄ and s₆ on the prodorsum and S₂, S₄ and S₅ on the opisthodorsum. The number of dorsolateral setae varies with species.
- f. **Sublateral setae (r₃ and R₁):** Two pairs of sublateral setae present in majority of the species on the lateral side of the dorsal shield. Presence or absence of sublateral setae depends on the species of phytoseiid mites.

The following shields and structures are present on the idiosomal venter surface of the phytoseiid mite.

- a. **Sternal shield (SS):** The setae present on the sternal shield are generally known as sternal setae. The number of sternal setae varies with species. Usually they are of 2 or 3 pairs in number. If only 2 pairs are present, they are positioned on the shield proper. If it is 3 pairs, then they are present on the membrane or may be at the shield proper. In males, sternal and the genital shields are fused to form a single large shield called sternogenital shield. Sternogenital shield bears 5 pairs of setae.
- b. **Metasternal plate (MSP):** A pair of metasternal plate present on the sublateral position to the sternal shield. Each of this small shield may bears a setae (ST₄).
- c. **Genital shield (GS):** Genital shield is truncated posteriorly with a pair of setae (ST₅)
- d. **Ventri-anal shield (VAS):** Generally ventri-anal shield carries 1-4 pairs of setae. In addition to this a pair of anal and a single post anal setae are also present along with a pair of pores/pre anal pores. The structure of the shield and the presence or absence of pores varies with respect to the phytoseiid species. However the

ventri-anal shield of male phytoseiid shows variation both in shape and size. They usually larger and broader than the female sometimes with characteristic reticulations. It may be either entire or fragmented, sometimes fused lightly with sternitigenital shield but the line of fusion is clearly visible. It bears 4-5 pairs of setae.

- e. **Metapodal plates (MP):** Generally metapodal plates are of 1 or 2 pairs positioned just behind the IVth coxae. They can be of round, oval or triangular with respect to the species difference.
- f. **Setae on membrane:** On the posterior side of the venter a variable number of setae or pores are present on the membrane surrounding the ventri-anal shield. Paired setae includes JV1, JV2, JV3, JV4 & JV5.
- g. **Spermatheca (Sp):** This is a female specific structure found in pairs which receives and stores spermatophore from the male phytoseiid. Shape and the structure of spermatheca varies with different species and is crucial in species identification. Each spermatheca have distinct parts viz., calyx, atrium, major duct and minor duct. Both the minor duct and a major duct both originates from the atrium and the later opens ventrally through an external orifice between coxae III and IV.
- h. **Peritreme (P):** The stigmata and the peritreme are positioned on the peritremal shield. In almost all the species, except few the peritremal shield fused anteriorly with dorsal shield and posteriorly curves around coxae IV.
- i. **Legs:** In general, mites possess four pairs of legs and the chaetotaxy of the legs plays a major role in generic and specific identification. Evans (1963) in his pioneering work pointed out that all phytoseiidsown a standard chaetotaxy of legs

II and III. The general leg chaetotaxy of genua II and III and tibia II and III are represented by leg chaetotactic formula as :

Genua. 2 2/0 2/0 1 or 2al 2ad/Oav 2pd/Opv 1pl

Where, al – anterolateral, ad – anterodorsal, av – anteroventral, pd – posterodorsal, pv – posteroventral and pl – posterolateral.

j.) Macrosetae: They are the taxonomically important special setae present on the genu, tibia and basitarsus of leg IV. Sometimes the genu and tibia of leg II and III bears macrosetae. The length and shape of macrosetae may vary with respect to the phytoseiid species. The shape can be of knobbed, spatulate, simple or in some other shapes.

❖ Key to the genera of Phytoseiid mites collected during the study

1. Either seta z3 or seta s6 or both present..... genus *Typhlodromus* Scheuten, 1857
 – Setae z3 and s6 absent..... **2**

2. Sternal shield with median posterior projection; deutosternal groove wider (>5 µm in width); forward migration of preanal setae JV2 and ZV2 to a varying extent on the female ventrianal shield; seta JV1 usually inserted away (backward) from the anterior margin of the ventrianal shield; preanal setae on male ventrianal shield usually arranged in tangential row, rather than in a triangular pattern..... *Euseius* Wainstein, 1962
 – Sternal shield without posterior projection; deutosternal groove narrower (< 5 µm in width); without forward migration of preanal setae JV2 and ZV2; seta JV1 usually inserted on or near the anterior margin of the ventrianal shield; preanal setae on male usually arranged in a triangular pattern rather than in a tangential row..... **3**

3. Seta S4 absent; some dorsolateral setae thickened, serrated, arising from tubercles; female ventrianal shield usually long, narrow, with preanal setae vertically aligned along lateral margins..... *Paraphytoseius* Swirski and Schechter, 1961
- Seta S4 present; dorsolateral setae, female ventrianal shield and preanal setae not as mentioned4
4. Ratio of seta s4:Z1 < 3.0:1.0; setae s4, Z4 and usually Z5 not greatly longer than other dorsal setae; usually lightly sclerotized, never with wide sternal shield; seta J2 always present.....5
- Ratio of seta s4:Z1 > 3.0:1.0; setae s4, Z4 and usually Z5 markedly longer than other dorsal setae; seta J2 present/absent; some species heavily sclerotized, red or dark brown in colour and with wide sternal shield, but other species without the above character states..... *Amblyseius* Berlese, 1914
5. Ge II without and Ge III rarely with a macroseta; fixed digit of chelicera usually with fewer than six teeth, rarely multidentate; never with both of the above two character states.....,.. *Neoseiulus* Hughes, 1948
- Ge II and Ge III rarely without macrosetae; fixed digit of chelicera usually with more than six teeth; most species with both the above two character states..... *Typhlodromips* De Leon, 1965

I.A.ii. Morphological description of *Neoseiulus longispinosus* (Plate 17)

Female

Measurements : Length: 329µm (325-336µm)

: Width: 190µm (187-193µm)

Dorsal shield smooth and well sclerotized, much longer than wide. Idiosoma bears 33 pairs of setae, 19 pairs inserted on the dorsal surface and 14 pairs on the ventral

surface. Out of the total 19 pairs of dorsal setae, 17 pairs inserted on the dorsal shield and two pairs on the lateral integument (R1 and r₃). All dorsal setae are medium long, smooth and setiform. Measurements of dorsal setae: j₁- 21µm (j₃ – 64µm, j₄ - 62µm (60-64 µm), j₅- 69µm (66-72µm), j₆ - 70µm (68-71µm), J₂ – 71µm (69-73µm), J₅ – 10µm (9-10µm), Z₁ – 76µm (74-78µm), Z₄ – 68µm (66-69µm), Z₅ – 80µm (78-81µm), z₂– 70µm (69-71µm), z₄ – 73µm (71-74), z₅ – 78µm (76-78µm), s₄ – 79µm (78-81µm), S₂ – 76µm (75-77µm), S₄ – 58µm (56-58µm), S₅ – 21µm (21-24µm), r₃ – 60µm (58-61µm), R₁ - 69µm (67-70µm). Peritreme extends up to j₁.

Sternal shield is wider than long. It is 55µm long and 72µm wide, bears 3 pairs of sternal setae (ST1, ST2 and ST3) and the fourth pair of sternal setae (ST4), inserted on the metasternal plate. Genital shield (60µm wide) is narrower than ventri-anal shield with a pair of setae (ST5). Both the sternal shield and the genital shield are slightly reticulated. Ventri-anal shield (112µm long and 100µm wide) is pentagonal in shape with slight reticulations. Lateral margins are slightly concave. Ventri- anal shield bears 4 pairs of setae viz. JV1, JV2, ZV2 and PA. But the other caudoventral setae viz., JV4, JV5, ZV1 and ZV3 arises from the integument around ventri-anal shield. A single post anal seta (PST) is also present on the ventri- anal shield. Of the two pairs of metapodal plates, the primary metapodal plate (25µm long) is longer than secondary metapodal plate (14µm long). Fixed digit of chelicerae bears 3 teeth and the movable digit with 1 tooth. Spermatheca as figured.

Legs

Legs I-III with no macrosetae while leg IV bears 1 macroseta on basitarsus with a dimension of 76µm long. Leg chaetotactic formula:

Genu II 2 2/0 2/0 1, tibia II 1 1/1 2/1 1, genu III 1 2/1 2/0 1, tibia III 1 1/1 2/1 1

Male

Dorsal chaetotaxy is similar to that of female except for the sub- lateral setae (r - R series) which is inserted on the lateral side of the dorsal shield. Spermatophoral process as figured.

I.A.iii. Morphological description of *Amblyseius paraaerialis* (Plate 18)

Female

Measurements : Length: 342µm (338- 349µm)

: Width: 258µm (252-263 µm)

Dorsal shield is smooth and broad. Posterior region is broader than anterior region. Idiosoma bears 33 pairs of setae, 19 pairs inserted on the dorsal side and 14 pairs on the ventral side. Out of the total 19 pairs of dorsal setae, 17 pairs inserted on the dorsal shield and two pairs on the lateral integument (R1 and r₃). Setae s₄, Z₄ and z₅ are very prominent and longer than that of all other dorsal setae. All dorsal setae are medium long, smooth, setiform and whip like in appearance, and among which, Z₅ is very long, j₁ and j₃ are smooth, setiform and are medium in length. All the remaining dorsal setae are very minute in size. Measurements of dorsal setae: j₁- 28µm (26-29µm), j₃ -52µm (49-54µm), j₄ - 5µm (4-5µm), j₅ - 4µm (4 -6µm) , j₆ - 4µm (4-6µm), J₂ - 5µm (4-5µm), J₅ - 5µm (4-6µm), Z₁ - 4µm (4-5µm), Z₄ - 112µm (110-114µm), Z₅ - 234µm (230-236µm), z₂- 5µm (4-5µm), z₄ - 7µm (4-7µm), z₅ - 4µm (4-5µm), s₄ - 82µm (80-85µm), S₂ - 7µm (5-7µm), S₄ - 5µm (4-5µm), S₅ - 6µm (4-7µm), r₃ - 11µm (12-12µm), R₁ - 7(6-8µm). Peritreme is long and extending beyond seta j₁.

Sternal shield is wider with a straight posterior margin. It is 60µm (58-64 µm) long and 75µm (72-77µm) wide, bears 3 pairs of sternal setae (ST₁, ST₂ and ST₃) and the fourth pair of sternal setae (ST₄) inserted on the metasternal plate. Genital shield

(60µm wide) is narrower than ventri-anal shield and with a pair of setae (ST5). Genital shield is smooth in appearance. Ventri-anal shield (112µm long and 100µm wide) is smooth and pentagonal in shape. Lateral margins are slightly concave. Ventri-anal shield bears 4 pairs of setae viz. JV1, JV2, ZV2 and PA. But the other caudoventral setae viz., JV4, JV5, ZV1 and ZV3 arise from the integument around the ventri-anal shield. A pair of para-anal setae (PA) and the single post anal seta (PST) are arranged in a triangular pattern. A pair of crescentic pores are clearly visible on the ventri anal shield. Of the two pairs of metapodal plates, the primary metapodal plate (19µm long) is longer than the secondary metapodal plate (14µm long). Fixed digit of chelicerae bears 9 teeth and the movable digit with 4 teeth. Spermatheca as figured.

Legs

Legs I-II with macrosetae on genu and notable erect setae on tarsus I. while leg III bears macrosetae on genu and tibia. Leg IV carries 3 prominent macrosetae, which are smooth, setiform and whip like. Length of each macrosetae on leg IV as follows. Genu 102 µm, tibia 74 µmand basitarsus 72µm.

Genu II 1 2/1 2/0 1, tibia II 1 2/1 1/1 1, genu III 1 2/1 2/0 1, tibia III 1 1/1 2/1 1/.

Male

Dorsal chaetotaxy is similar to that of female except for the sub- lateral setae (r - R series) which is inserted on the lateral side of the dorsal shield. Ventrianal shield possesses reticulations. Spermatophoral process as figured.

I.A. iv. Morphological description of *Euseius rhododendronis* (Plate 19)

Female

Measurements : Length: 321 µm (317-323µm)
: Width: (218-225µm)

Dorsal shield smooth and well sclerotized with reticulations on the lateral side. Idiosoma bears 33 pairs of setae, 19 pairs inserted on the dorsal side and 14 pairs on the ventral side. Out of the total 19 pairs of dorsal setae, 17 pairs inserted on the dorsal shield and two pairs on the lateral integument (R1 and r₃). All dorsal setae are medium long, smooth and setiform. . Measurements of dorsal setae: j1 31µm (30–32 µm), j3 16µm (14–15 µm), j4 8 (8-9), j5 8 (6-8), j6 11µm (10-12), J2 11µm (10–11 µm), z2 10 (9-11), z4 10µm (8–10 µm) z5 9 µm (7–9 µm), Z1 12µm (10–13 µm), Z4 12µm (13–14 µm), Z5 9µm (8–9 µm), s4 14µm (12–14 µm), S2 15µm (14–15 µm), S4 16µm (14–18 µm), S5 16µm (13–19 µm), r3 11µm (6–9 µm), R1 15µm (12–17 µm). Peritreme extends up to the base of j3.

Sternal shield 70µm (70–71 µm) long and 80µm wide, with ST1, ST2 and ST3 and the fourth pair of sternal setae (ST4), inserted on the metasternal plate. Genital shield is 89µm long and 84µm wide which bears a pair of setae (ST5)). Ventrianal shield (112µm long and 72µm) wide pentagonal in shape, ZV1 22µm, ZV2 18 µm ZV3 11µm, JV1 23µm, JV2 19µm, JV4 11µm, JV5 28µm long. A thick fold present between genital and ventri-anal shields. A single post anal seta (PST) is also present on the ventri-anal shield. Of the two pairs of metapodal plates, the primary metapodal plate 20 long) is longer than secondary metapodal plate (7 long). Chelicerae bear three teeth on the apical portion of fixed digit and one tooth on movable digit. Spermatheca as figured with tubular calyx (20µm long).

Legs

Legs I-III with no macrosetae while leg IV bears 3 macrosetae with broadened tips present on genu 32µm (27–34 µm), tibia 30µm (26–32 µm) basitarsus 46µm (42–50 µm).

Genu II 2 2/0 2/0 1, tibia II 1 1/1 2/1 1, genu III 1 2/1 2/0 1, tibia III 1 1/1 2/1 1/.

Male

Dorsal chaetotaxy is similar to that of female except for the sub-lateral setae (r - R series) which is inserted on the lateral side of the dorsal shield. Spermatophoral process as figured.

II EVALUATION OF PREDATORY POTENTIAL OF SELECTED SPECIES OF PHYTOSEIID MITES

II.A. QUALITATIVE ASSESSMENT OF THE PREDATORY POTENTIAL OF PHYTOSEIID MITES

II.A.i. Prey capturing habit and mode of attack

The prey capturing and mode of attack of all the three species of phytoseiid mites selected viz. *N. longispinosus*, *E. rhododendronis* and *A. paraaerialis* appeared to be more or less similar and hence the predatory habit described here is applicable to all the three species. The foraging behaviour of predatory mites could be grouped in to two modes viz., searching and ambush mode. All the three species of phytoseiid predators considered in the present study exhibited 'searching mode' of foraging behaviour, in which the predator actively searched for the prey in ambulatory fashion. The predatory activity of the phytoseiid species was found initiated by a tactile stimulation received by the pedipalps and the sensory setae present on the first pair of legs, upon contact with the body of the prey mite. The predator exhibited swift movements towards the prey upon first contact with the mobile life stages of the prey mite, unlike that of the egg stage. When the predator started to attack the actively moving prey stage, its chelicerae, pedipalp and the first pair of legs were effectively managed to handle the prey till the prey stage became stabilized and rest of the legs were used to cling upon to the

substratum. The predator then exhibited a ventrad movement of its gnathosoma and bent down and touched the prey integument forming a 90⁰ angle with its longitudinal body axis. As soon as the prey got stabilized, the predator was observed to make an incision with its chelicerae on the integument of the prey mite, through which it sucked out the internal body contents of the prey mite. Slide mounted specimens of prey carcasses revealed multiple incisions on their integument, induced by the predator.

II.A.ii. Mode of consumption

In most cases, the predators were found to hold the appendages of the prey mite (adult spider mite), rather than its main opisthosoma and induced an incision on the leg cuticle, through which the body fluid of the prey mite started to ooze out. Controlled and co-ordinated movement of the pharyngeal muscles could be clearly visible from outside through the more or less transparent cuticle of the predatory mite. Such muscular movements triggered a suction force which instantaneously led to an inward flow of body fluids from the prey to the predator's gut, through food channel. As the feeding activity continued, the colour of the predator also got changed from creamy white to brown, corresponding to the body colour of the prey mite species. On completion of feeding activity, only the collapsed egg shells and shrivelled carcasses of the prey mites were found left on the leaf surface. The predators occasionally displayed partial feeding activity and unwanted killing of prey mites in which the predator killed the prey mite, but without consuming it completely. The nature of predation and feeding activity were found almost similar for all the three different species/ individual life stage of predatory mites selected for the study. However, the time taken to complete the feeding activity was found to vary for different life stages of the prey mite. More precisely, irrespective of the variations in the prey species or the life stage differences of the prey species, the predators exhibited high preference to the egg stages of the prey mites as evidenced

through their faster consumption of eggs, rather than the immatures and adult stages of the same prey. The time required for devouring a single life stage could be recorded as 2-4 minutes for eggs and 4-10 minutes for active life stages.

II.A.iii.Feeding preference

In the present study, life stage wise variation was observed in the feeding preference of each species of phytoseiid predator selected for the study. Results of the feeding experiments revealed that the selected phytoseiid predatory mites viz., *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* represented the Type II, Type III and Type IV categories, respectively. The specialist feeder, *N. longispinosus* showed great preference to the eggs of spider mites rather than their active life stages. Despite of this, the generalist feeders viz., *A. paraaerialis* and *E. rhododendronis* showed significant preference to the active life stages of spider mites rather than their inactive egg stages.

II.A.iv.Dispersal and colonization to new habitats

In the present study, the ambulatory dispersal of the selected species of phytoseiid predators was found triggered by a decrease in the prey density and subsequent starvation. It was also observed that prey deprivation could lead to random movement, increased walking speed and edge walking behaviour in *N.longispinosus* both under laboratory and field conditions. However, such characteristic behavioural patterns associated with dispersal of were appeared to be in the minimum level in the remaining two species of phytoseiids viz. *A. paraaerialis* and *E. rhododendronis*. Usually, under field conditions, all the three species of phytoseiid predators exhibited only a low distance dispersal trend (from one prey patch to another patch in the adjacent leaf, on the same plant). After consuming majority of the pest population in a particular prey patch,

the predators showed a tendency to wander in and around that specific leaf area, and then moved away from the foliar surface with low pest density in search of a new habitat, through the leaf petiole and the main stem. Both the deutonymphs and adult females of all predators enjoyed rapid dispersal power when compared to that of the early immature stages. The power of mobility was observed to be the minimum in the larval stage of the predators. While raising stock cultures of predatory mites in the laboratory, adult females of the predators exhibited rapid colonisation within the prey patches, soon after their transfer to new sets of spider mite infested leaves.

II.B. QUANTITATIVE EVALUATION OF PREDATORY POTENTIAL OF PHYTOSEIID MITES

Quantitative assessment of feeding preference of the adult stages of the three selected species such as *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* on the different life stages of the spider mite pests like *T. urticae*, *T. macfarlanei* and *O. biharensis* was carried out in the laboratory conditions of 30 ± 2 °C and $70 \pm 5\%$ RH. Results of the study enabled to record significant variations ($P < 0.05$) in the feeding rates of all the three species towards varied life stages of the three major spider mite pest species tested, upon statistical analysis using ANOVA by SPSS (IBM SPSS Statistics 20).

II.B.i. Evaluation of the predatory potential of the adult female of *Neoseiulus longispinosus* towards the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Fig. 6, PLATE 22-24)

N. longispinosus was recognized as the most voracious predator of spider mites as evidenced during the laboratory feeding experiments. The results of feeding experiments revealed considerable differences in the consumption rates of *N. longispinosus* with

respect to variations in the prey species/life stages of the prey species. Accordingly, the percentage consumption by the adult female of *N. longispinosus* on the life stages viz. egg, larva, nymph and adult female of the prey mite, *T. urticae*, was recorded as 80, 8.5, 15.5 and 6.6 respectively. The feeding preference of the predator decreased in the sequence: egg > nymphs > larva > adult (Table 6). Similarly, the prey stage preference of the adult female of *N. longispinosus* towards the varying life stages of *T. macfarlanei* was found to follow a decreasing order of Egg > Nymphs > Larva. However, the adult female predator did not show any preference towards the adult female stages of the prey mites, leaving them untouched. The percentage consumption of the adult female predator on the egg, larvae and nymph of *T. macfarlanei* could be recorded as 68, 6.6 and 13.3, respectively (Table 7). Despite its voracious predatory habit on spider mites, the predatory female of *N. longispinosus* showed less preference to all life stages of the third prey mite species, *O. biharensis* when compared to the former two species of spider mite preys viz., *T. macfarlanei* and *T. urticae*. The feeding preference of *N. longispinosus* showed a decreasing trend towards the varied life stages of *O. biharensis* in the order: nymph > larva > egg > adult, with the corresponding percentage consumption rates of 14.1, 13.3, 10.4 and 2.2, respectively (Table 8). As indicated in tables 5, 6&7, the female predator totally neglected the adult stages of the prey mite, *T. macfarlanei* whereas its consumption rates averaged to 6.6% and 2.2% respectively on the adults of *T. urticae* and *O. biharensis*.

II.B.ii. Evaluation of the predatory potential of the adult female of *Amblyseius paraaerialis* towards the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Fig. 9, PLATE 27-29)

Results of laboratory feeding experiments on the prey stage preference of the phytoseiid predator, *A. paraaerialis* towards the different life stages of the prey mite, *T.*

urticae disclosed its potential in predating both the active life stages as well as the eggs of the above prey species. However, a significant preference in feeding was recorded towards the larval stages of the prey mite, by the predator. The mean rates of consumption of the adult female of *A. paraaerialis* could be recorded as 33.3% on egg, 46% on the larval, 32% on the nymphal and 14.4% on the adult stages of the prey mite (Table 9). Even though the adult female predator devoured considerably high number of active prey stages such as the larvae and nymphs, it showed significantly higher preference to the eggs of *T. macfarlanei*. Results of laboratory feeding experiments revealed that the prey stage preference and the percentage consumption rate of the adult female predator on the life stages of *T. macfarlanei* decreased in the order of egg (42.6%) > larva (38.6%) > nymph (30.6%) > adult (14%) (Table 10). The feeding rate of the adult female of *A. paraaerialis* on *O. biharensis* was comparatively low. Irrespective of the life stage variations, the predatory female of *A. paraaerialis* showed a preference to feed on the active stages of the prey mite rather than its eggs. The prey stage preference of the adult female predator decreased in the order: larva > nymph > adult > egg and its mean consumption rates could be recorded as 9.3% egg, 25.3% larva, 17.3% nymph and 16.1% adult stages of the prey mite (Table 11).

II.B.iii. Evaluation of the predatory potential of the adult female of *Euseius rhododendronis* against the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Fig.13, PLATE 32-34)

Results of laboratory feeding experiments clearly disclosed the great preference of the adult female of *E. rhododendronis* towards the immature stages of the prey mites provided. The prey stage preference of the adult female predator when assessed based on the mean rate of consumption towards the different life stages of *T. urticae* showed a decrease in the order of nymph (52.6%) > egg (46%) > larva (33.3%) > adult (12.6%)

(Table 12). Despite of its low rate of consumption, the adult female of *E. rhododendronis* showed a specific preference to feed on the larvae of *T. macfarlanei*, followed by its nymphal stages, when compared to the eggs and adults. The total consumption rate of the predator was recorded to be 8.6% on the prey mite, *T. macfarlanei* and the life stage wise consumption rates of the predator were 6.6% egg, 12.5% larva, 8.8% nymph and 6.6% adult. The order of prey stage preference of the predator showed a decreasing order of larva > nymph > egg = adult (Table 13). In the case of the cassava spider mite, *O. biharensis* a slight variation was observed in the feeding preference of the predator, as the consumption rate was maximum for the nymphal stages of the prey, by recording 41.3%, followed by a very slight decrease of 40% for the prey larvae. However, unlike the previous species of mite, the eggs of *O. biharensis* were found left untouched by the predator. The total prey consumption rate of the adult female of *E. rhododendronis* was 21.9% , with the life stage- wise variation being 40% for the larva, 41.3% for the nymph and 6.6% for the adult (Table 14) of the prey mite.

A comparison of the total consumption rates of the adult females of the three species of predatory mites mentioned above, on the prey mite, *T. urticae*, revealed that *E. rhododendronis* had a significantly higher feeding rate of 36.1% (Fig. 13). As mentioned earlier, the adult predator devoured 52.6% nymphs, 46% eggs, 33.3% larvae and 12.6% adults of the prey mite, which together contributed to its highest feeding rate (Table 12). At the same time, it also displayed comparatively greater feeding potential towards *O. biharensis* with a total consumption rate of 21.9% (Fig. 13). Even though the predator was reluctant to attack the prey eggs and left them untouched, it consumed a great deal of immature stages viz. nymph (41.3%) and larva (40%) followed by adult (6.6%) (Table 14). On the other hand, the adult predatory female of *A. paraaerialis* consumed a great number of individual stages of *T. macfarlanei* within the experimental duration of 24

hours, with the total percentage consumption rate of 31.4%. It was also observed that the adult predator preferred to feed on the immature stages such as the egg and larva, with respective mean consumption rates of 42.6% and 38.6%, followed by the nymph (30.6%) and adult stages (2%) of the prey mite (Table 10).

III. COMPARATIVE EVALUATION OF PREDATORY POTENTIAL OF THE DIFFERENT LIFE STAGES OF PHYTOSEIID MITES

The biocontrol potential of the different life stages of the three species of phytoseiid predators, viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* on the different life stages (egg, larva, nymphs and adults) of the three species of prey mites viz. *T. urticae*, *T. macfarlanei* and *O. biharensis* was also assessed during the study by conducting the laboratory feeding experiments. Data gathered on the prey consumption rates of individual predatory life stages when subjected to statistical analysis through ANOVA by SPSS revealed significant variation ($P < 0.05$) in the rate of predation of the individual species/life stages on the different life stages of the prey mite species.

III.A. Evaluation of the predatory potential of the nymph of *Neoseiulus longispinosus* on the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Fig. 7, PLATE 22-24)

Results of laboratory feeding experiments enabled to record a significant variation in the feeding potential of the nymphal stages of *N. longispinosus* towards the different life stages of the two spotted spider mite, *T. urticae*. The nymphal stages of *N. longispinosus* exhibited considerably high rate of feeding towards the egg stage of the prey mite, and the feeding preference decreased in the order of egg > larva > nymph > adult. The mean consumption rates of the adult predatory nymph on the egg, larva, nymph, and adult female stages of the prey mite could be recorded as 56.6%, 14.6%,

9.5% and 6.6% respectively (Table 6). Similarly, the nymphal stage of the predator devoured significantly higher number of eggs of *T. macfarlanei* and the rates of prey consumption towards the egg, larvae and nymphal stages of the prey mite were recorded as 22.6%, 6.6% and 6.6% respectively (Table 7). However, it was also noted that the predator never attacked or fed any of the adult females of the prey mite, *T. macfarlanei*. The predatory nymphal stage exhibited a different trend towards the life stages of the prey mite, *O. biharensis*, in which the larva formed the preferred stage with a mean consumption rate of 22.2%, followed by the egg and nymphal stages with the corresponding consumption rates of 17.7% and 10% respectively (Table 8). At the same time, the predatory nymph displayed no feeding preference towards the adult stages of the prey mite, *O. biharensis* which appeared to be physically larger in size and hence would be difficult to handle. Yet, the total consumption rate of the predatory nymph was calculated to be slightly higher than that of the adult predator (Fig.5).

III.B. Evaluation of the predatory potential of the nymphal and larval stages of *Amblyseius paraaerialis* on the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Figs. 10 & 11, PLATES 27-29)

Results of the study disclosed slight variation between the immature and adult stages of the predatory mite, *A. paraaerialis* in their feeding preference towards the different life stages of the prey mite, *T. urticae*. Both the nymph and larva of *A. paraaerialis* showed more preference to the eggs by consuming more number of eggs followed by larva, nymph and adult of *T. urticae* with respective consumption rates of 18.6% & 12% egg, 12.6% & 6.6% larva, 6.6% & 6.6% nymph and 6.6% & 0% adult (Table 9). Despite of this, the nymph of *A. paraaerialis* exhibited an increased rate of consumption on the larval stages of *T. macfarlanei* followed by the egg, nymph and adult female, with the respective consumption rates of 22%, 15.2%, 12.5% and 11.1%.

However, the total consumption rate of the larval stage of the predator was comparatively low and the order of its prey stage preference with respect to mean percentage consumption was, egg (18.3%) > larva (13.3%) > nymph (8.8%) > adult (7.7%) (Table 10). The rate of predation of the nymph of *A. paraaerialis* on the larvae of *O. biharensis* was found higher when compared to that on its other life stages. The mean rate of consumption was found to be 20%. Based on the mean rates of consumption, the feeding preference to the various prey stages could be recorded as larva (20%) > nymph (13.3%) > egg (10%) > adult (8.8%). However, the larval stage of the predator displayed an equal preference to the egg and adult stages of the prey mite, with the mean consumption rate being 9.3%. Still, the predatory larva showed a notable preference towards the prey larva, followed by its nymphal stage with the consumption rates of 12.5% and 11.4%, respectively. (Table 11)

III.C. Evaluation of the predatory potential of the nymphal and larval stages of *Euseius rhododendronis* on the life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* (Figs. 14&15, PLATE 32-34).

Despite of the difference in spider mite species provided as test food items, both the nymphal and larval stages of *E. rhododendronis* showed significant preference towards the immature stages, either the larvae or the nymph of the pest mite species provided. The consumption rates of the immature stages of the predator were minimum when compared to that of the adult stage of the predator. Based on their prey consumption rates, the feeding preference of the nymph of *E. rhododendronis* towards varying life stages of *T.urticae* could be presented as: larva (20.6%) > egg (17.3%) > nymph (9.3%) > adult (6.6%). At the same time, the larval stage of the predator exhibited a different order of preference with the maximum feeding preference shown towards the nymphal stages of the prey. Its order of prey stage preference was noted as: nymph

Table 6

Rate of consumption (%) of adult female of the predator, *Neoseiulus longispinosus* on different life stages of the prey mite, *Tetranychus urticae* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH.

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	80	8.5	15.5	6.6	27.6
Nymph	56.6	14.6	9.5	6.6	21.8
Larva	0	0	0	0	0

Table 7

Rate of consumption (%) of nymph of the predator, *Neoseiulus longispinosus* on different life stages of the prey mite, *Tetranychus macfarlanei* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	68	6.6	13.3	0	21.9
Nymph	22.6	6.6	6.6	0	8.9
Larva	0	0	0	0	0

Table 8

Rate of consumption (%) of the life stages of the predator, *Neoseiulus longispinosus* on different life stages of the prey mite, *Oligonychus biharens* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	10.4	13.3	14.1	2.2	10
Nymph	17.7	22.2	10	0	12.4
Larva	0	0	0	0	0

Table 9

Rate of consumption (%) of life stages of the predator, *Amblyseius paraaerialis* on different life stages of the prey mite, *Tetranychus urticae* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	33.3	46	32	14.4	31.4
Nymph	18.6	12.6	6.6	6.6	11.1
Larva	12	6.6	6.6	0	6.3

Table 10

Rate of consumption (%) of life stages of *Amblyseius paraaerialis* on different life stages of the prey mite, *Tetranychus macfarlanei* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey Stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	42.6	38.6	30.6	2	31.4
Nymph	15.2	22	12.5	11.1	15.2
Larva	18.3	13.3	8.8	7.7	12

Table 11

Rate of consumption (%) of life stages of the predator, *Amblyseius paraaerialis* on different life stages of the prey mite, *Oligonychus biharens* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	9.3	25.3	17.3	16.1	17
Nymph	10	20	13.3	8.8	13
Larva	9.3	12.5	11.4	9.3	10.6

Table 12

Mean rate of consumption (%) of life stages of the predator, *Euseius rhododendronis* on different life stages of the prey mite, *Tetranychus urticae* at 30± 2°C & 70 ± 5%

RH

Predator	Percentage consumption of predator on prey Stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	46	33.3	52.6	12.6	36.1
Nymph	17.3	20.6	9.3	6.6	13.4
Larva	4.6	9.3	14.4	6.6	8.7

Table 13

Mean rate of consumption (%) of life stages of the predator, *Euseius rhododendronis* on different life stages of the prey mite, *Tetranychus macfarlanei* at 30± 2°C & 70 ± 5%

RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	6.6	12.5	8.8	6.6	8.6
Nymph	25.3	13.3	10.4	6.6	13.9
Larva	17.5	8.1	6.6	6.6	9.7

Table 14

Mean rate of consumption (%) of life stages of the predator, *Euseius rhododendronis* on different life stages of the prey mite, *Oligonychus biharensis* at $30 \pm 2^{\circ}\text{C}$ & $70 \pm 5\%$ RH

Predator	Percentage consumption of predator on prey stages				Total consumption
	Egg	Larva	Nymph	Adult	
Adult female	0	40	41.3	6.6	21.9
Nymph	0	20	16	8.8	11.2
Larva	0	19.3	12.5	6.6	9.6

(14.4%) > larva (9.3%) > adult (6.6%) > egg (4.6%) (Table 12). The mean consumption rates of the nymphal stage of the predator on the various life stages of the prey mite, *T. macfarlanei* were recorded as 25.3% egg, 13.3% larva, 10.4% nymph and 6.6% adult. Similarly, for the larval stage of the predator, the consumption rates on the life stages of *T. macfarlanei* were recorded as 17.5% egg, 8.1% larva and 6.6% each for both the nymph and adult stages. The order of preference for both the larval and the nymphal stages of the predator followed a more or less similar trend. The feeding preference of the predatory nymph was: egg > larva > nymph > adult, and the predatory larva also followed the same order except in having an equal preference towards the nymph and adult stages of the prey mite, *T. macfarlanei* (Table 13). The predatory potential of the nymphal and larval stages of *E. rhododendronis* was found comparatively higher on the larvae and nymph of *O. biharensis* where as it was lower towards the adult stage of the pest mite. Interestingly, irrespective of its life stage variation, this phytoseiid predator was found reluctant to attack the eggs of the prey mite, *O. biharensis*, and all the prey eggs were left untouched. The mean consumption rates of the nymph of *E. rhododendronis* on the prey stages such as larvae, nymph and adult could be noted as 20%, 16% and 8.8% respectively. Whereas, the predatory larva ingested 19.3%, 12.5% and 6.6% of larvae, nymph and adult stages of *O. biharensis*, respectively. Despite the differences in their predatory potential, both the larva and nymph of the predator exhibited a similar order of prey stage preference and which could be presented as larvae > nymph > adult (Table 14)

Results of the feeding experiments unequivocally revealed the predatory potential of the immature stages of the three species of phytoseiid predators in controlling the pest mite population. The nymph of *N. longispinosus* consumed more number of individual life stages of *T. urticae*, with a total consumption rate of 21.8%, which constituted the

Table 15

Rate of consumption of *Neoseiulus longispinosus* on prey mite eggs

Egg density of prey mite	Species of prey mites			
	<i>Tetranychus urticae</i>		<i>Tetranychus macfarlanei</i>	
	Mean consumption	Percentage consumption (%)	Mean consumption	Percentage consumption (%)
2	1.6 ± 0.26	80	1.5 ± 0.22	75
4	2.8 ± 0.35	70	3.1 ± 0.23	77.5
8	5 ± 0.53	62.5	5.5 ± 0.96	68.7
16	10 ± 1.57	62.1	13.8 ± 0.97	86.2
32	17.8 ± .69	55.6	17.1 ± 1.14	53.4
64	21 ± 1.65	32.8	21.3 ± 1.08	33.2
128	25 ± 1.58	19.5	21.4 ± 1.82	16.7

Table 16

Functional response parameters of *Neoseiulus longispinosus* females to varying densities of eggs of *Tetranychus urticae* and *Tetranychus macfarlanei* at 30 ± 2°C and 70±5% RH

Prey	Functional response parameters					
	Type of functional response	a	T _h (hours)	r ²	a/T _h	K
<i>T. urticae</i>	Type II	0.82	0.74	0.99	1.10	32.43
<i>T. macfarlanei</i>	Type II	0.78	0.43	0.99	1.81	55.81

a. attack rate, T_h. handling time, K. maximum predation rate, a/T_h. effectiveness of predation

highest rate of predation observed among the immature stages of the phytoseiid predators considered for the present study (Fig. 16). The nymphal stage of *A. paraaerialis* showed a total consumption rate of 15.2% on *T. macfarlanei* and 13% on *O. biharensis* with a significant preference towards the larval stage of the prey species. While considering the total consumption rates of the larval stages of the phytoseiid predators, a great number of individual stages of *T. urticae* were found consumed by *E. rhododendronis* and the total consumption rate could be recorded as 8.7%. On the contrary, larvae of *A. paraaerialis* were found to feed more number of individual life stages of both the prey species viz. *T. macfarlanei* and *O. biharensis*. The corresponding consumption rates could be evaluated as 12% and 10.6%, respectively (Fig. 16). The larvae of *N. longispinosus* despite their active nature, were found non-feeding and hence were not considered for laboratory feeding experiments. These larvae were proved to have zero predatory potential, in controlling the spider mite pests tested.

Furthermore, the results of the feeding experiments also helped to identify the most potent predator, with the highest percentage consumption in controlling the individual life stages of the spider mite species selected for the study. The adult female of the predator, *N. longispinosus* devoured 80% of the eggs of *T. urticae* within a period of 24 hours (Table 6). In addition, the predator also was found to ingest 68% of *T. macfarlanei* eggs, offered as test food in the experimental arena (Table 7).

IV. STUDIES ON THE FUNCTIONAL RESPONSE OF THE PHYTOSEIID REPRESENTATIVE, *Neoseiulus longispinosus*.

Based on the significant feeding preference and high rate of predatory potential exhibited by the predator, *N. longispinosus* towards the eggs of the pest mites, *T. urticae* and *T. macfarlanei*, attempts were made during the study, to calculate the functional

response of the above predator to each of the spider mite pests mentioned above, using the Holling's disc equation. Results of the study enabled to compare as well as contrast the functional response parameters of *N. longispinosus* responsible for its higher feeding potential towards the eggs of both species of pest mites viz. *T. urticae* and *T. macfarlanei*.

The results of feeding experiments carried out with the phytoseiid predator, *N. longispinosus* towards the seven different egg densities (2, 4, 8, 16, 32, 64 and 128) of *T. urticae* and *T. macfarlanei* have been presented in Table 15. As illustrated in Table 15, the feeding rate of the predator showed a decrease with the increasing prey density. The percentage consumption of the predator was recorded as 80% on *T. urticae*, when its egg density was 2 and it showed a sharp decrease to reach 19.5% when the egg density was increased to 128. Towards *T. macfarlanei*, the maximum percentage consumption of predator was 86.2 when offered with an egg density of 16, whereas its percentage consumption was the minimum (16.7) when offered with an egg density of 128. Thus, the predator showed the minimum percentage of prey consumption for both species of pest mites tested, when the maximum egg density (128) was offered. The functional responses of the predator towards the different densities of eggs of both the species of spider mite pests were approximated to the Holling's type II model by a cyrtoid curve, and a decreasing trend was observed even at an increased egg density, leading to the formation of an almost plateau (Figs. 17& 19). As shown in Fig. 18, in the case of *T. urticae*, linear regression yielded a straight line equation of $y=1.213x + 0.031$ and for *T. macfarlanei*, the corresponding equation was $y=1.278x + 0.018$ (Fig. 20). The attack rate (a) and the handling time (Th) of *N. longispinosus* when fed on the eggs of *T. urticae* were calculated as 0.82 and 0.78 respectively. On the other hand, the attack rate and the handling time of the predator towards the eggs of *T. macfarlanei* were evaluated as 0.78

and 0.43 respectively (Fig. 21& 22). Regardless of the higher attack rate of *N. longispinosus* on eggs of *T. urticae*, both the parameters, like the maximum predation rate (K) and the effectiveness of predation (a/T_h) were found higher towards the eggs of *T. macfarlanei* and were calculated as 55.81 and 1.18 respectively. Towards the eggs of *T. urticae*, the values recorded for the above parameters were found slightly lower, and could be presented as 32.43 and 1.10 respectively (Table 16).

V. EXPLORATION OF MASS REARING POSSIBILITIES OF THE TYPE III PHYTOSEIID PREDATOR, *Amblyseius paraaerialis* UNDER LABORATORY CONDITIONS

Studies on the breeding biology of the phytoseiid predator, *A. paraaerialis* were carried out in the laboratory at $30 \pm 2^{\circ}\text{C}$ and $70 \pm 5\%$ RH on different combination of diets viz., castor pollen, honey, honey-pollen mixture and the pest mite species, *T. urticae*. The results of breeding biology experiments revealed that the honey-pollen mixture could be considered as a potential alternative diet for the mass rearing of the species, as the predator could successfully complete its life cycle on this diet (Plate 39, Figs. a-d). The predator failed to complete its life cycle and even failed to attain its deutonymphal stage when it was fed with castor pollen or honey alone. Hence the above diets which did not promote the successful completion of life cycle of the predator were not considered for breeding biology experiments and hence further studies were focused to trace the development on potential diets such as *T. urticae* and honey-pollen mixture.

The predator, *A. paraaerialis* was found to successfully complete its development when reared on both the diets like the prey mite, *T. urticae* as well as honey-pollen mixture, by following a similar life history with a considerable variation in the developmental duration of individual life stage (Tables 17, 18). The various processes

involved in the life history of the species such as mating, oviposition, quiescence, moulting etc. have been discussed here along with data on the duration of various life stages.

V.A. DEVELOPMENTAL STUDIES ON THE TYPE III PREDATOR, *Amblyseius paraaerialis*

V.A.i. Developmental pattern of *Amblyseius paraaerialis* (PLATE 10, 39).

Results of laboratory observations on the breeding biology revealed pseudo-arrhenotokous pattern of development in *A. paraaerialis*, in which the males were haploid, got developed from fertilized eggs. In the predatory population, the sex ratio appeared to be significantly female biased and the number of female individuals was three to four times greater than that of the male individuals. Breeding biology of the species started with the process of mating followed by the production and hatching of eggs. The life cycle of *A. paraaerialis* was found to comprise stages like the egg, larva, protonymph, deutonymph, and the adult, with intermediate quiescent stages. The quiescent stages were found inactive in nature and were designated as protochrysalis (Q1), deutochrysalis (Q2) and teliochrysalis (Q3) and which could be observed in between larvae – protonymph, Protonymph - deutonymph, and deutonymph - adult respectively.

Mating was proved to be a prerequisite for oviposition (PLATE 10, Fig. f). It occurred shortly after emergence of the adult female, from the third quiescent (Q3) stage. The adult males were observed to be randomly searching for the newly emerged adult female. Usually, the males exhibited competition with other potential males, on encountering a newly emerged female for mating at first place. The adult male was found to make the initial contact with the female by sensing with its pedipalps. The successful contact with the female was found followed by the subsequent climbing of the

male up on the dorsum of the female. After orienting the venter to dorsum position, the male was found to keep a firm grip over the female body and continued certain orientation changes, leading to the establishment of a venter to venter position with the adult female. Still in this paired position, the female exhibited active movement over the leaf surface with the male on her ventral side. Copulation was found initiated by lifting up of the female hysterostoma by the adult male and which was followed by sperm transfer. On successful copulation, the male female pair moved apart and the male started rapid searching for food or other newly emerged female for the next round of copulation event. The entire period of mating of *A. paraaerialis* from the initial recognition of female to the detachment of male-female pair was found to last for 40 – 50 minutes.

V.A.ii. Pre- oviposition, Oviposition and post oviposition periods of *Amblyseius paraaerialis*.

Mating and fertilization of the adult female predator was found followed by discrete events including the production of eggs, egg laying and stoppage of both egg production and egg laying, and which in turn were termed as the pre- oviposition, oviposition and post- oviposition periods respectively. The duration of each period was found greatly influenced by the quality of diet on which the species subsisted during the period. In the pre- oviposition period, the development of eggs was initiated within the body of the adult female and it became physiologically prepared to lay eggs. The end of the pre- oviposition period was marked by the initiation of egg laying or the period of oviposition. A slight variation was observed regarding the duration of the pre-oviposition period of *A. paraaerialis* when fed on different food items viz., *T. urticae* and honey- pollen mixture in the laboratory, at $30 \pm 2^{\circ}\text{C}$ and $70 \pm 5\%$ RH. As shown in Table 17 & Fig. 23, the female predator when fed with honey-pollen mixture finished its

pre- oviposition period and observed to lay eggs fastly than the one reared on *T. urticae* with the respective durations of 1.6 and 1.9 days.

The oviposition period was recognised as the phase with continuous production of eggs and subsequent egg deposition. The female of *A. paraaerialis* was found to lay a single egg at a time on the adaxial surface of leaves in the field. The eggs were oval in shape, creamy white in colour and translucent in nature. The eggs were usually found glued on to the substratum with a sticky substance produced by the adult female prior to deposition. In the field condition, the predatory females preferred to lay eggs close to the tuft of hairs on the leaf surface and away from the prey patch. The period of oviposition showed variation with respect to the food item consumed by the predatory species. Results of laboratory studies revealed a significant difference in the duration of oviposition of *A. paraaerialis* with regard to the type of diet on which it was fed. The oviposition period had a maximum duration of 19.3 days when the adult female of *A. paraaerialis* was fed with *T. urticae*. Whereas, on honey- pollen mixture, the average duration of oviposition could be recorded as 16.5 days (Table 17, Fig. 23).

The oviposition period of *A. paraaerialis* was succeeded by the post- oviposition period. This period was characterised by a cessation in egg production and egg deposition, reduced food consumption and rate of dispersal. All the activities were found to be limited in this period and most of the time the individual female was found to be resting near the midrib or in between the hairs of the leaves. This inactive phase eventually would lead to the death of the organism. However, the quality of diet greatly influenced the duration and behaviour of the adult females, in their post- oviposition period. The females of *A. paraaerialis* reared on castor pollen-honey mixture disclosed a longer duration of post- oviposition period rather than those fed with the pest mite, *T. urticae*. It was also observed that the females reared on honey -pollen mixture were able

to feed during the entire post-oviposition period. On the other hand, the females reared on the pest, *T. urticae* stopped their feeding activity and remained in the non-feeding state for the last three days of their post-oviposition period (Table 17, Fig. 23).

V.A.iii. Hatching and emergence of larva

The adult female of *A. paraaerialis* was found to lay single eggs and the eggs were larger in size when compared to the prey eggs. The eggs were crystalline- white in colour and translucent in appearance during the initial period of development. As the development progressed, it was also noted that the egg colour got changed to creamy-white and appeared to become more opaque. As shown in Table 18, no significant variation could be observed in the incubation period with respect to the difference in the food items provided. The results of the study enabled to record 40.4 hours as the mean incubation period of *A. paraaerialis* when fed on a diet of honey- pollen mixture whereas, it was 41 ± 0.4 hours on a diet comprised of the prey mite, *T.urticae*. The process of hatching was initiated by the appearance of two converging lines on the egg shell, leading to the formation of a slit, through which the larval hysterosoma protruded out. The larva wriggled out and extended its 2nd and 3rd pairs of legs. Later, through a characteristic wriggling movement, the larva extended out its whole body from the egg shell and the empty egg case was found left behind. The larvae of *A. paraaerialis* were crystalline -white in colour and like every other predatory species, possessed 3 pairs of legs. Once hatched out, the larva showed a brief period of inactive state, thence forth started to search the whole area instead of feeding the prey stage on first contact. Successful predation/consumption was noted after multiple prey/prey stage contact. Even though the food item comprising the honey - pollen mixture, was readily available in the experimental arena, the larvae exhibited an initial wide search rather than immediate consumption of the food stuff. The mean duration of larval period showed a considerable

variation with regard to the different diets provided. The mean duration of larval period of *A. paraaerialis* could be recorded as 17.6 ± 0.5 hours when fed with the alternative diet consisting of honey-pollen mixture whereas it was 19.1 ± 0.45 hours when it was reared on the prey mite, *T.urticae*.

V.A.iv. Quiescent periods

The active developmental stages viz., larva, protonymph and deutonymph were usually succeeded by an inactive stage of development recognised as quiescent period. These inactive periods, the so called quiescent phases would help in the metamorphosis of each of the life stages, ensuring physical and physiological changes of the individual. Three distinct quiescent periods were recognised during the whole life cycle of *A. paraaerialis* viz., protochrysalis (Q1), deutochrysalis (Q2) and teliochrysalis (Q3), in between the transition of larva- protonymph, protonymph- deutonymph and deutonymph- adult respectively. All the quiescent periods were characterised by reduced food intake and searching activity. During the onset of quiescent period, all the active stages were found to assume a resting posture in which the 1st two pairs of legs were stretched parallel to the pedipalp anteriorly while the hind legs were extended posteriorly, creating a maximum stretch throughout the integument. Table 18 illustrates more or less similar mean durations of quiescent periods in *A. paraaerialis* with respect to change in type of food they consumed. The protochrysalis had a more or less similar duration when the rearing was done on a diet of honey – pollen mixture (1.5 ± 0.05 hours) than that reared on the prey mite, *T. urticae* (1.6 ± 0.04 hours). The deutochrysalis and teliochrysalis were observed to have a little longer duration than the previous stage, irrespective of their diet difference.

Table 17

Reproductive parameters (in days) of adult female of *Amblyseius paraaerialis* on different food items provided at laboratory conditions of 30±2°C & 70±5% RH

Food items	Reproductive parameters (in days)			
	Pre-oviposition	Oviposition	Post-oviposition	Adult female longevity
Castor pollen and honey	1.6 ± 0.04	16.5 ± 0.4	11.4 ± 0.4	29.6 ± 0.9
<i>Tetranychus urticae</i>	1.9 ± 0.09	19.3 ± 0.3	4.8 ± 0.20	26.2 ± 0.4

Table 18

Developmental duration (in hours) of the different life stages of *Amblyseius paraaerialis* on selected food items offered in the laboratory at 30± 2°C &70+5% RH

Diet	Life stage							Total
	Egg	Larva	Q1	Proto nymph	Q2	Deuto nymph	Q3	
Castor pollen and honey	40.4 ± 0.6	17.6 ± 0.5	1.5 ± 0.05	22.7 ± 0.8	2.0 ± 0.04	16 ± 0.7	2 ± 0.04	102.3 ± 2.8
<i>Tetranychus urticae</i>	41 ± 0.45	19.1 ± 0.45	1.6 ± 0.04	25.4 ± 0.7	1.9 ± 0.04	20.7 ± 0.4	2.1 ± 0.06	112.0 ± 2.2

The emergence of the active life stage of predator from the preceeding quiescent stage was facilitated through the process of moulting in *A. paraaerialis* also. The process of moulting resulted in both physical and physiological changes including larger body size and development of reproductive organs. The initiation of moulting process was characterised with the formation of a longitudinal slit at the posterior hysterosoma of the moulting individual. The upward movement of the hysterosoma of the moulting instar facilitated the expansion of the slit, through which the new instar emerged out, leaving behind the separated exuvium.

V.A.v. Protonymphal period

The protonymphal stage emerged out through the moulting of the quiescent phase (protochrysalis, Q1) of the larval stage showed several major morphological changes including the appearance of fourth pair of leg, larger body size and creamy white colouration. The protonymph was more active than the larvae, with intense prey searching habit and more rate of prey consumption. Diet variation caused considerable variation in the protonymphal duration and as shown in Table 17, the mean duration of protonymphal stage lasted for 22.7 ± 0.8 hours on a diet of honey- pollen mixture and it got extended to 25.4 ± 0.7 hours on a diet comprised of the prey mite *T. urticae* (Table 18, Fig. 24).

V.A.vi. Deutonymphal period

The deutonymph emerged out from the deutochrysalis was characterised by a larger body size with narrow and more flattened hysterosoma. It appeared more active than the previous stage. Soon after food consumption, a transition of body colour was observed from a transparent-white to pale brown. The deutonymph showed high searching ability and dispersal rate like the adults, and its active period lasted for $16 \pm$

0.7 hours on honey – pollen mixture whereas the same could be recorded as 20.7 ± 0.4 hours when fed with *T. urticae* (Table 18, Fig. 24).

V.A.vii. Duration of development, lifespan and sex ratio

Results of breeding experiments disclosed significant differences in the developmental duration of immature life stages with regard to the type of food they consumed. *A. paraaerialis* showed a total developmental duration of 102.3 ± 2.8 hours (4.26 days) when reared on the alternative diet comprising honey – pollen mixture. On the other hand, an extended period of 112 ± 2.2 hours (4.66 days) was recorded when provided with the natural diet comprised of mixed life stages of *T. urticae* (Table 18, Fig. 25).

A significant variation in the longevity of the adult female was observed in *A. paraaerialis* with respect to the change in food type. The adult female longevity was found to be comparatively short on the natural prey, *T. urticae* (26.2 ± 0.4 days). Interestingly, it was increased to 29.6 ± 0.9 days when supplied with alternative diet. However, the total lifespan of *A. paraaerialis* was observed to be 30.86 days on *T. urticae*, which appeared to be very short when compared to a lifespan of 34 days on the honey – pollen mixture. The experimental result also revealed a female biased sex ratio for *A. paraaerialis* and was not influenced by the type of diet they consumed. More or less similar sex ratio was observed in predatory mites reared on honey-pollen mixture and *T. urticae* life stages. The corresponding sex ratio could be recorded as 4: 1 in both diets.

CHAPTER V
DISCUSSION

DISCUSSION

Conventional agricultural practices using pesticides jeopardize the overall health of the environment. Only one percentage of the chemical pesticides applied in agricultural fields reaches the target pest and the rest enters the environment, endangering the existence and survival of other organisms in the habitat (Fathipour & Maleknia, 2016). As an eco-friendly management approach, biological control has gained momentum as the key strategy to suppress and maintain the arthropod pest populations below economic injury level, with the minimum environmental damage. It employs the utilization of natural enemies to reduce the population density of target pests and thereby ensuring crop protection as well as safety of the environment and animal health. Currently, around 20 species of natural enemies have been mass reared and sold by about 50 companies worldwide (Gerson *et al.*, 2003). Among the wide range of natural enemies successfully exploited for biocontrol programmes, predatory mites of the family Phytoseiidae have been labelled as good candidates against arthropod pests (Altieri 1999; Power 2010) infesting cultivated and non-cultivated plants. The family Phytoseiidae contains more than 2400 described species (Demite *et al.*, 2018), categorised under 90 genera and three subfamilies viz. Amblyseiinae, Phytoseiinae, and Typhlodrominae (Chant 1993; Chant & McMurtry 2003). These mites are found distributed in all the seven biogeographic regions viz. Nearctic, Neotropical, Ethiopian, West Palaearctic, East Palaearctic, Oriental, and Australasian with a higher species diversity in the Neotropical, Oriental, and West Palaearctic regions (Tixier *et al.*, 2008). In India, a total of 211 species have been identified under 21 genera, eight tribes and three subfamilies (Mandape & Shukla, 2017). Phytoseiids possess a combination of various adaptive features such as high rate of reproduction, rapid developmental rates, female-biased sex ratio, numerical response to increased prey density, ease of mass

rearing etc. which attest the candidacy of these mites as good biocontrol agents (Hoy, 2011) and thereby reducing the need for application of chemical pesticides (Prischmann *et al.*, 2006; McMurtry *et al.*, 2015).

Majority of the phytoseiid mites are known to be generalist feeders (McMurtry *et al.*, 2013, 2015), not depending on a given prey species, but some species are known to feed on plants (Chant, 1959; Nomikou *et al.*, 2003; Sengonca *et al.*, 2003; Adar *et al.*, 2012). Despite this, several species are specialist feeders, restricting their feeding habit to members of a particular family or genera etc. and accordingly they have been categorised as type-I, type II, type III and type IV predators with more inclusive subdivisions under the major categories (McMurtry *et al.*, 2013). Phytoseiids often exhibit feeding specificity towards different pest mite species and preference towards particular life stage of its specific prey. This necessitates the need to undertake indepth studies for the evaluation of their feeding preference towards varied prey species as well as different life stages of the same prey species, for their effective utilization in biocontrol programmes. With this intention, the present investigation was undertaken with major objectives like evaluation of predatory potential of selected species of phytoseiid mites on the common and widely distributed pest mites infesting the leafy vegetables and fruit crops of North Kerala, comparative assessment of the prey stage preference of these mites, studies on the functional response parameters of selected predatory mites, exploration of mass rearing possibilities of selected phytoseiid representatives on alternative diets, and also comparison of the developmental duration of selected phytoseiid representative on prey mites as well as alternative diets etc.

As the first step to initiate the evaluation of feeding potential of predatory mites, in the present investigation, attempts were made to locate and identify the most common,

widely distributed and injurious species of pest mites and associated phytoseiid predators, inhabiting selected species of leafy vegetables and fruit crops grown/cultivated in various localities of North Kerala, through extensive surveys. The predatory habit and rate of predation of selected species of phytoseiid mites representing the Type II, Type III and Type IV feeding categories viz., *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* respectively, against three species of spider mite pests such as *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis*, as well as different life stages of the same species of pest mite were evaluated by conducting laboratory feeding experiments. Assessment of functional response parameters of the predator, *N. longispinosus* towards the egg stages of the potential spider mite pests viz. *T. urticae* and *T. macfarlanei* was also carried out simultaneously. Further, attempts were also made to explore the mass rearing possibilities of the Type III predatory species, *A. paraaerialis* on various alternative diets like honey, pollen, combination of honey and pollen etc. with an intention to provide data on the biological control potential of the above predators against the spider mite pests.

Extensive surveys undertaken during the present study to document the diversity and distribution of phytophagous mite fauna associated with the major leafy vegetables and fruit crops grown/cultivated in North Kerala enabled to record the association of 20 species belonging to three superfamilies viz. Tetranychoidae, Tarsonemoidea and Eriophyoidea and five families viz. Tetranychidae, Tenuipalpidae, Tarsonemidae, Eriophyidae and Diptilomiopidae. Of these, Tetranychidae was found to be the most diverse and highly distributed family with a total of 11 species, thereby forming 55% of the total number of species recovered during the study, thereby recording spider mites as the major group of pest mites on fruit crops of Kerala. Thus the present study helped to confirm the earlier finding on spider mites as the most important

agricultural pests throughout the world, owing to their polyphagous nature, high reproductive rate and short life cycle which contributes to resistance development to acaricides (Hildebrand *et al.*, 1986).

In the light of the results of the survey carried out during the study, three species of major spider mite pests infesting both the leafy vegetables and fruit crops viz. *T. urticae*, *T. macfarlanei* and *O. biharensis* were considered as the test prey species for conducting detailed feeding experiments. The two spotted spider mite, *T. urticae* is considered as one of the notorious spider mite pests of agricultural crops grown in both green houses and open fields, attacking about 1200 plant species, of which 150 represent economically important plants (Tehri, 2014). The species is widely distributed throughout the temperate, tropical and sub tropical zones and is considered as a cosmopolitan species in terms of distribution (Sabelis, 1985a,b). The species causes severe damage to host plants there by adversely affecting crop production and inducing yield loss in an unprecedented scale (Palevsky *et al.*, 2005; Aldosari, 2009; Alatawi, 2011). Apart from the feeding damage, the species also helps in the transmission of plant viruses including, potato virus Y, tobacco mosaic virus and tobacco ring spot virus, by excreting them on to the leaf surface and allowing them to enter the plant tissue through feeding damage (Oldfield, 1970; Jeppson *et al.*, 1975). The continuous usage of chemical pesticides for controlling *T. urticae* resulted in resurgence and pesticide resistance (Khodayari *et al.*, 2016). The present study could record the infestation of the two spotted spider mite on a wide range of host plants including both leafy vegetables and fruit crops viz. *Vigna unguiculata*, *Amaranthus blitum*, *Amaranthus cruentus*, *Moringa oleifera*, *Carica papaya*, *Achras sapota*, *Colocasia esculenta* and *Cucurbita maxima*. This species was already reported from host plants like, rose, chrysanthemum, gerbera and okra grown in various districts of Kerala (Prakash *et al.*, 2021; Maheswary *et*

al., 2015). Initially, the mite was found to establish colony on the abaxial surface of the leaves and as the infestation progressed, the mite colony was found extending to the adaxial surface of the leaf too and in severe situations the entire plant was found attacked by the species.

T. macfarlanei, another spider mite representative considered as test prey species for conducting feeding experiments is a well known and most threatening spider mite species recorded in serious portions on wide array of economically important crops worldwide (Moutia, 1958; Gupta, 2005; Satish *et al.*, 2018). This species is distributed in tropical and warm subtropical zones, inducing severe damage to their host plants (Seeman and Beard, 2011). As far as India is concerned, the species has been reported as a sporadic to serious pest of eggplant, causing leaf fall and 40 – 60 percentage yield reduction in Soyabean fields (Jose & shah, 1989; Gupta & Gupta, 1994; Satish *et al.*, 2018). Seeman and Beard, (2011) has raised a concern over *T. macfarlanei* becoming a persistent problem on several vegetable crops in tropical regions of Australia. The present investigation revealed the presence of *T. macfarlanei* on leafy vegetables viz. *V. unguiculata*, *A. blitum*, *A. cruentus* and *M. oleifera*. It has already been reported from other vegetables crops cultivated in central Kerala including Okra, Brinjal and Snake gourd (Maheswary *et al.*, 2015).

The third test prey species considered for the conduct of feeding experiments viz. *O. biharensis* is a sporadic pest of many of the important vegetables and fruit crops grown in tropical and subtropical countries of the world. It has a host range of about 78 plant species, of which it adverse impact was reported on the yield of loquat, mango, grape, eucalyptus, cassava, rose, camphor and litchi etc. (Channabasavanna *et al.*, 1972; Ghosh *et al.*, 1986; Cai & Wen 2002; Ji *et al.*, 2008; Kaimal, 2013; Migeon & Dorkeld,

2022). However, in the present study the distribution of the above species could be recorded only on two species of plants viz. *V. unguiculata* and *M. indica*. Considering its potential to become a sporadic pest of various vegetables and fruit crops, this species was included in the present study for further laboratory experiments.

The results of the present survey envisaged to record the association of 17 species of phytoseiid mites belonging to six genera with the fruit crops and leafy vegetables screened during the study. Hardly any plant could be collected without phytoseiids. These predatory mites were found actively feeding on phytophagous mites like the tetranychids, tenuipalpid, tarsonemids and eriophyids. Though all the above species of phytoseiid mites were found predatory in their habit, their considerable variation in their feeding preferences, as reported by many investigators (McMurtry *et al.*, 2013). Phytoseiid mites have already been grouped into four feeding categories such as Type-I, Type-II, Type III and Type IV predators based on their feeding preferences (McMurtey & Croft 1997; Mcmurtry *et al.*, 2013). Type I and Type II phytoseiids represent the specialist feeders of the members of the spider mite genus *Tetranychus* and the family Tetranychidae respectively. On the other hand, Type III and Type IV predators are the generalist feeders, capable of feeding on a wide range of food items including plant exudates, pollengrains, and pest mites belonging to different families including spider mites, small insect pests like mealy bugs, white flies, thrips and aphids (McMurtry *et al.*, 2013, 2015).

Among the 17 species of phytoseiids collected during the present survey, three common species viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* representing the Type II, Type III and Type IV feeding categories respectively were identified and selected for detailed laboratory experiments. In addition to diverse feeding

habits, the above three species were found closely associated with many of the potential acarine pest species surveyed during the study. Moreover, when compared to the other phytoseiid species collected during the field surveys, the above species of predators were found highly accessible and sustainable under laboratory conditions. *Neoseiulus longispinosus* was found in association with the pest mites, *T. urticae*, *Tetranychus neocaledonicus*, *Tetranychus ludeni*, *Tetranychus udaipurensis*, *T. macfarlanei*, *Tetranychus truncatus* and *O. biharensis* infesting various leafy vegetables and fruit crops such as *V. unguiculata*, *A. blitum*, *A. cruentus*, *C. papaya* and *M. oleifera*. This species was first described from the tuber crop, *Manihot utilissima* cultivated in Indonesia (Evans, 1952). Since then, it was reported from more than 30 countries in the tropical and sub tropical regions. Its distribution was already reported from various Indian states also like West Bengal, Orissa, Bihar, Arunachal Pradesh, Sikkim, Tamil Nadu, Karnataka and Uttar Pradesh (Gupta, 2003). *N. longispinosus* is considered as a common phytoseiid species that actively feeds on tetranychid mites in India (Karmakar & Gupta, 2011; Haneef & Sadanandan, 2013). The species has been reported to have a high potential to get acclimatized faster in warmer environmental conditions and which makes it as a potent candidate for the bio control of agricultural pests in south Indian conditions (Mallik *et al.*, 1998). It has been reported as a most common phytoseiid predator associated with the horticultural ecosystems in Kerala (Binisha & Bhaskar, 2013). In several countries, *N. longispinosus* is commercially available as an Acarine Biocontrol Agent (ABA) for the control of spider mite populations (Huyen *et al.*, 2017).

The results of field surveys encountered the common association of *A. paraaerialis*, with acarine pests like *T. urticae*, *T. neocaledonicus*, *T. ludeni*, *T. macfarlanei*, *Brevipalpus phoenicis* and *Polyphogotarsonemus latus* on various host plants including *V. unguiculata*, *A. blitum*, *A. cruentus* and *Psidium guajava*. The species

was originally reported from citrus plants in Kerala, India (Muma, 1967). Since then, it was reported from four other states of India such as Arunachal Pradesh, Assam, Meghalaya and West Bengal, inhabiting on several species of host plants like, Citrus, Palm, Bamboo and in some grass species (Gupta, 2003). Apart from India, *A. paraaerialis* was reported from other countries like China, Malaysia and Thailand (Demite *et al.*, 2022). *A. paraaerialis* is considered as a common phytoseiid predatory species associated with major vegetable crops cultivated in Kerala. Moreover, it exhibits a close association with phytophagous pest species, *T. macfarlanei*, *P. latus* and *Aceria litchi*. (Binisha & Bhaskar, 2013; Maheswary *et al.*, 2015).

During the present investigation, the phytoseiid predator *E. rhododendronis* was found associated with the pests, *T. urticae*, *T. macfarlanei*, *O. biharensis*, *Brevipalpus phoenicis* and *Cisaberoptus kenyae* infesting respective host plants like *V. unguiculata*, *A. blitum* and *Mangifera indica*. Earlier studies marked its presence in the field along with the pest populations of *T. ludeni* (Krishnamoorthy, 1983). Originally this species was reported from West Bengal on *Rhododendron* sp. (Gupta, 1970). Now it has been reported from other host plants such as, *Shorea robusta*, Guava, lemon, litchi, pear and coffee, distributed in six states of India viz. Karnataka, Kerala, Tripura, Sikkim, Mizoram and Tamil Nadu (Gupta, 2003; Banerjee *et al.*, 2017; Demite *et al.*, 2022). Thailand is the only country other than India, from which this species was previously reported. Because of its low distribution pattern, very few studies have been carried out on the predatory characteristics of *E. rhododendronis*, worldwide.

Results of the field surveys clearly disclosed the close association of three phytoseiid species selected for further feeding experiments viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* with spider mite pests and also provided substantial

evidences on their predatory habitson these pests. This prompted to design studies to analyse both the qualitative and quantitative aspects of predation through evaluation of predatory potential and elucidation of prey stage preference of these predators to the varying life stages of the very common, noxious species of spider mite pests under laboratory conditions. Apart from these, attention was also focussed to study the functional response parameters of one of the most potent phytoseiid predators, out of the three selected. In order to find out the possibilities for mass rearing of a generalist predator, like *Amblyseius aerialis* which represented the Type III category of phytoseiid predators, response towards alternative food items like honey, pollen, pollen-honey mixture apart from spider mites preys was also assessed during the present study. Data gathered on the above lines of studies were analysed statistically in order to find out the level of significance, recorded and presented appropriately.

During the qualitative assessment of predatory potential, observations were made on sequence of predatory behaviour such as prey capture, mode of attack and mode of consumption. More or less similar behavioural patterns were observed in *N. longispinosus*, *E. rhododendronis* and *A. paraaerialis*. The predators exhibited a 'searching mode' of foraging behaviour rather than ambushing the prey. Despite this, species like *N. fallacis* during its search for prey, *T. urticae* was reported to track the odours produced by mite infested plant (Hislop & Prokopy, 1981). However, once the prey patch was identified, the predator started random searching pattern (Berry & Holtzer, 1990). Similarly, in species like *Phytoseiulus persimilis*, the initial contact with prey was reported to be a matter of chance, resulting from its random searching behaviour (Mori & Chant, 1966). All the three predators considered in the present study were observed to make initial contact with their prey, with their pedipalps and the first pair of legs, thereby concurring with the earlier findings of Jackson and Ford (1973)

who, through scanning electron micrographs, suggested the presence of mechanoreceptors and contact-chemoreceptors on the setae of pedipalps and anterior tarsi of leg I, which could help in the detection and identification of prey stages. pedipalps, first pair of legs and the chelicerae are used together to handle the prey. After detection of the prey with its tarsal sensillae (trichobothria) of the front legs, the predator often move close to its prey and eventually the mouth parts are pushed through the integument of the prey (Sabelis, 1981). The movement of body fluid of the prey was well visible from outside, through the transparent body wall. Apparently, pre-digestive fluids would be injected for extra intestinal digestion (Akimov & Starovir 1978). Predators occasionally displayed partial feeding as already reported (Sabelis, 1981) in which, the predators seemingly left their prey while feeding and sometimes they returned back to the prey and started feeding again. Irrespective of the species differences, the time required for devouring a single life stage by the adult females of all the three predators could be recorded as 2-4 minutes for eggs and 4-10 minutes for active life stages. This is comparable with the feeding time recorded earlier (Sabelis, 1981) for *Metaseiulus occidentalis* and *Amblyseius potentillae* while devouring spider mite eggs (2- 6 minutes) and nymphal stages (3-11 minutes).

Neoseulus longispinosus exhibited more preference to the egg stages of the prey mite, while *A. paraaerialis* and *E. rhododendronis* preferred to feed on the other active prey stages. This result appears to correlate well with the degree of overall specialization for feeding on spider mites. According to the life-style categorisation (McMurtry & Croft 1997; McMurtry *et al.*, 2013), specialist Type-I species preferred eggs of spider mites, specialist Type-II species preferred eggs or exhibited no prey-stage preference, generalist Type-III species displayed no preference or preferred larvae, and generalist Type-IV species preferred larvae (Blackwood *et al.*, 2001). It is also suggested that (Flechtmann

& McMurtry 1992) the mouth parts of generalist species may not be much effective as the other categories for piercing the egg shells of tetranychids. The above authors also reported that the common cheliceral characteristics among species that feed primarily on spider mites were different from those of the species which feed primarily on pollen.

Irrespective of the species differences, all the three species of predatory mites selected for the present study displayed ‘ambulatory dispersal’ triggered by decline in the prey population. Ambulatory dispersal is considered as a strategy to overcome low risk of mortality (Strong *et al.*, 1999). Usually, the dispersal behaviours such as random movement, increased walking speed and edge walking behaviour were found triggered by food deprivation in the prey patch. Low distance dispersal was observed under field condition, in which predatory mite travelled from one prey patch to the other within a plant (intra patch). Movement of mites from one isolated plant to another (interpatch) occurs very less and has more risk for mortality than intrapatch movement (Nachman, 1988). Interestingly, dispersal behaviour was found to be higher in *N. longispinosus* whereas, other phytoseiids viz. *A. paraaerialis* and *E. rhododendronis* exhibited minimal and slower dispersal activity. It may be due to the ‘specialist predatory’ nature of *N. longispinosus*. Since *N. longispinosus* is an obligate spider mite feeder, it may have to disperse faster to the new prey patch in order to ensure its survival. On the other hand, the generalist feeders like *A. paraaerialis* and *E. rhododendronis* would withstand low prey density prey patch, with plant derived alternate diets. Despite this, Croft *et al.*, (1995a) reported that the resident time of the specialist feeder, *N. fallacis* was longer than that of the generalists.

The rate of dispersal was observed variable among the different life stages of the predatory mites studied. The adult females of *N. longispinosus*, *A. paraaerialis* and *E.*

rhododendronis dispersed more rapidly than that of their immature life stages. However, no dispersal activity was observed in the case of the non feeding larval stage of *N. longispinosus*. This observation coincides with the findings of Zhang and Croft, (1994), suggesting low dispersal in non-feeding larvae than the actively feeding larval stage. The rate of dispersal followed a decreasing order of adult female > nymph > larva. An increase in predatory mite density may also trigger the dispersal behaviour as it increases the chance of predator- predator encounter rather than predator- prey encounter. Kuchlein (1966) observed an increased tendency of young females of *M. occidentalis* to disperse from the experimental leaf discs in the presence of another female in that area. Predatory dispersal is influenced by several factors like, prey-mediated infochemicals (Hislop & Prokopy, 1981; Hoy & Smilanick, 1981), predator hunger (Jung & Croft, 2001b), degree of food specialization of species (Pratt *et al.*, 1998; Jung & Croft 2001a), temperature and humidity (Penman & Chapman, 1980) and spatial structure of the patch (Takafuji, 1977; Strong *et al.*, 1999).

Results of the feeding experiments revealed a considerable difference in the rate of consumption of predatory species/ life stage with respect to varied prey species/life stages of spider mites selected for the present study. The predatory potential was found positively correlated with the developmental progression of the predatory life stages. The maximum predation rate was observed in the adult female stages of the predatory mites. They were recognised as the most voracious life stage of phytoseiid predators with regard to prey consumption rate. Adult female consumed more number of prey stages in their oviposition period (Blackwood *et al.* 2004). The adult female of *N. longispinosus* exhibited a remarkably very high feeding preference towards the egg stages of the spider mites, *T. urticae* and *T. macfarlanei* whereas, a low rate of consumption was noted towards other active life stages of the same prey species. The mean rate of egg

consumption could be recorded as 80% and 68% for *T. urticae* and *T. macfarlanei* respectively. The order of prey stage preference of adult female of *N. longispinosus* was identified in the decreasing order, Egg > Nymph > Larva > Adult for both the species of prey mites. Similar results were recorded for this predator feeding on varied lifestages of the vegetable spider mite, *T. neocaledonicus* with the mean rate of egg consumption being 48.4% (Jyothis & Ramani, 2019). The present observation supports the earlier findings (Blackwood *et al.*, 2001) suggesting the presence of effective mouth parts in the specialist predator *N. longispinosus* would be responsible for the considerably higher rate of consumption towards the egg stages of *T. urticae*. It is also found that the other specialists, *Phytoseiulus macropilis* and *P. persimilis* preferred eggs to larvae of *T. urticae*. The present investigation also disclosed the low rate of feeding exhibited by the adult female of *N. longispinosus* on different life stages of *O. biharensis*. However, the order of preference was found to be in the decreasing order, Nymph > Larva > Egg > Adult, as observed on *T. urticae* (Ibrahim and Palacio 1994) and *O. coffeae* (Rahman *et al.* 2012). Similarly, the predatory mites *N. womersleyi* (Ali *et al.*, 2011) and *Neoseiulus barkeri* (Jafari *et al.*, 2012) were also shown to consume more number of *T. macfarlanei* larve and *T. urticae* nymphal stages respectively. Likewise, Li *et al.* (2014) also reported a similar order of preference in *Neoseiulus californicus* to the active life stages of *Tetranychus cinnabarinus*. Contrary to this, the generalist phytoseiid predator, *Neoseiulus californicus* was found to express preference towards the eggs of *Tetranychus kanzawai* (Santoso & Iswella, 2013) and *T. urticae* (Blackwood *et al.*, 2001). At the same time, this predator also showed a more or less similar preference to both the eggs and larvae of *T. urticae* (Canlas *et al.*, 2006, Akyazi *et al.*, 2019). But Rahmani *et al.* (2016) and Rezaie *et al.* (2017) elucidated its feeding preference towards the immature stags of *T. urticae*. This suggests that, apart from the prey species/ life stage differences,

several other factors were also involved in determining the feeding preference of the predatory mites.

Adult females of *A. paraaerialis* exhibited significant variation in the feeding preference towards different species of spider mites. It was observed to devour more number of larvae of the spider mite pests, *T. urticae* and *O. biharensis* with the mean rate of consumption being 46% and 25.3% respectively. The order of prey stage preference was found to be Larva > Egg > Nymph > Adult towards *T. urticae* and Larvae > Nymph > Adult > Egg towards *O. biharensis*. Similar findings were already reported in other phytoseiids like, *Amblyseius tsugawai* (Yang *et al.*, 2019), *Amblyseius andersoni* (Blackwood *et al.*, 2001) and *Amblyseius swirskii* (Akyazi *et al.*, 2019) feeding on *T. urticae*. Similarly, when preying upon different life stages of *T. cinnabarinus*, *Amblyseius orientalis* preferred protonymphs over other stages (Zhang *et al.*, 2015). Contradictorily, Soleymani *et al.* (2016) and Grafton-Cardwell *et al.* (1997) observed a significantly high feeding rate of *A. swirskii* towards the eggs of *T. urticae* when presented with other life stages. Interestingly, during the present feeding experiments, adult females of *A. paraaerialis* displayed a considerably higher feeding rate towards all the life stages of *T. macfarlanei* with a strong preference to their eggs. This result suggests that, prey stage preference of *A. paraaerialis* varied with prey species and probably would be guided by various factors like, level nutritional value of individual prey stage, searching behaviour and hunger level of the predator (Sandness & McMurtry, 1970). The above observation coincides with the earlier findings on *A. tetranychivorous* and *A. indicus* when fed with varied life stages of *T. neocaledonicus* (Singh & Singh, 2018). Similar trend was noticed in *Amblyseius largoensis* also when offered with varied lifestages of the red palm mite, *Raoiella indica* (Carrillo & Pena, 2012).

The experimental studies to determine the prey stage preference of the adult female of *E. rhododendronis* disclosed a variation in feeding preference towards different life stages/ species of spider mite pests. The species exhibited strikingly high rate of feeding towards the nymph, egg and larvae stages of *T. urticae*. The corresponding mean consumption rates could be recorded as 52.6%, 46% and 33%. In contrast, earlier studies on *Euseius hibisci*, *Euseius andersoni* and *Euseius finlandicus* uncovered their feeding preference towards the larvae to eggs of *T. urticae* (Blackwood *et al.*, 2001). Adult females of *E. rhododendronis* also exhibited a strong preference to feed on the active life stages of other spider mite pests considered in the present study, especially the larvae of *T. macfarlanei* and nymph of *O. biharensis*. It was also observed that the adult females never attacked even a single egg stage of *O. biharensis* as reported earlier in the case of the phytoseiid predator, *Euseius stipulatus* preying up on *Panonychus citri* (Ferragut *et al.*, 1992). This may be due to the presence of thickened egg-shells of *Oligonychus* species as suggested by Rahman *et al.* (2012b). Similarly, Badii and McMurtry, (1984) reported preference of *E. stipulatus* towards the larvae of *Polyphagotarsonemus latus*. De Toledo *et al.*, (2013) also identified the egg stages of *Oligonychus ilicis* as the least preferred prey stage by adult female of *Euseius alatus*. On the other hand, the egg predation was found predominant in the adult females of *E. hibisci* (Badii *et al.*, 2004) and *Euseius concordis* (Costa *et al.*, 2014) on prey species like *T. urticae* and *Mononychellus tanajoa* respectively. At the same time, rate of feeding by *E. rhododendronis* adult female towards *T. macfarlanei* was found to be very low when compared to the other two pest species, thus expected to have a moderate and partial impact on biological control of the same pest.

In general, the predatory potential of immature life stages of predatory mites was found to be moderate when compared to the consumption rates of adult females.

However, the nymphal stages exhibited relatively higher rate of feeding than that of the larval stages and often, quite comparable to that of the adults. Usually, the larval phase of the predators is least efficient, perhaps due to the small size (Reis & Alves 1997a; Reis *et al.*, 1998). Since the lifestage duration is short for immature predators, their impact in biocontrol is poor, yet significant. The predatory potential of the predators under the study, showed a decrease in the sequence of Adult female > Nymph > Larva. The consumption rates of immature stages of the three species of phytoseiids studied, were found to be statistically significant at 0.01 level, towards different species/life stages of the prey mites. Results of feeding experiments disclosed that the nymph of *N. longispinosus* displayed a similar trend to that of their adult females when provided with varied life stages of *T. urticae*. It consumed a large share of *T. urticae* eggs provided (56.6%) and manifested significant preference in feeding towards the egg stages followed by larva, nymph and adult of the same prey species as reported in *N. longispinosus* feeding on *T. neocaledonicus* (Jyothis and Ramani, 2019) and *N. californicus* predating on *T. kanzawai* (Santoso & Iswella, 2013) and *T. urticae* (Rahmani *et al.*, 2016). On the other hand, a low rate of feeding was observed towards the life stages of other spider mite pests, viz. *T. macfarlanei* and *O. biharensis*. The predatory nymph showed a similar trend of prey stage preference comparable to that of their adult female where it preferred the larvae of *O. biharensis* and the eggs of *T. urticae* and *T. macfarlanei*. Similar feeding preference towards the larval stage over the eggs was reported in *N. longispinosus*, when consuming varied life stages of *Oligonychus coffeae* (Rahman *et al.*, 2013). The larvae of *N. longispinosus* were found to be non-feeding and usually exhibited a very short duration of development. This is in agreement with previous studies conducted by Ibrahim and Palacio (1994) and Sharma and Chauhan (2013). Several authors reported non-feeding larval stage in different phytoseiid species (Chant, 1959; Putman, 1962;

McMurtry & Scriven, 1964; Ma & Laing, 1973; Moraes & McMurtry, 1981). Shorter developmental period and lower searching efficiency of the larvae might be the reason for its non-feeding nature (Rao *et al.*, 2017).

The predatory nymph of *A. pararaerialis* was identified as a voracious feeder of *O. biharensis* and its rate of consumption was found to be higher than that of its adult females, with a marked preference towards the active lifestages. Similar preference in feeding was noted towards the spider mite species, *T. macfarlanei*. Zhang *et al.* (2000) reported much longer handling time and relatively low successful attack rate of nymphal stage in *A. cucumeris* against the adult stages of *Schizotetranychus nanjingensis*. When the predatory nymph of *A. pararaerialis* was provided with different developmental stages of *T. urticae*, its preference got changed to eggs over active lifestages as reported earlier in the case of *Iphiseiodes zuluagai* when feeding on varied developmental stages of *B. phoenicis* (Reis *et al.*, 2000). Similarly, predatory larvae preferred to feed more number of eggs of *T. urticae* and *T. macfarlanei*, whereas, displayed a significant feeding preference towards the active stage of *O. biharensis*, with low rate of consumption when compared to that of the adult female predator.

The mean rate of consumption of immature life stages of the phytoseiid, *E. rhododendronis* appeared comparable with the rate of feeding of immature stages of other predators included in the present study. As in the case of adult female, the nymph and larvae of *E. rhododendronis* were able to consume all the prey stages except the eggs of *O. biharensis*. The immature predatory stages displayed a similar order of preference towards varying stages of spider mite pests viz. *T. urticae*, *T. macfarlanei* and *O. biharensis*. They preferred to feed on the active stages of *T. urticae* and *O. biharensis*, whereas the preference was changed to the egg stage of the prey while predating life

stages of *T. macfarlanei*. A significant preference towards the larva and nymph of *B. phoenicis* (Reis *et al.*, 2000) and *O. ilicis* (DeToledo *et al.*, 2013) was reported on the immature life stages of *E. alatus*. The nymph of *E. rhododendronis* showed a maximum rate of feeding (25.3%) towards the eggs of *T. macfarlanei*. On the other hand, for the predatory larva the same could be recorded as 19.3% towards the larvae of *O. biharensis*.

As far as biological control is concerned, the preference of predators to prey eggs could be considered as desirable, as it would help in the eradication of pests even before attaining its injurious stage and thus regulating the pest population well below the economic threshold level. Since the spider mite eggs lay their eggs close together, the chances for prey contact also would be enhanced and subsequently would increase the success rate of predation. The higher feeding rate towards the egg stages might be due to their smaller size, immobility and low biomass. In order to compensate the nutritional requirement, the predator would have to devour more number of eggs. Moreover, the predators would often exhibit an innate tendency to attack the smaller prey. The defenceless nature and long duration (3-4 days) of pest mite eggs would facilitate the ease of predation (Ganjisaffar and Perring, 2015). It was also noted that, the egg chorion is easily penetrable, when compared to the hard and sclerotized cuticle of the active life stages (Perring *et al.*, 1984). The egg preference was found predominant in *N. longispinosus* while feeding on *T. urticae* and *T. macfarlanei*. Similar trend was reported earlier in other phytoseiids viz. *Amblyseius bibens* (Blommers & Etten 1975), *E. hibisci* (Badii *et al.*, 2004) and *Amblyseius fallacis* (Santos, 1975). The rate of consumption of the predatory mite decreased as the size of the prey increased (DeToledo *et al.*, 2013). In several instances, the predation rate was higher towards the larvae when compared to the nymph and adult stages as recorded in *A. andersoni* feeding on *P. ulmi* (Van de Vrie, 1974), *Amblyseius alstoniae* feeding on *Euseius orientalis* (Dhooria, 1981) and *A.*

swirskii feeding *T.urticae* (Xu and Enkegaard, 2010). The higher prey mobility and defensive mechanisms usually result in reduced encounter rate and attack success. Similarly, it would increase the handling time and result in low prey profitability (Zarghami *et al.*, 2014). Contrastingly, in some cases spider mite larva was found preferred over egg stages by phytoseiid predators like, *Typhlodromips pyri* (Zaher & Shehata, 1971), *Galendromus occidentalis* and *N. cucumeris* (Popov & Kondryakov., 2008) and *N. californicus* (Marafeli *et al.*, 2011; Rezaie *et al.*, 2017). In the present study, the eggs of *O. biharensis* were observed as the least attacked stage when compared to other spider mite eggs. This is probably due to the thickened chorion and concaved disc shape of *O. biharensis* eggs, which appeared to add geometrical stability from the attack of predatory mites, as observed in different mite species (Franco *et al.*, 2007; Kasap & Athihan, 2011). Additionally, Blackwood *et al.* (2001) suggested that larvae are nutritionally superior and less time-consuming to handle than the eggs of some spider mite pests. Regardless of the species differences, all the predatory life stages exhibited a diminished rate of feeding towards the spider mite adults, throughout the present laboratory feeding experiments. The larger size, rapid movement and the presence of hard exoskeleton might be the possible reasons for the low rate of predation towards adult stages of spider mites. This observation is in agreement with studies on *Iphiseius zuluagai*, *Euseius citrifolius* and *Amblyseius herbicolus* when offered with varying life stages of *O. ilicis* (Franco *et al.*, 2007).

Results of the present study clearly demonstrated that the phytoseiid predators viz. *N. longispinosus*, *A. parvaerialis* and *E. rhododendronis* could be used as biocontrol agents in spider mite pest management programmes. However, *N. longispinosus* was identified as the most efficient predator that helps to manage pest populations of *T. urticae* and *T. macfarlanei* by consuming lion share (68% - 80%) of the prey eggs

provided. Hence, this species is to be considered as the most efficient predator among the three species of phytoseiids studied and the release of the species is advisable during the early phase of mite infestation in the field. Contrastingly, *E. rhododendronis* devoured most of the active stages of *T. urticae* and displayed the highest total rate of consumption. This attribute can be exploited in biocontrol of *T. urticae* by field release of *E. rhododendronis* in the late stages of pest infestation. *Amblyseius paraaerialis* was recognised as an effective natural enemy of *T. urticae* and *T. macfarlanei* with the consumption rate being 30%. On the other hand, *E. rhododendronis* was found to be effective in predating pest population of *O. biharensis*. The present investigation thus unequivocally demonstrated the ability of the above three phytoseiids in controlling the population of the notorious agricultural pest, *T. urticae*.

Functional response studies further revealed the efficacy of adult females of *N. longispinosus* in controlling the populations of *T. urticae* and *T. macfarlanei*. Solomon (1949) defined functional response as the change in the number of prey killed per predator in response to a change in prey density. The functional response parameter describes the way in which a predator responds to the changing prey density (Holling, 1959). As the term functional response defines, *N. longispinosus* exhibited significant difference in feeding with respect to the change in egg densities of both pest species. The functional response in phytoseiid mites has been extensively studied by Everson, (1979), Sepúlveda and Carillo, (2008), Fantinou *et al.*, (2012), Kasap and Atlihan, (2011), Jafari *et al.*, (2012) and Seiedy *et al.*, (2012).

Holling (1959) identified three types of functional responses viz. type I, type II and type III. Among these, type II functional response is most common among arthropod predators (Akpodje *et al.*, 1990). Generally, the predators exhibiting type II and type

III functional responses were considered as efficient control agents. However, most of the predators currently employed in augmentative release as part of biocontrol programs have shown type II functional response on their prey (Xiao & Fadamiro, 2010). The present investigation disclosed a typical Holling type II functional response in adult females of *N. longispinosus* towards seven different egg densities of *T. urticae* and *T. macfarlanei* provided separately in the laboratory. The significant decline in consumption rate of the predator at higher prey density can be of satiation as suggested by Mills (1982). Type II functional response curve revealed that the female predator responded vigorously at lower egg densities of both the spider mite species, indicating that the predator would be more effective in controlling pest species at lower population densities, especially in the early phase of infestation as reported in *Neoseiulus womersleyi* predating on *T. macfarlanei* (Ali *et al.*, 2011). The type II functional response has also been reported for several phytoseiid mite species such as *E. hibisci*, *P. plumifer*, *Phytoseius persimilis*, *Chilaseius camposi*, *N. cucumeris*, *N. longispinosus*, *N. californicus*, *Typhlodromus bambusae* and *Typhlodromus bagdasarjani* feeding on different pest mites (Zhang *et al.*, 1998, 1999a, 1999b, 2000; Shirdel, 2003; Skirvin & Felon, 2003; Badii *et al.*, 2004; Gotoh *et al.*, 2004; Sepulveda & Carrillo, 2008; KouhjaniGorji *et al.*, 2009).

The attack rate (a) and handling time (T_h) are the parameters used to determine the magnitude of functional response (Pervez & Omkar, 2005) and it can be calculated by fitting data on to Holling's disc equation (Holling, 1959) followed by linear transformation according to Livdahl and Stiven, (1983). Fantinou *et al.* (2012) suggested that this transformation avoids the statistical problems associated with other transformation methods proposed by Royama (1970) and Rogers (1972). Functional response is affected by several factors like, temperature, humidity, type of host plant,

type of diet, age and lifestage of both prey and predatory species (Eveleigh & Chant, 1981; Wei & Walde, 1997; Doker *et al.*, 2016; Afshar & Latifi, 2017; Fathipour *et al.*, 2017; Rezaie *et al.*, 2017). The attack rate and handling time for the phytoseiid predator, *N. longispinosus* on the eggs of *T. urticae* were found to be 0.82 h^{-1} and 0.78 h respectively. On the other hand, a lower attack rate (0.74 h^{-1}) was recorded by the predatory female towards the eggs of *T. macfarlanei*. Predators with higher attack rate (a) and lower handling time (T_h) were considered as better biocontrol agents (Fathipour & Maleknia, 2016). Since the time for handling the prey was very short (0.43 h), the maximum predation rate ($K=T/T_h$) was found to be very high for the females of *N. longispinosus* attacking the eggs of *T. macfarlanei* and it could be recorded as 55.81 whereas the same could be identified as 32.43 towards *T. urticae* eggs. On the contrary, Song *et al.*, (2016) observed a lower attack rate (0.1196 h^{-1}) and higher handling time (1.3020 h) for *N. longispinosus* on the egg stage of *T. urticae*, with a reduced maximum predation rate (K) of 18.43 . Similarly, lower value for maximum predation rate was recorded in *T. bagdasarjani* (Farazmand *et al.*, 2012), *Cydnodromus picanus* (Tello-Mercado *et al.*, 2017), *N. californicus* and *N. cucumeris* (Zheng *et al.*, 2017). Earlier studies revealed comparable results in other phytoseiids predating the eggs of *T. urticae* with corresponding attack rate and handling time of 0.0375 h^{-1} 0.69 h in *E. finlandicus* (Shirdel, 2003) 1.452 day^{-1} 0.061 day in *Kampimodromus aberrans* (Kasap & Atlihan, 2011) 0.0936 h^{-1} 1.64 h in *N. californicus* (Farazmand *et al.*, 2012) 0.054 h^{-1} , 0.70 h in *A. swirskii*, 0.120 h^{-1} 2.51 h in *P. persimilis*, and 0.058 h^{-1} 0.580 h in *N. barkeri* (Maleknia *et al.*, 2015). When comparing the functional response parameters for phytoseiid predators reported previously, the results of the present study disclosed a higher attack rate for *N. longispinosus* feeding on the eggs of both *T. urticae* and *T. macfarlanei*. However, higher attack rates of 0.935 h^{-1} and 0.813 h^{-1} were reported in *N. californicus*

(Landeros *et al.*, 2013) and *E. hibisci* (Badii *et al.*, 2004) respectively, predating the eggs of the two spotted spider mite. In the present study, the effectiveness of predation (a/T_h) was calculated to be higher on *T. macraflanei* (1.18) and slightly lower towards *T. urticae* (1.10). In the case of female predator of *C. picanus*, the value for the above parameter was observed to be very low (0.080) towards the eggs of *T. urticae* (Tello-Mercado *et al.*, 2017).

Based on the results of feeding experiments, *A. paraaerialis* was identified as one of the most potent predatory species that would help in the control of spider mite pests. Considering the scanty information available on the food range as well as mass rearing possibilities of the type III species like *A. paraaerialis* included in the present study, an attempt was made to explore the mass rearing possibilities of the species by offering alternative food items like honey, castor pollen, honey-pollen mixture as well as spider mite pests, so as to collect data on the developmental durations of individual instars of the species. Results of laboratory observations on the breeding biology revealed pseudo-arrhenotokous pattern of development in *A. paraaerialis*. This parahaploid condition is considered to be most common among Phytoseiidae (Schulten, 1985). The sex ratio was found significantly female biased and the number of female individuals was three to four times greater than that of the male individuals, which is quite advantageous for the successful exploitation of the species in IPM (Integrated Pest Management). Sex ratio is considered as an important parameter as far as biological control using natural enemies is concerned. This is because of the fact that, the growth of natural enemy population is positively correlated to the frequency of females in the population (Waage, 1992). Frequent mating was found very essential for the reproductive success and this was evident in the present study also as multiple copulations were observed in *A. paraaerialis*. Thus the present finding seems to support the earlier reports on other species like

Amblyseius umbraticus (Kinsley & Swift, 1971), *Amblyseius brazilli* (El Banhawy, 1975), *A. swirskii* (Momen & El Saway, 1993) and *A. barkeri* (Momen, 1995). The mating behaviour of *A. paraaerialis* was found to be more or less similar, and closely following that of other members of the genus *Amblyseius* (El Banhawy, 1975; Amano and Chant, 1978 a, b).

The life cycle of *A. paraaerialis* was found to include various stages like the egg, larva, protonymph, deutonymph, and the adult, with intermediate quiescent stages. However, the qualitative variation in feeding habits was reported to exert significant alterations in the developmental duration, rate of development, fecundity, survival etc in phytoseiid mites (Sharma & Sadana, 1989; Elbanhawy *et al.*, 2000). According to the life style classification (McMurtry & Croft, 1997; McMurtry *et al.*, 2013), Type III and Type IV categories of predators would take the advantage of plant derived nutrients viz. floral nectar, extra-floral exudates, pearl bodies and most importantly the pollen grains of several plants for their survival. Pollen improves the overall growth and development, rate of predation and thereby enabling survival during periods of prey scarcity of phytoseiid predators (Gerson *et al.*, 2003). Moreover, the alternative diet is very important in decreasing starvation of predatory mites and preventing subsequent escape of the same (Nguyen & Shih, 2010).

The present study demonstrated that the predatory mite, *A. paraaerialis* could complete its life history on a diet consisting of mixed stages of *T. urticae*. Furthermore, results of the present study also disclosed the astonishing potential of the alternative diet comprising a mixture of pollen grains of the medicinal plant, *Ricinus communis* and honey in rearing and maintenance of population of the Type III predator, *A. paraaerialis* in the laboratory conditions of $30 \pm 2^{\circ}\text{C}$ and $70 \pm 5\%$ RH. *A. paraaerialis* could

successfully complete its lifecycle solely on this diet combination and at the same time was proved unsuccessful when pollen and honey were presented separately. On the contrary, castor pollen alone supported the development of other phytoseiids in the same genus like, *A. brazili* (El Banhawy, 1975) and *Amblyseius sojaensis* (Osakabe *et al.*, 1986). Excepting the incubation period, all other life stages of the predator developed faster on the alternative diet of honey-pollen mixture than the natural diet, *T. urticae*. No significant difference was noted in the incubation period, with varied food items. Contrastingly, *A. swirskii* exhibited variations in the incubation period with respect to differences in food items (Momen & El Saway 1993). A shortest developmental duration of 102.3 ± 2.8 hours (4.25 days) was recorded for *A. parvaerialis* when reared on honey-pollen mixture whereas, a longer developmental duration of 112.0 ± 2.2 hours (4.66 days) was observed when fed with mixed life stages of *T. urticae*. However, the total developmental duration of the immature stages of *A. andersoni* was observed to be 6.60 days, 5.53 days, 5.29 days and 4.89 days when fed with *T. urticae* (Genini *et al.*, 1991), *P. ulmi*, *Eotetranychus carpini* and *Calepitrimerus vitis* (Duso & Camporese, 1991) respectively whereas, a short duration of 4.60 days was recorded when supplied with *Mesembryanthemum criniflorum* pollen. Parallel with the above observation, successful development was observed in several other phytoseiid species viz. *E. stipulatus* (5.50 days) and *T. phialatus* (8.80 days) feeding on *Carpobrotus edulis* pollen (Ferragut *et al.*, 1987), *T. pyri* on *M. criniflorum* pollen (7.08 days) (Duso & Camporese, 1991), *E. finlandicus* reared on *Prunus avium* pollen (6.09 days), and *Juglans regia* pollen (6.62 days) (Broufas & Koveos, 2000), *Euseius ovalis* reared on Cucumber pollen (5.40) (Pai & Shih, 2002), *Typhlodromalus aripo* on Maize pollen (6.9 days) and *Leucaena* pollen (8.6 days) (Gnanvossou *et al.*, 2005), *N. baraki* on coconut pollen (7.70 days) (Domingos *et al.*, 2010). Nguyen and Shih, (2010) found a longer duration of development for *N.*

womersleyi and *E. ovalis* when reared on Maize (*Zea mays*) pollen and Chinese loofah (*Luffa acutangula*) pollen than on spider mite diet.

A significant variation was also noted in the durations of pre-oviposition, oviposition, post-oviposition periods as well as longevity of the adult females of *A. paraaerialis* with respect to changes in food type. The duration of oviposition period of predatory mites is a criterion which determines the population dynamics of the species and it is highly significant in the field of biological control. Higher longevity and longer oviposition period would ensure production of more number of eggs and thereby increasing the chances of survival of the species in its habitat. The pre-oviposition and oviposition periods of the predator was found shorter when it was reared on alternative diet. Such kinds of differences in pre-oviposition, oviposition, post-oviposition and adult longevity with respect to changes in food type was already reported in other predatory species also like *N. californicus* (Gotoh & Tsuchiya, 2009; Sarwar *et al.*, 2009), *Amblyseius scutalis* and *A. swirskii* (El-laithy & Fouly, 1992) feeding on *T. urticae*. A total of 19.3 ± 0.3 days were recorded as the oviposition period for *A. paraaerialis* when fed on a diet comprised of mixed stages of *T. urticae*. At the same time, a reduction in the oviposition period (16.5 ± 0.4 days) was noticed when the predator was offered with honey-pollen mixture. Regardless of the short oviposition period, adult females exhibited a remarkable increase in the post-oviposition period and a subsequent higher longevity (29.6 ± 0.9) when supplied with alternative diet. The oviposition period of *N. womersleyi* was short on maize and Chinese loofah pollen whereas it was longer on spider mites, *T. urticae*, *T. kanzawai*, and *P. citri*. Contradictory to this, *E. ovalis* exhibited a longer oviposition period on varied diets on *T. urticae*, *T. kanzawai*, and *P. citri* (Nguyen & Shih, 2010). Similarly, a comparable oviposition period of 16.06 ± 1.8 days and a lower adult longevity of 23.20 ± 1.74 days were noted in *Cydnoseius negevi* when fed with date

palm pollen at $60 \pm 5\%$ RH and 30 ± 2 °C. (Alatawi *et al.*, 2018c). A significant hike in oviposition period was observed in *N. californicus* on the alternative diet comprising a mixture of honey, sucrose, tryptone, yeast extract, egg yolk, distilled water and maize pollen (20%) (Khanamani *et al.*, 2017). Yazdanpanah *et al.*, (2021) reported huge variation in adult longevity of *N. cucumeris* as 6.88 days on maize pollen to 60.4 days on castor bean pollen. Results of the present study thus exposed the possibilities for laboratory mass rearing of *A. paraaerialis* for the purpose of augmentative release of the predator in to the fields showing spider mite infestation. However, prior to field release, in depth studies are warranted on the behavioural aspects of the predator, impact of climatic factors on the predator population, natural enemy complex operating in the field etc.

CHAPTER VI

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Phytophagous mites cause considerable levels of damage and heavy yield loss in a wide spectrum of economically important plant species around the globe and hence are considered as potential pests. Tetranychidae, Tenuipalpidae, Tarsonemidae and Eriophyidae are the most common families of phytophagous mites that are extremely injurious to leafy vegetables and fruit crops. Among these, the most diverse and highly polyphagous species belong to the family Tetranychidae and are commonly called as the spider mites. Conventional methods of pest control through chemical pesticides pose a severe threat to the environment. Apart from environmental pollution, chemical pesticides have been reported to induce development of pesticide resistance in various arthropod pests, including the spider mites. This, in fact has much reduced the popularity and usefulness of chemical pesticides in the past few decades. In this context, biological control, owing to their efficacy, environmental safety as well as reduced health hazards has gained much recognition as a substitute to chemical pesticides, in controlling arthropod pests, especially the spider mites. Among the various natural enemies, predatory mites of the family Phytoseiidae are widely used as effective biological control agents against phytophagous mites and other small insects like thrips, mealy bugs, whiteflies and scale insects. The family phytoseiidae are cosmopolitan in distribution and presently includes 2400 species. These mites possess most of the desirable attributes required for typical biocontrol agents like the extreme prey specificity, lower handling time, high fecundity with short developmental duration compared to the prey species, superior searching ability and increased dispersal rate etc. Moreover, their ability to thrive on alternative diets makes them a plausible biocontrol candidate for managing spider mite populations. Proper understanding of predator-prey interactions is a prerequisite for any pest control programme. Duly considering the

above, the present study was designed to locate the most common and widely distributed species of phytoseiid mites associated with the most injurious species of pest mites infesting selected species of vegetables and fruit crops grown in North Kerala. Simultaneously, attempts were also made to evaluate the predatory habit and rate of predation of phytoseiid mites. In addition, the functional response parameters were also assessed. Attention was also focused to explore the mass rearing possibilities of a generalist phytoseiid predator included in the study.

During the present study, surveys were carried out to locate and identify the most common and widely distributed species of pest mites and associated phytoseiid predatory mites inhabiting on 16 species of host plants comprising leafy vegetables and fruit crops viz. *Vigna unguiculata*, *Amaranthus viridis*, *Amaranthus tricolour*, *Moringa oleifera*, *Murraya koenigii*, *Cucurbita maxima*, *Colocasia esculenta*, *Psidium guajava*, *Carica papaya*, *Achras sapota*, *Mangifera indica*, *Artocarpus heterophyllus*, *Artocarpus hirsutus*, *Syzigium aquem*, *Morus alba* and *Citrus limon*. The results of the survey revealed the presence of 20 species of phytophagous mites belonging to three superfamilies viz. Tetranychoidae, Tarsonemoidea and Eriophyoidea and five families viz. Tetranychidae, Tenuipalpidae, Tarsonemidae, Eriophyidae and Diptilomiopidae. The generic diversity was found maximum in Tetranychidae (40%) followed by Tenuipalpidae (20%), Eriophyidae (20%) Diptilomiopidae (10%) and Tarsonemidae (10%). The various genera of phytophagous mites recovered during the study could be arranged in the decreasing order, *Tetranychus* > *Eutetranychus* = *Tenuipalpus* > *Polyphagotarsonemus* > *Oligonychus* = *Schizotetranychus* = *Brevipalpus* = *Aceria* = *Cisaberoptus*=*Diptilomiopus* based on their species diversity. The species diversity of the various families of phytophagous mites recovered during the study could be presented in the sequence as Tetranychidae (55%) > Tenuipalpidae (20%)>

Tarsonemidae (10%) = Eriophyidae (10%) > Diptilomiopidae (5%). Among the 20 species of phytophagous mites collected during the present study, *Tetranychus urticae* was identified as the highly polyphagous species in the family Tetranychidae with a host range of 7 plant species surveyed viz. *V. unguiculata*, *A. blitum*, *A. cruentus*, *M. oleifera*, *C. papaya*, *A. sapota* and *C. esculenta*. Similarly, *Brevipalpus phoenicis* was found to have broad host range among tenuipalpid mites. On the other hand, pest species identified under the families viz. Eriophyidae, Tarsonemidae and Diptilomiopidae were appeared to be monophagous.

A total of 17 species belonging to 6 genera of predatory mites were collected under the family Phytoseiidae, from the leafy vegetables and fruit crops screened during the study. The species diversity observed under the various genera could be presented as *Amblyseius* (52.9%), *Euseius* (17.6%), *Typhlodromips* (11.7%), *Neoseiulus* (5.8%), *Typhlodromus* (5.8%) and *Paraphytoseius* (5.8%). The predatory species, *Amblyseius largoensis* was identified as the most widely distributed species with the maximum host range. The results of the study disclosed *A. paraaerialis* as a common species associated with both the mite and insect pests and thereby proving its potential as a broad spectrum biocontrol agent in the agricultural fields. However, its population was found to be comparatively lower in the field. On the other hand, another phytoseiid predator viz. *Neoseiulus longispinosus* was observed to be distributed in every prey patch with high population density, thereby reflecting its extraordinary dispersal ability. During the study, the association of another predator, *Euseius rhododendronis* was also observed with pest mites viz. *T. urticae*, *T. macfarlanei*, *O. biharensis* and *B. phoenicis*. In the field, these mites devoured different life stages of pest mites, especially the active stages of spider mites.

Based on the results of field surveys, three species of spider mite pests viz. *T.urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* were selected as the test prey mites for subsequent feeding experiments under laboratory conditions. The species selection was done duly considering their dominant distribution on the host plants and the common availability for making regular observation. Similarly, three species of phytoseiid predators viz. *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* were selected as the test species of predators, representing the respective feeding categories such as Type II, Type III and Type IV predators, for detailed studies concerned with the evaluation of predatory potential.

The results of qualitative assessment of the predatory potential of selected species of phytoseiid mites enabled to understand various aspects of predation such as the prey capturing habit, mode of attack, mode of consumption, feeding preference, dispersal and subsequent colonisation to new habitat. Chelicerae, pedipalp and the first pair of legs were found to play cardinal roles in identifying, capturing and handling the prey. The predators were observed to pierce the cuticle/egg shell of prey mites with the help of their chelicerae and the contents were sucked up using the suction force created by their pharyngeal muscles. The time required for devouring a single prey life stage was recorded as 2 - 4 minutes for eggs and 4 - 10 minutes for active life stages. The results of the study enabled to confirm the predatory habit of the three species, *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* and their inclusion in the Type II, Type III and Type IV categories respectively. Dispersal of predatory mites was found triggered by a decrease in the prey density and subsequent starvation. It resulted in random movement, and increased walking speed in *N. longispinosus* whereas, *A. paraaerialis* and *E. rhododendronis* exhibited low dispersal activity.

Predatory mite life stages exhibited a significant difference in the mean rate of consumption on the various life stages of the selected species of spider mite pests. The predatory potential was found increased as the development got progressed. Consequently, the maximum rate of predation was exhibited by the adult female stages of the predatory mites and they were proved to be the voracious feeders of spider mites, probably due to their high nutrient requirement, for oviposition. The predatory potential of the predatory life stages decreased in the order: Adult female > Nymph > Larva. The larval phase of the predators was the least efficient feeder, perhaps due to their small size and low metabolic activity. Results of feeding experiments also helped to identify the most potent predator, with the highest percentage consumption in controlling the individual life stages of the spider mite pests considered for the study. The adult female of *N. longispinosus* was identified as the efficient predatory life stage which devoured 80% of the eggs of *T. urticae* and 68% of *T. macfarlanei* eggs, within a period of 24 hours. This indicated that the above predator would be more effective in controlling *T. urticae* and *T. macfarlanei* populations during the early stages of infestation. Strong preference of the predator to feed on the egg stage would be advantageous in pest management, as it would help in the eradication of pests even before it attains the injurious stage. While comparing the total consumption rates of the adult females of the three species of predatory mites on the prey mite, *T. urticae*, it was observed that *E. rhododendronis* had a significantly higher feeding rate of 36.1%. Its feeding potential was comparatively greater towards *O. biharensis* with a total consumption rate of 21.9%, thereby revealing the unique ability of the predator to control the above sporadic pest. Similarly, adult females of *A. paraaerialis* exhibited an incredible performance in consuming the life stages of both *T. urticae* and *T. macfarlanei*, with the total consumption rates of 31.4% and 31.5% respectively. Regardless of the species

differences, both the adult and immature stages of *A. paraaerialis* preferred to feed on the active immature stages of the pest mites provided.

The nymph of *N. longispinosus* consumed more number of individual life stages of *T.urticae*, with the total consumption rate being 21.8%, which constituted the highest rate of predation observed among the immature stages of the phytoseiid predators considered for the present study. While considering the total consumption rates of the larval stages of the phytoseiid predators studied, it was observed that *E. rhododendronis* consumed the greater number of individual stages of *T. urticae* with the total consumption rate being 8.7%. On the contrary, larvae of *A. paraaerialis* consumed more number of individual life stages of both the prey species viz. *T. macfarlanei* and *O. biharensis*, with the corresponding consumption rates of 12% and 10.6% respectively. On the other hand, the larvae of *N. longispinosus* though appeared active, were proved to be a non-feeding stage.

The functional response of adult female *N. longispinosus* towards the seven different egg densities of *T. urticae* and *T. macfarlanei* were found to follow the Holling's type II model, thereby emphasising its potential in controlling respective spider mite species, especially at prey density. In general, biocontrol programmes make use of predatory species that exhibits type II and type III functional response. The significant decline in consumption rate of the predator at higher prey density can be considered to reach a satiation limit. Functional response parameters such as the attack rate (a) and handling time (T_h) were calculated during the study, by fitting the data on to Holling's disc equation followed by linear transformation method. These parameters serve as the indicators of predation efficiency. Predators with higher attack rate and lower handling time are considered as better biocontrol agents. *Neoseiulus longispinosus* displayed a higher attack rate (0.82 h^{-1}) towards the eggs of *T. urticae*, whereas a short handling time

could be calculated towards the eggs of *T. macfarlanei* (0.43 h). Since the time for handling the prey was very short, the maximum predation rate (K) was found to be very high for the females of *N. longispinosus* attacking eggs of *T. macfarlanei* and it could be recorded as 55.81 whereas the same could be identified as 32.43 towards *T. urticae* eggs. Similarly, a higher value for the effectiveness of predation (a/T_h) was calculated on *T. macfarlanei* (1.18) and was found slightly lower towards *T. urticae* (1.10). All the functional response parameters elucidated during the present study helped to reaffirm the potentiality of *N. longispinosus* in regulating spider mite population within a short period of time.

Predatory mites belonging to the Type III lifestyle category are capable of feeding and reproducing on varied alternative food items, including plant derived resources like, floral nectar, extra-floral exudates, pearl bodies and pollen grains of several plants. This life style reduces the risk of starvation in predatory mites to a considerable extent. Among the three phytoseiid species focused in the present study, *A. paraaerialis* was identified as the generalist feeder with a great affinity towards the spider mite pests, *T. urticae* and *T. macfarlanei*. This prompted to explore its mass rearing possibilities through a comparative study on the postembryonic development of *A. paraaerialis* on various alternative diets like castor pollen (*Ricinus communis*), honey, honey – pollen mixture and the natural diet comprised of the mixed life stages of spider mite pest, *T. urticae* under the laboratory conditions of $30 \pm 2^\circ\text{C}$ and $70 \pm 5\%$ RH. The sex ratio in *A. paraaerialis* was observed to be strictly female biased and the number of female individuals was three to four times greater than that of the male individuals, which is a desirable quality as far as the IPM (Integrated Pest Management) is concerned. The predator failed to complete its development when the honey and pollen provided separately but was successful to develop on honey-pollen mixture and the

natural prey *T. urticae*. The incubation period of *A. paraaerialis* showed no significant variation with respect to the difference in food items provided. Immature life stages developed faster on the alternative diet (102.3 ± 2.8 hours) than on *T. urticae* (112.0 ± 2.2 hours). A significant variation was observed in the durations of pre-oviposition, oviposition and post-oviposition periods as well as longevity of the adult predator, *A. paraaerialis* with respect to the changes in type of food consumed. On a diet of honey-pollen mixture, the adult female of *A. paraaerialis* completed its pre-oviposition period and laid eggs early when compared to the corresponding duration when it was reared on a diet of the prey mite, *T. urticae*. The oviposition period of the predator was found maximum when fed on a diet comprised of mixed life stages of *T. urticae*. The females of *A. paraaerialis* when reared on castor pollen-honey mixture, disclosed a longer duration of post-oviposition period rather than those fed with the pest mite, *T. urticae*. The longevity was observed to be higher when the predator was reared on the alternative diet comprised of honey-pollen mixture.

The results of the present study further provide insights into the biological control ecology of phytoseiid predators inhabiting the leafy vegetables and fruit crops. The results of studies carried out on the prey stage preference and functional response parameters indicated that augmentative release of *N. longispinosus* and *A. paraaerialis* should be done early in the season when the prey density is low, for getting effective control of populations of *T. urticae* and *T. macfarlanei*. Contrastingly, *E. rhododendronis* has to be released in the late stages of pest infestation, as it preferred to devour more active stages of *T. urticae* and *O. biharensis*. Conclusively, the present study revealed for the first time, the exceptional predatory potential of *A. paraaerialis* towards the life stages of spider mite pests and its ability to develop and reproduce on the alternative test food item. Furthermore, the present investigation expanded the current

knowledge in mass rearing of beneficial predators under controlled laboratory conditions. In a nutshell, the current investigation helped to demonstrate that the phytoseiid predators viz. *N. longispinosus*, *A. paraaerialis* and *E. rhododendronis* have the potential to be rated as promising biocontrol agents against the spider mite pests viz. *T. urticae*, *T. macfarlanei* and *O. biharensis*. However, further studies under field or semi-field conditions are required to validate the effectiveness of the above predators in controlling pest populations in the open field conditions/ agro-ecosystems.

CHAPTER VII

RECOMMENDATIONS

RECOMMENDATIONS

Alarming increase in pest outbreaks during the past few decades and the subsequent heavy yield loss in agricultural crop production jeopardised the world food security. Even though, the modern engineering and sophisticated technologies transformed the traditional agricultural practices into smart farming, the threat of pest outbreak is still baffling our modern world. Apart from the conventional chemical pest control measures, exploitation of natural enemies as biological control agents in IPM (Integrated Pest Management) appeared to be a promising way to subdue agricultural pest populations, well below the economic injury level. In this context the present study dealing with the identification, evaluation and exploration of predatory potential, prey stage preference, functional response and mass rearing possibilities of phytoseiid predatory mites associated with spider mite pests infesting leafy vegetables and fruit crops seems to be most appropriate to satisfy the need of the hour.

The present investigation unequivocally proved the efficacy of three species of phytoseiid predatory mites viz. *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* in subduing the populations of three common and widely distributed spider mite pests like *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* under laboratory conditions. The present study would recommend the augmentative release of *N. longispinosus* and *A. paraaerialis* during the initial stages of spider mite infestation as it exhibited a striking feeding preference to the egg stages of spider mites. On the other hand, *E. rhododendronis* exhibited a strong preference in feeding towards the active life stages of spider mite pests and are recommended to be released during the later stages of pest attack. However, in order to validate the present results, more detailed studies are needed in the semi-field or field

conditions so as to assess the factors affecting the predatory efficacy in relation to more complex real-field conditions. Furthermore, studies concerned with the assessment of numerical response and life table parameters of all species of phytoseiid predators are also welcome to enrich the existing knowledge in biological pest control programmes using acarine predators.

A cost effective rearing method for the mass production of biological control agent is very essential in any biocontrol programme. Usually, three trophic levels (natural enemy, prey species and its host plant) have to be maintained simultaneously in a facility to ensure the survival of the natural enemy population. But, maintaining three trophic levels at a time gives rise to high-cost associated with space and labour. However, the cost effectiveness in mass rearing of phytoseiid predatory mites can be achieved by rearing them on an artificial diet, thereby eliminating the two other trophic levels. The present study very clearly revealed the mass rearing possibilities of *A. paraaerialis* on the artificial diet comprised of honey-pollen mixture in the laboratory conditions. Further research is needed for the quantitative assessment of nutritional quality of honey-pollen mixture and also to identify other suitable alternative diets to ensure the constant supply of laboratory reared phytoseiid predators for facilitating their augmentative release. In short, the present investigation has opened up new avenues in acarine pest management using phytoseiid predatory mites.

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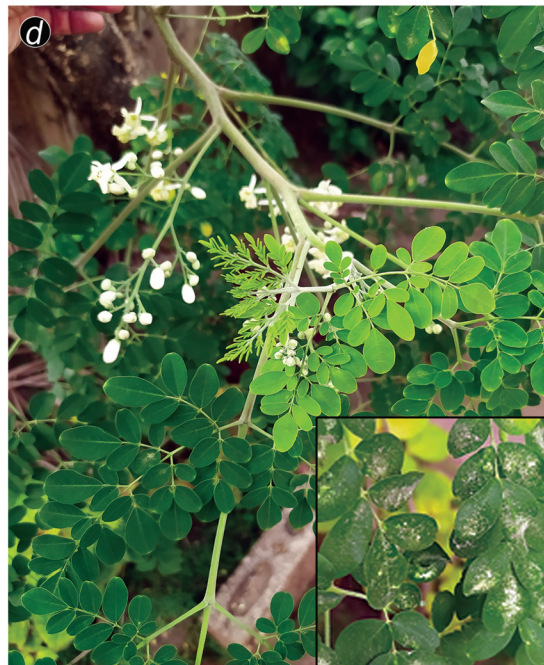
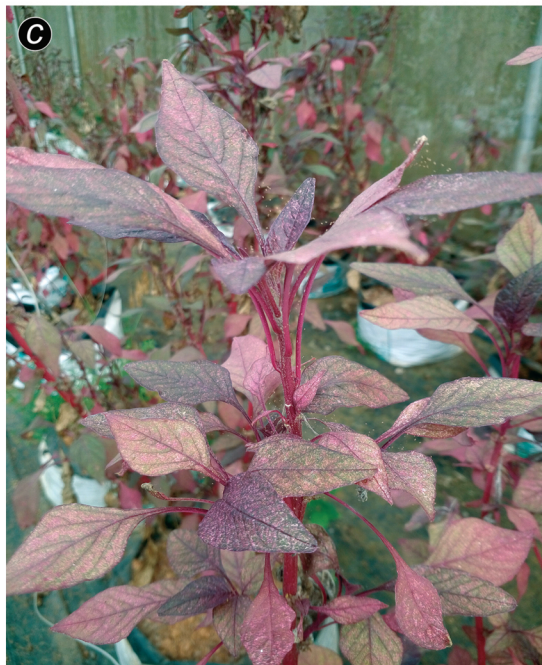
PLATE 1

MAP OF KERALA SHOWING COLLECTION SITES



PLATE 2

Host plants surveyed



a. *Vigna unguiculata*; **b.** *Amaranthus blitum*; **c.** *Amaranthus cruentus*;
d. *Moringa oleifera*

PLATE 3
Host plants surveyed



a. *Murraya koenigii* ; b. *Cucurbita maxima*; c. *Colocasia esculenta* ; d. *Psidium guajava*

PLATE 4

Host plants surveyed



a. *Carica papaya* ; b. *Achras sapota*; c. *Mangifera indica* ;
d. *Artocarpus heterophyllus*

PLATE 5

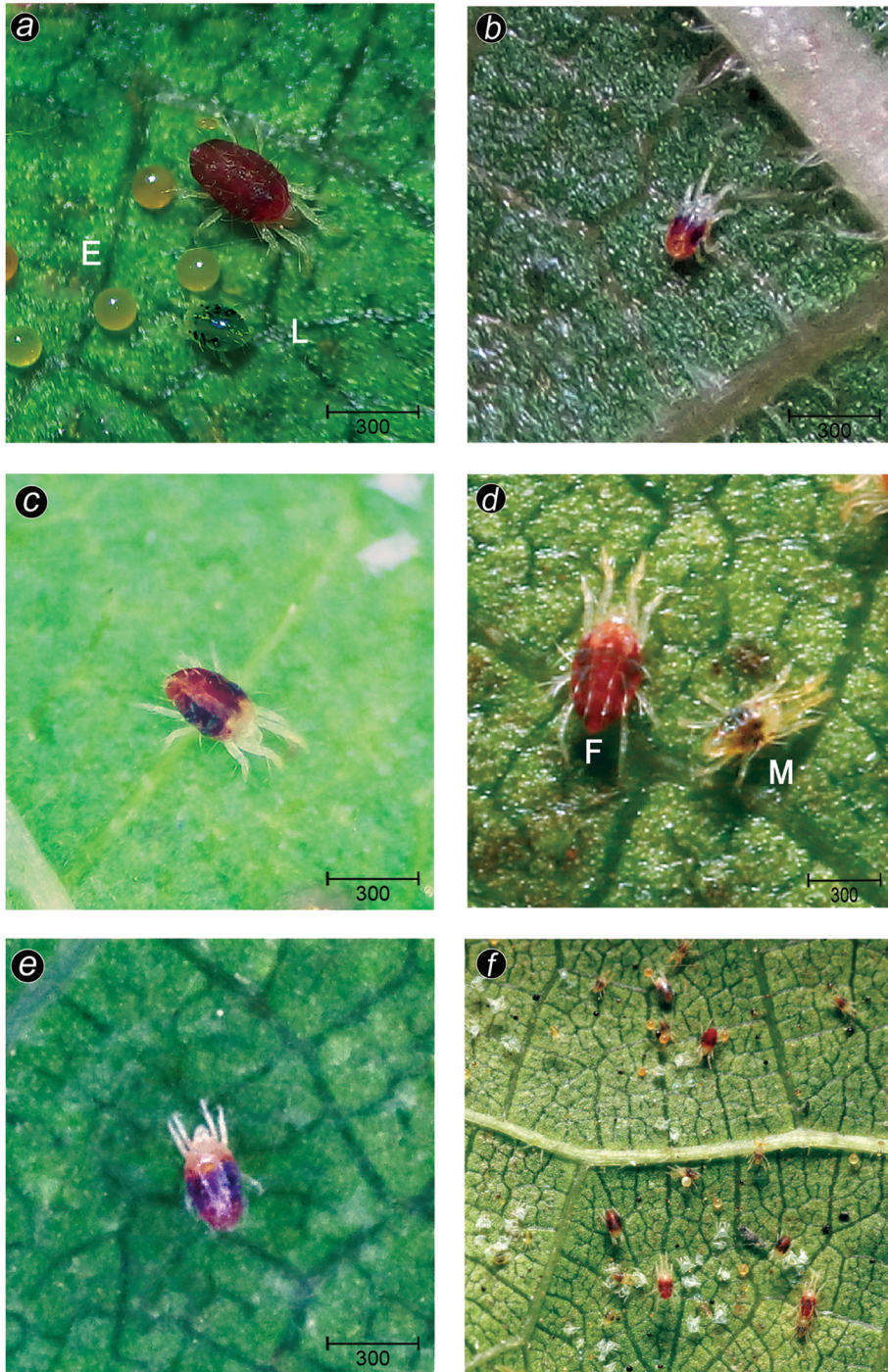
Host plants surveyed



a. *Artocarpus hirsutus* ; b. *Syzygium aqueum*; c. *Morus alba* ;
d. *Citrus limon*

PLATE 6

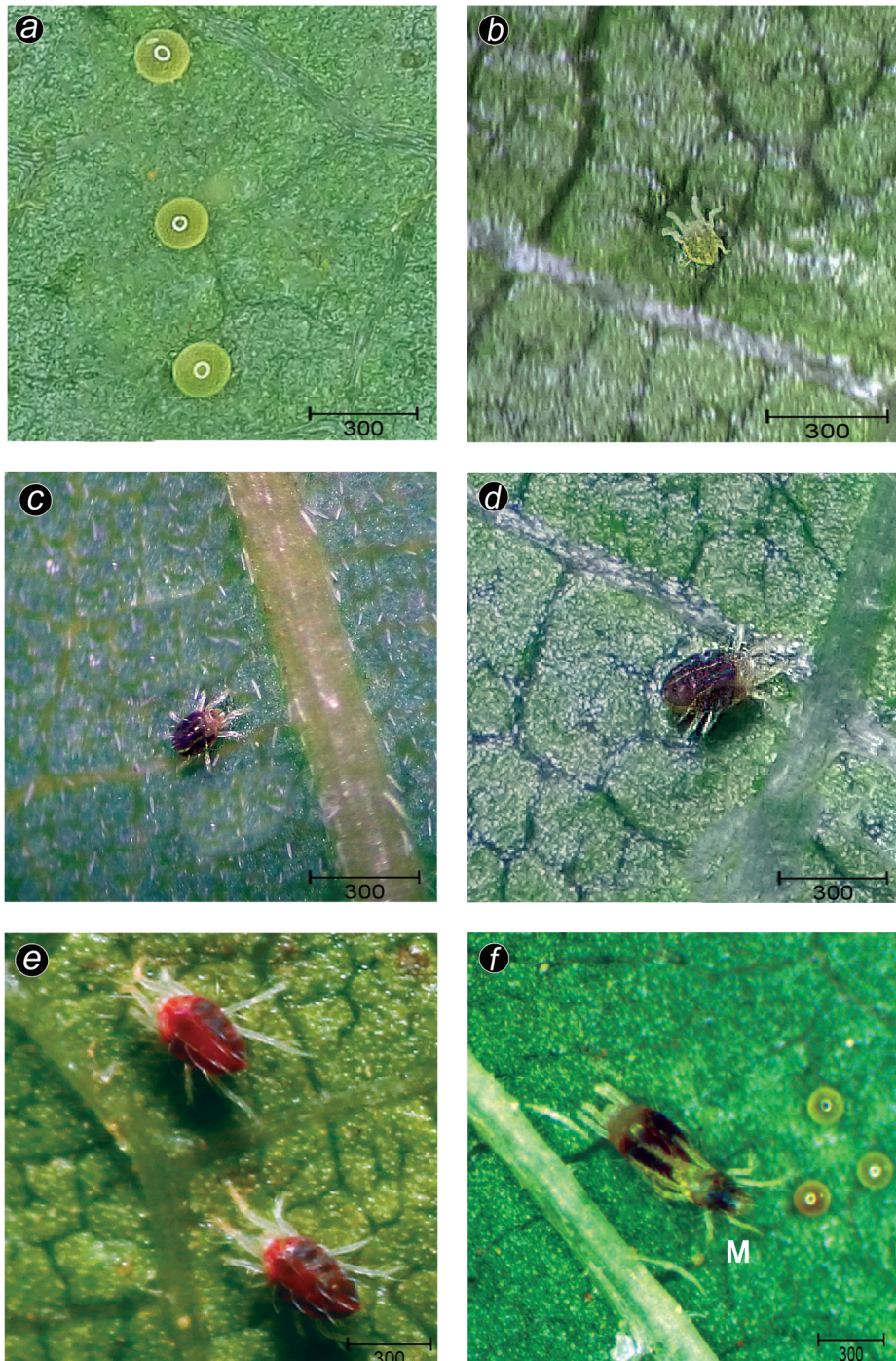
Developmental stages of *Tetranychus urticae*



a. Egg (E) and Larva (L); **b.** Protonymph; **c.** Deutonymph;
d. Adult male (M) and female (F); **e.** Quiescent stage (Q);
f. Colony of *T. urticae*

PLATE 7

Developmental stages of *Tetranychus macfarlanei*



a. Egg; **b.** Larva; **c.** Protonymph; **d.** Deutonymph;
e. Adult female; **f.** Adult male (M) guarding female
teliochrysalis stage.

PLATE 8

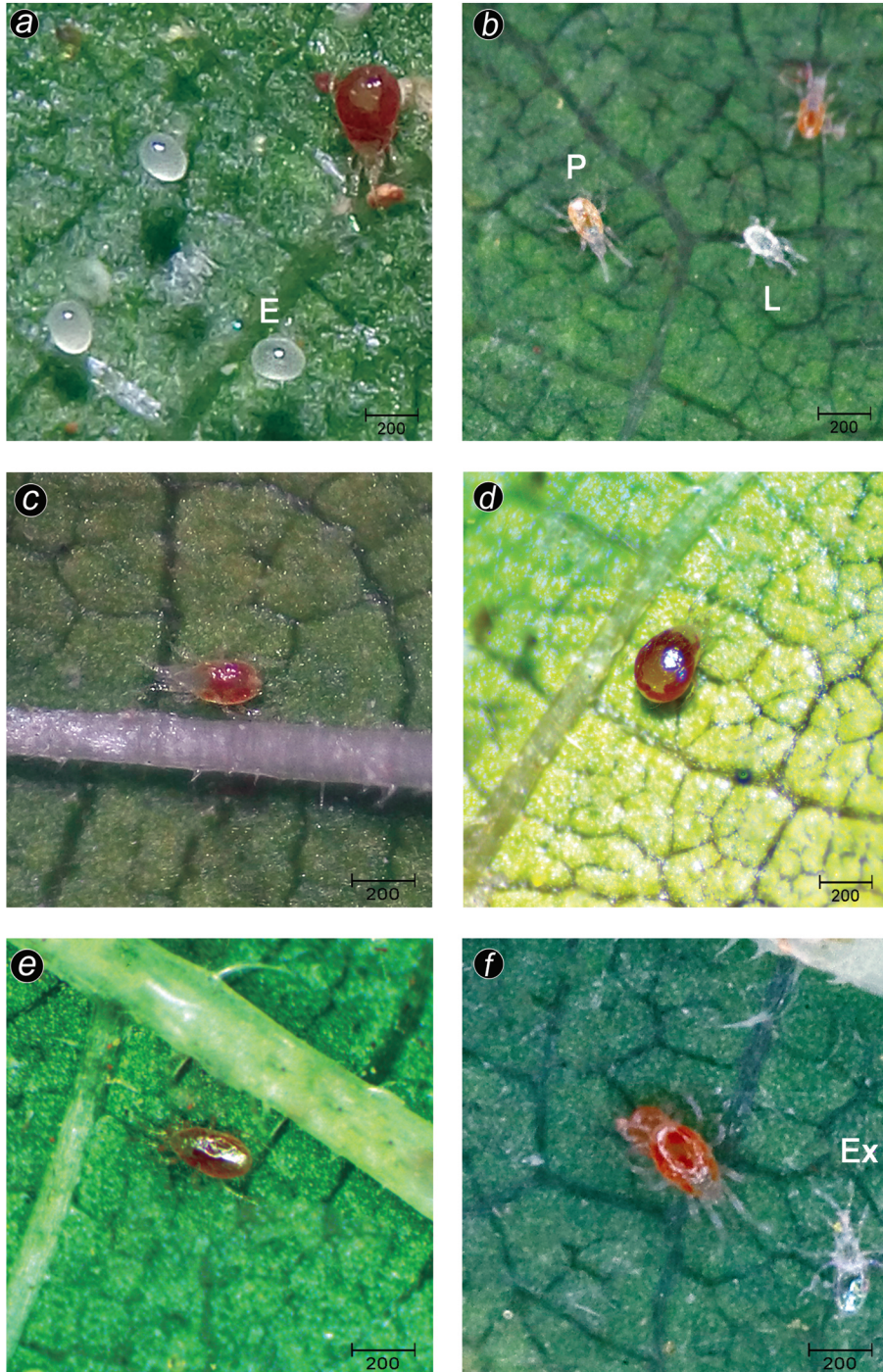
Developmental stages of *Oligonychus biharensis*



a. Egg; **b.** Larva; **c.** Protonymph (P), Deutonymph (D) and Quiescent stage (Q); **d.** Adult female; **e.** Adult male; **f.** Mating

PLATE 9

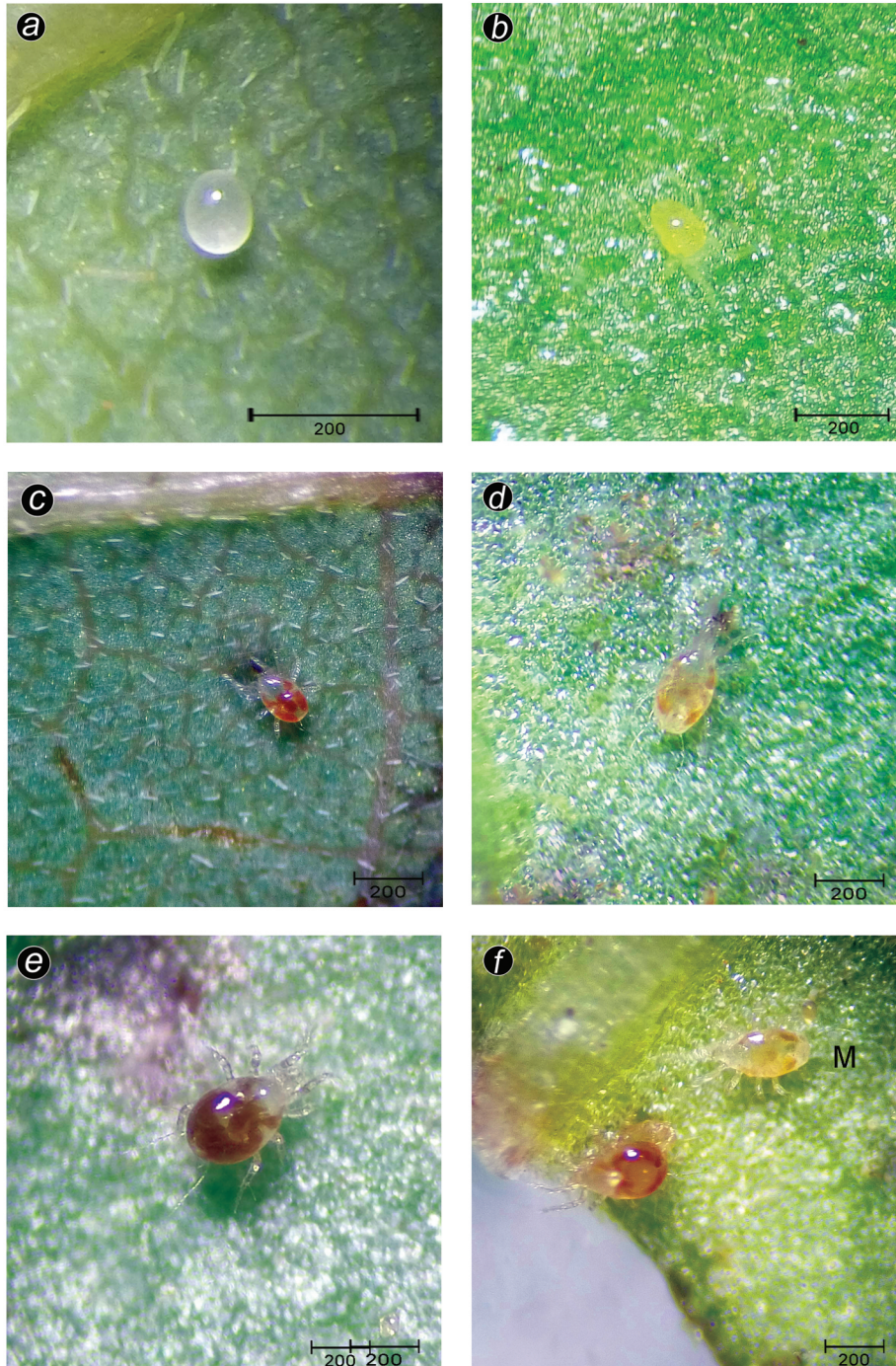
Developmental stages of *Neoseiulus longispinosus*



a. Egg (E); **b.** Larva (L) and Protonymph (P);
c. Deutonymph ; **d.** Adult female; **e.** Adult male;
f. Mating and Exuviae (Ex)

PLATE 10

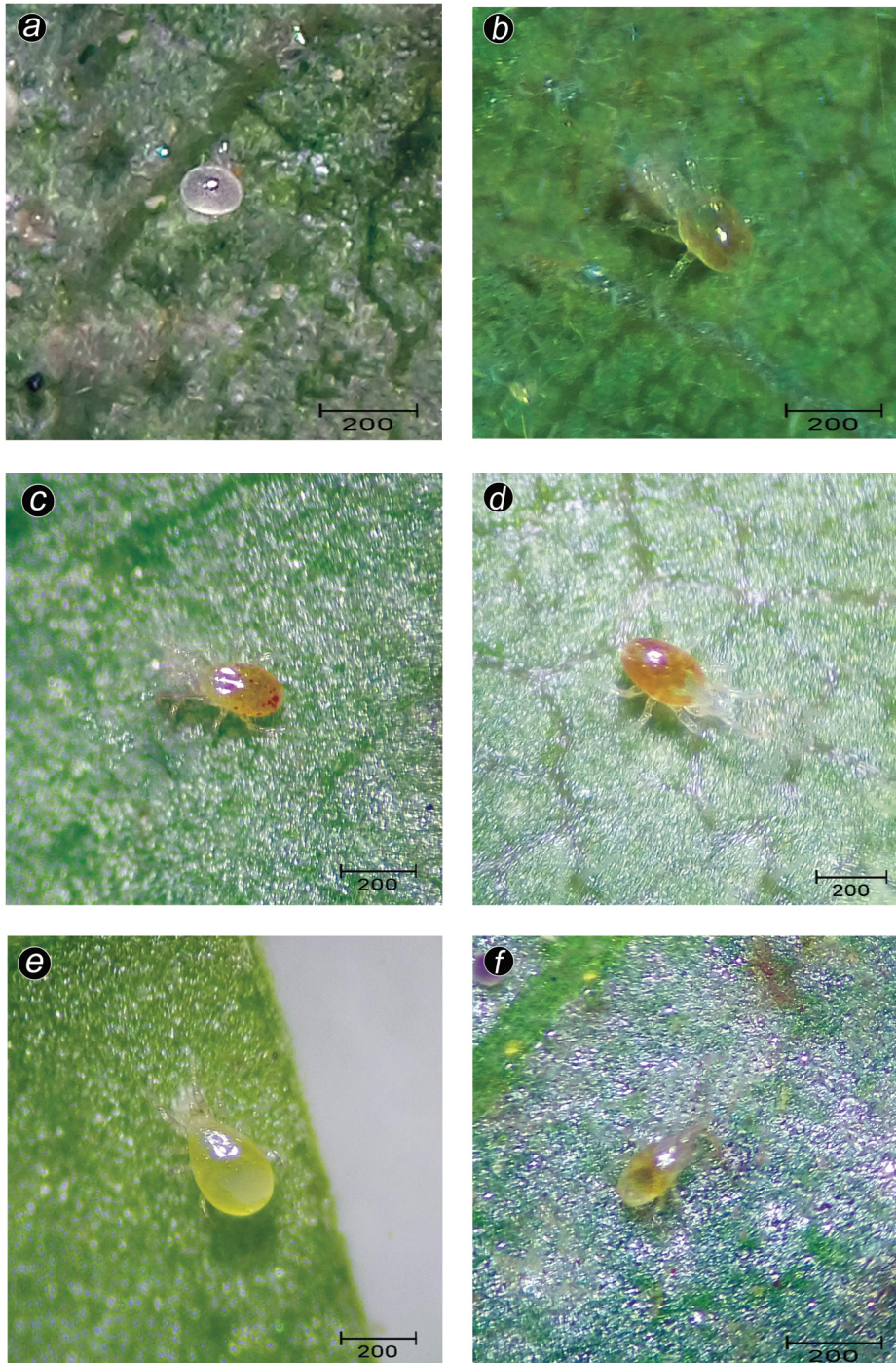
Developmental stages of *Amblyseius paraaerialis*



a. Egg; b. Larva; c. Protonymph; d. Deutonymph ;
e. Adult female; f. Adult male (M) and Mating.

PLATE 11

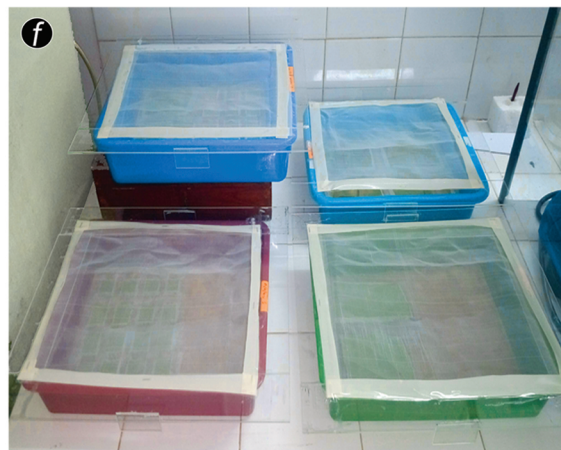
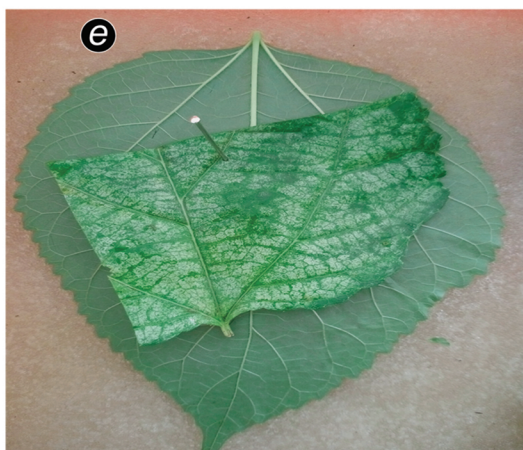
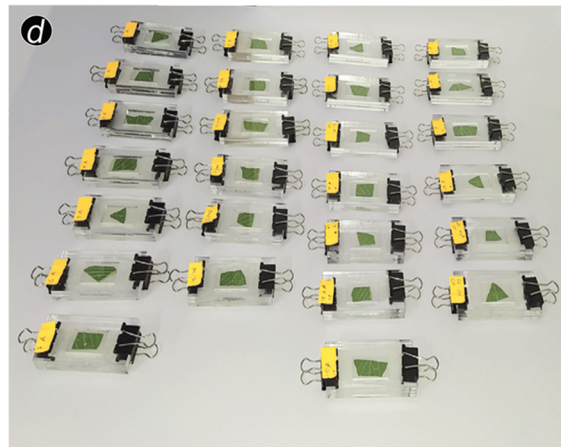
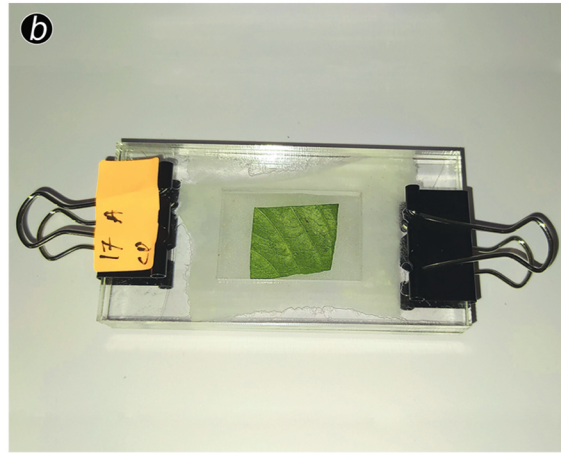
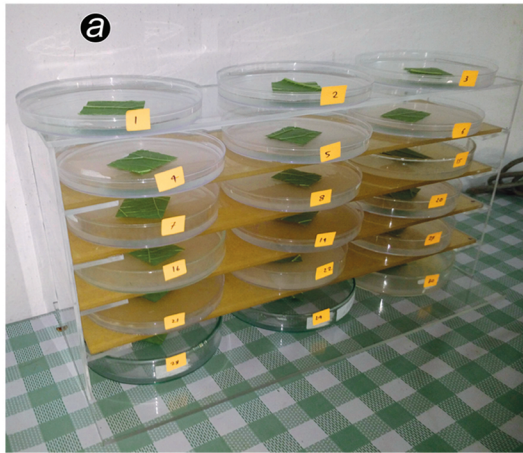
Developmental stages of *Euseius rhododendronis*



a. Egg; b. Larva; c. Protonymph; d. Deutonymph ; e. Adult female; f. Adult male.

PLATE 12

Culture arena



a. Experimental arena I; **b.** Experimental arena II; **c.** Arena for rearing spidermites; **d.** Entire set of experimental arena II aligned for biological studies of predatory mites; **e.** Arena for rearing predatory mites; **f.** A view of stock culture sets of pest and predatory mites, covered with nylon mesh.

PLATE 13

Alternative food items and experimental arena



a. *Ricinus communis*; **b.** Castor flowers with pollen grains;
c. Closed experimental arena II with honey-pollen mixture
given as the alternative diet for the predatory mites

PLATE 14

Fig. 1

Diversity of the various families of phytophagous mites collected from the leafy vegetables and fruit crops.

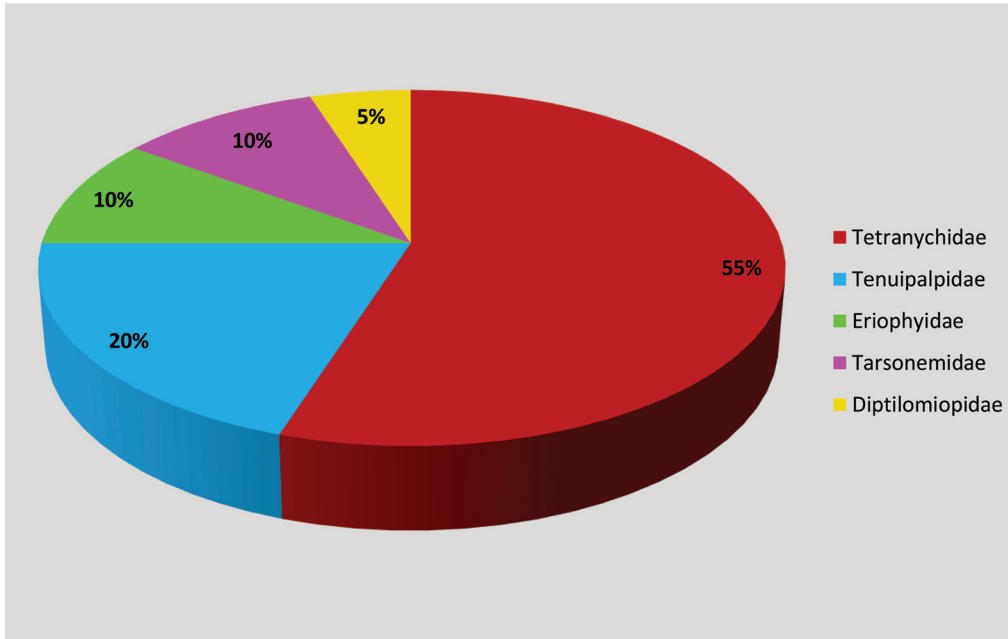


Fig.2

Generic diversity of the various families of phytophagous mites recovered from the leafy vegetables and fruit crops.

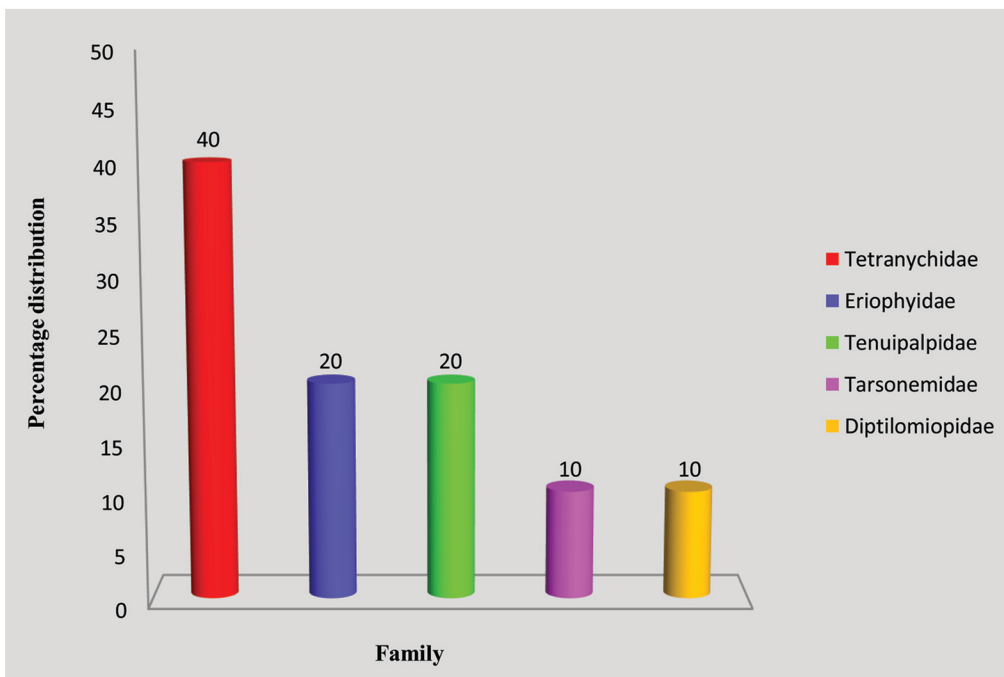


PLATE 15

Fig. 3

Species diversity of the various genera of phytophagous pest mites recovered from the leafy vegetables and fruit crops.

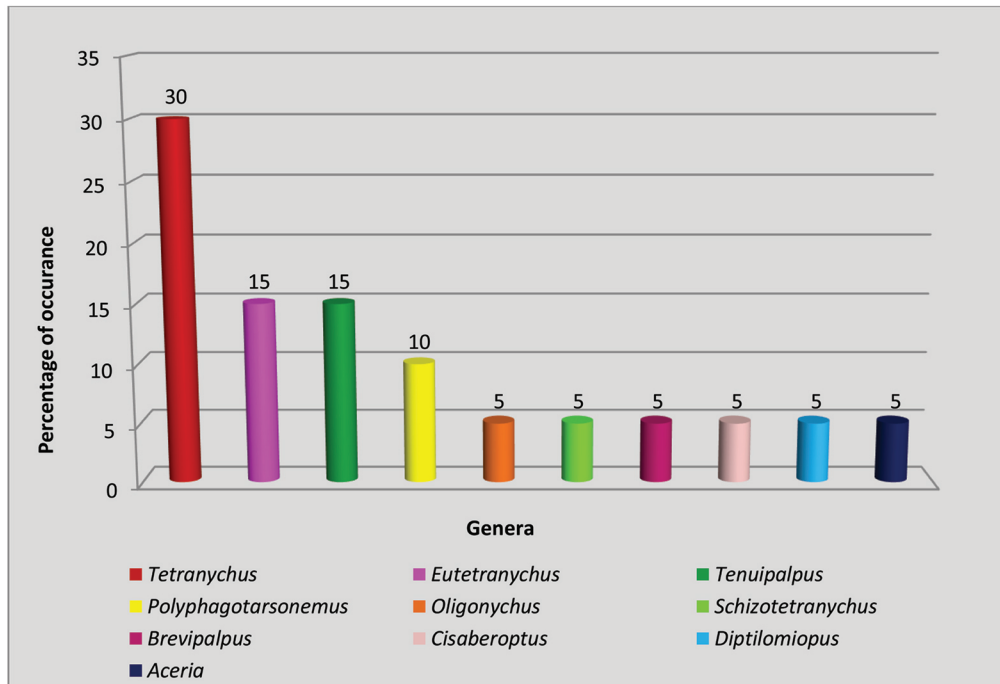


Fig.4

Diversity of various taxa of phytoseiid mites recovered from the leafy vegetables and fruit crops.

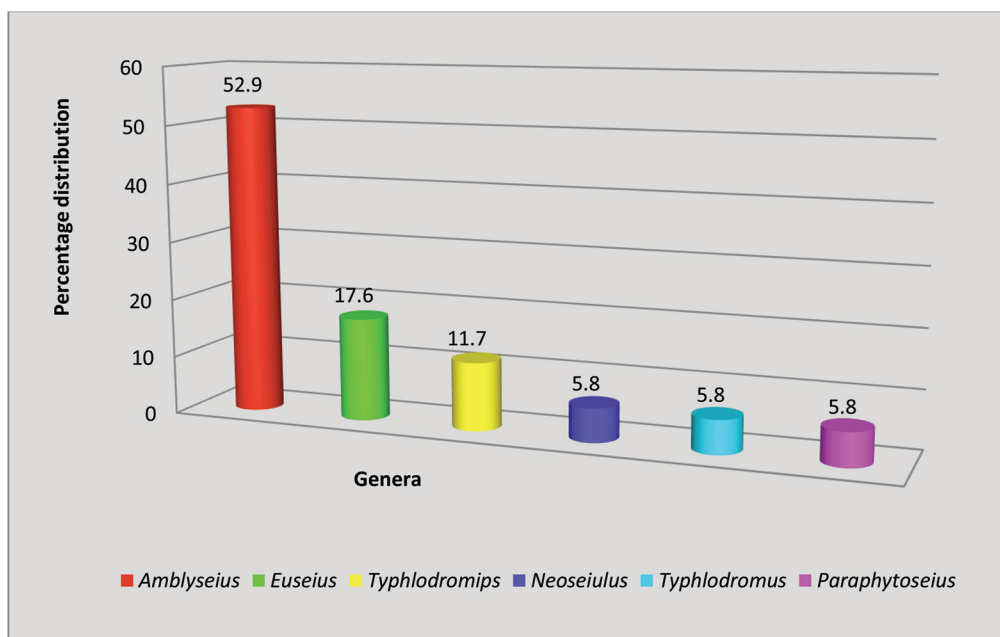
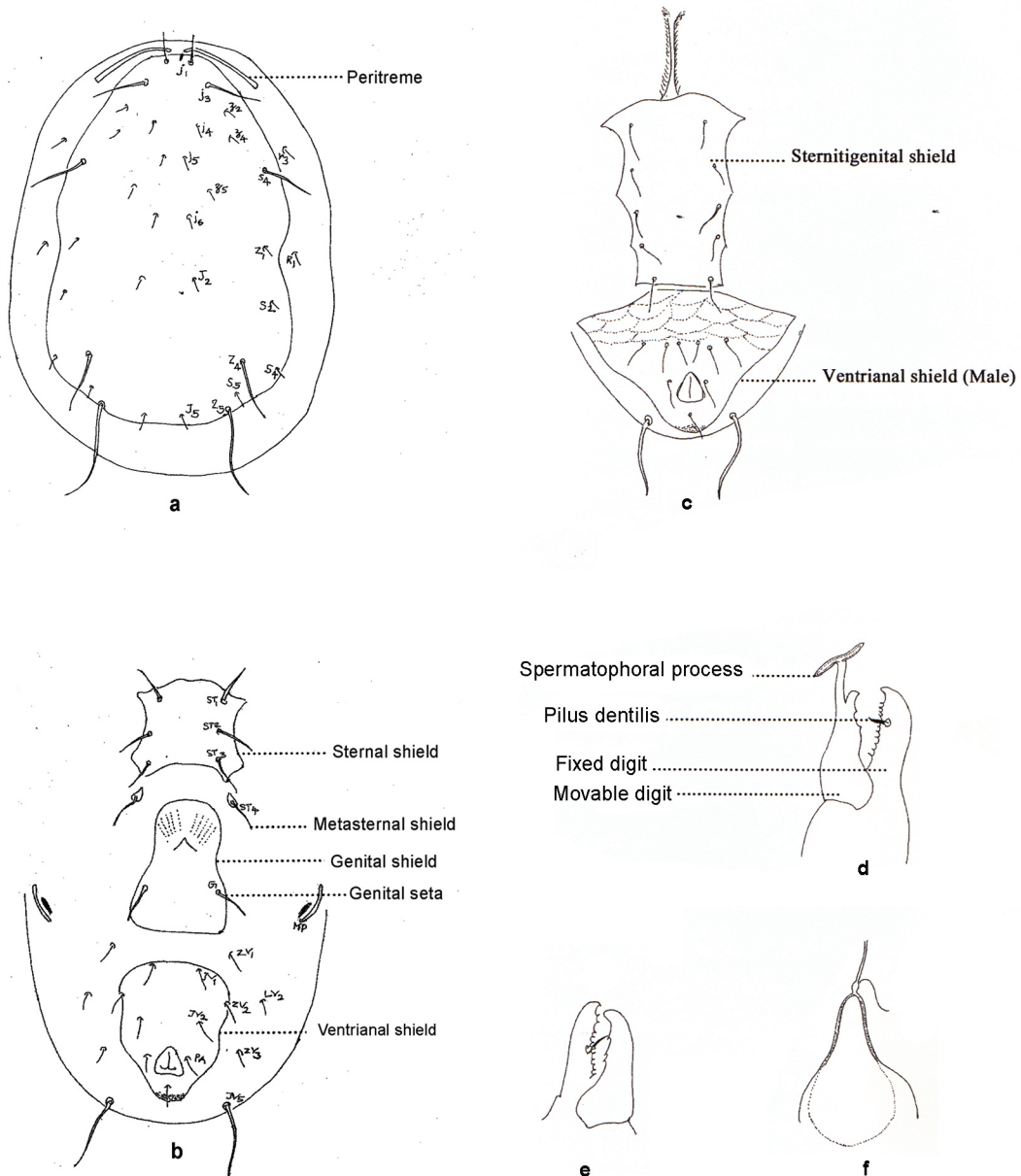
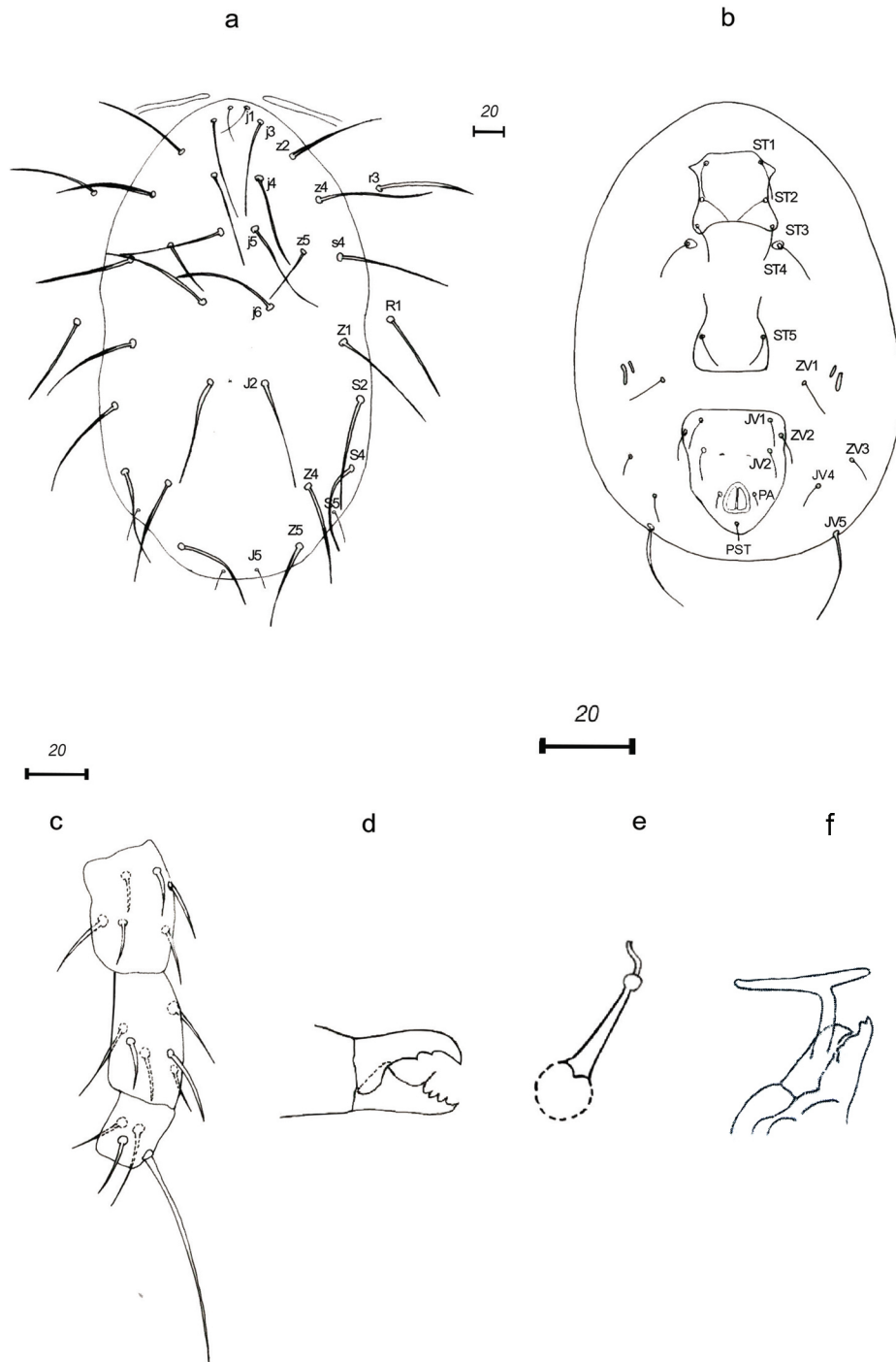


PLATE 16



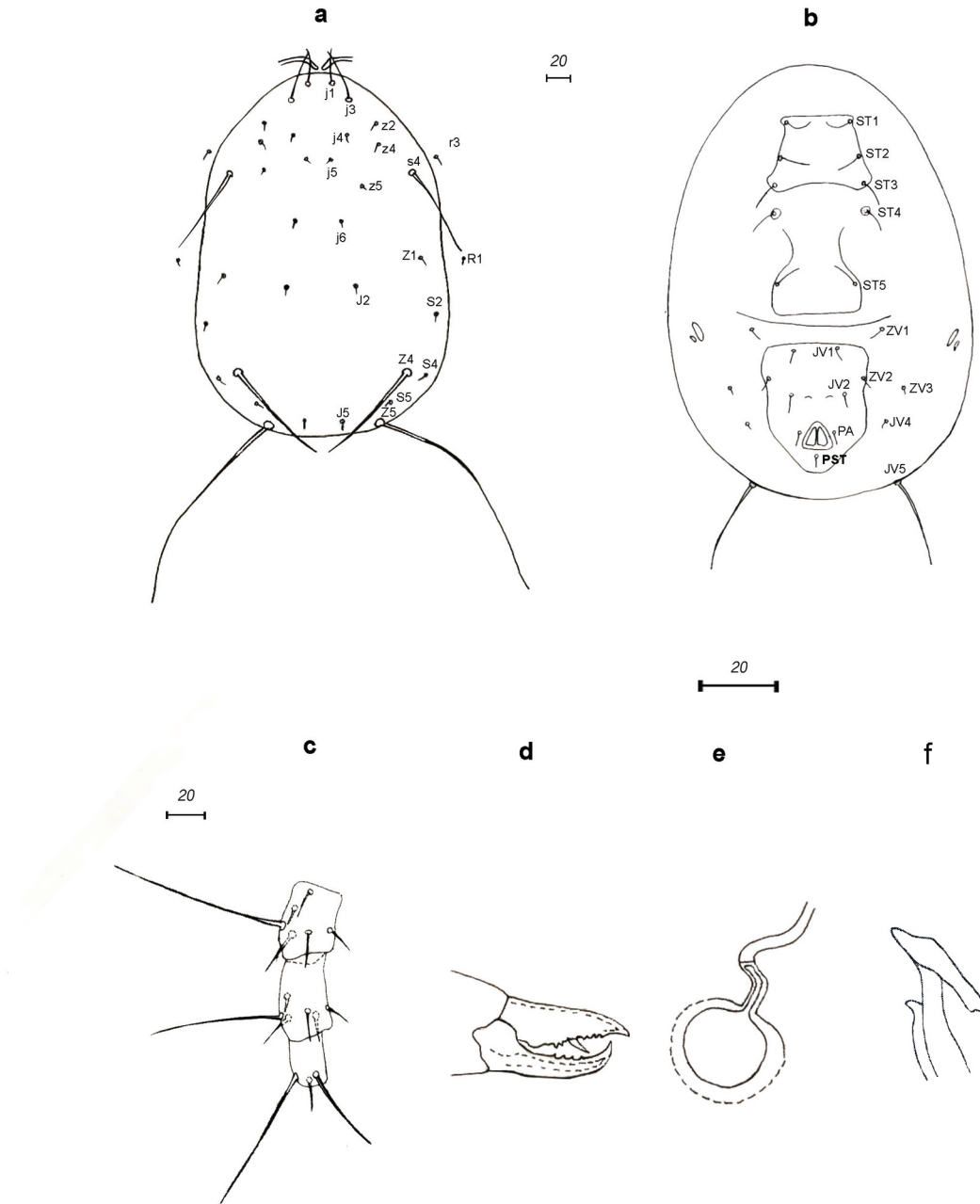
General morphology of phytoseiid mites- a, Dorsal view of female; b. Ventral view of female; c. Ventral view of male; d. Spermatophoral process; e. Chelicera; f. Spermatheca

PLATE 17



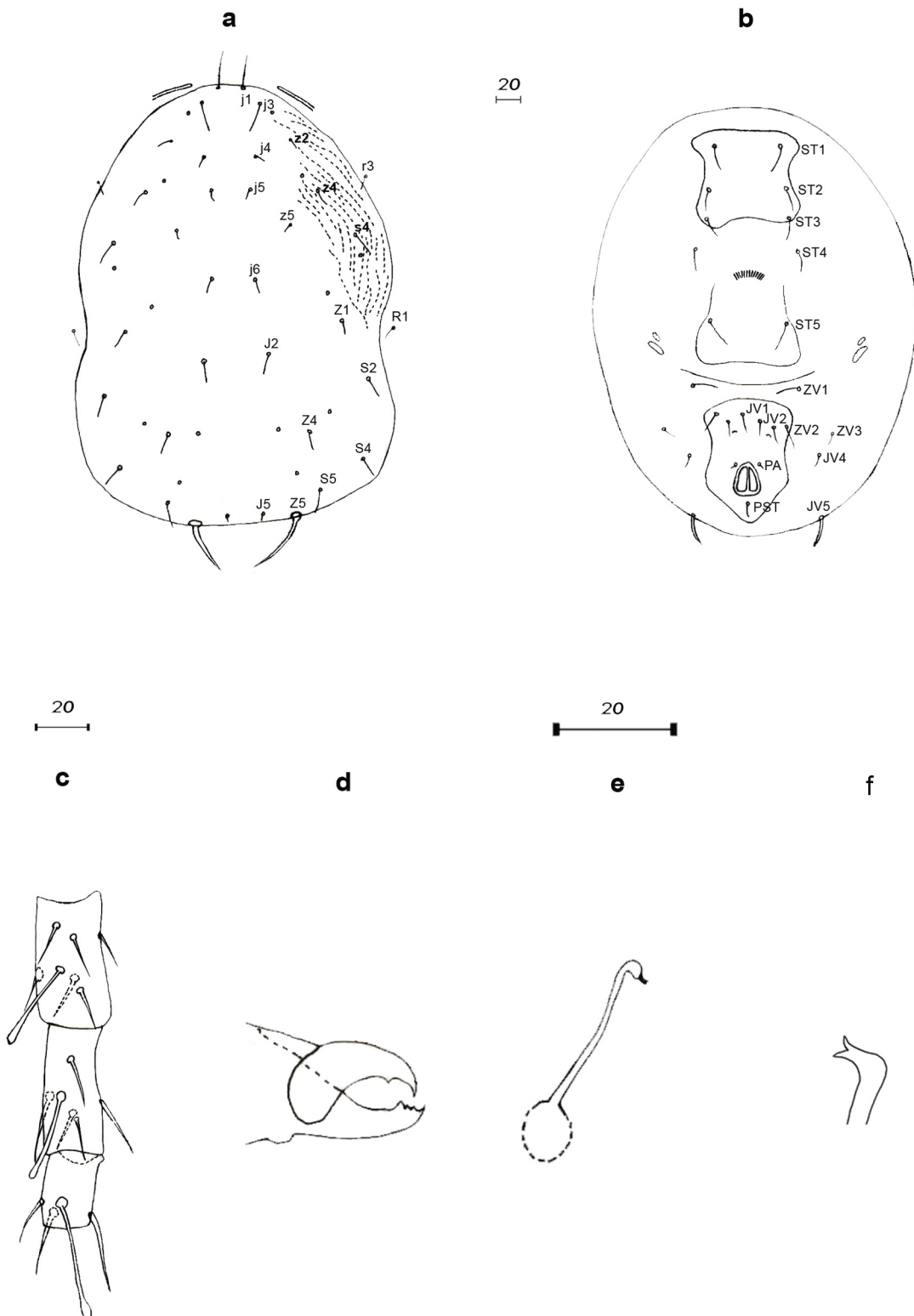
Neoseiulus longispinosus (Evans): (Female); a. dorsal shield; b. ventral surface
c. portion of leg IV; d. chelicerae; e. spermatheca ; f. Spermatophoral process (Male)

PLATE 18



Amblyseius paraaerialis Muma - Female - a. dorsal surface; b. ventral surface
c. portion of leg IV; d. chelicera ; e. spermatheca; f. Spermatophoral process(Male)

PLATE 19



Euseius rhododendronis Gupta; (Female); a. dorsal shield; b. ventral surface
c. portion of leg IV; d. chelicerae; e. spermatheca; f. Spermatophoral process (Male)

PLATE 20

Fig. 5

Total rate of consumption (%) of life stages of *Neoseiulus longispinosus* on pest mites, *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and $70 \pm 5\%$ RH

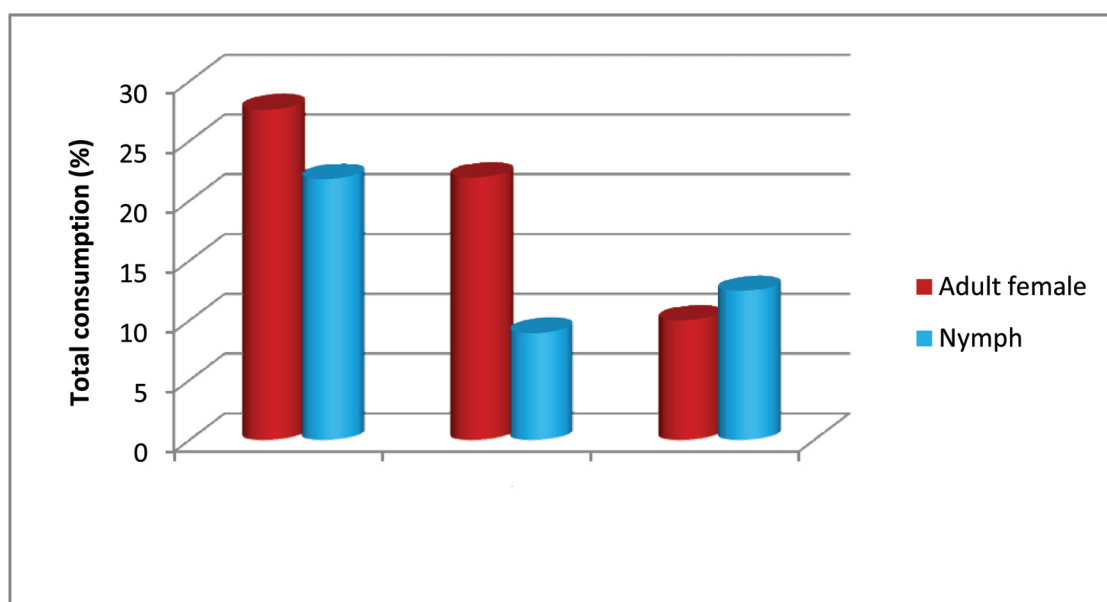


PLATE 21

Fig. 6

Mean rate of consumption (%) of adult female of *Neoseiulus longispinosus* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and $70 \pm 5\%$ RH

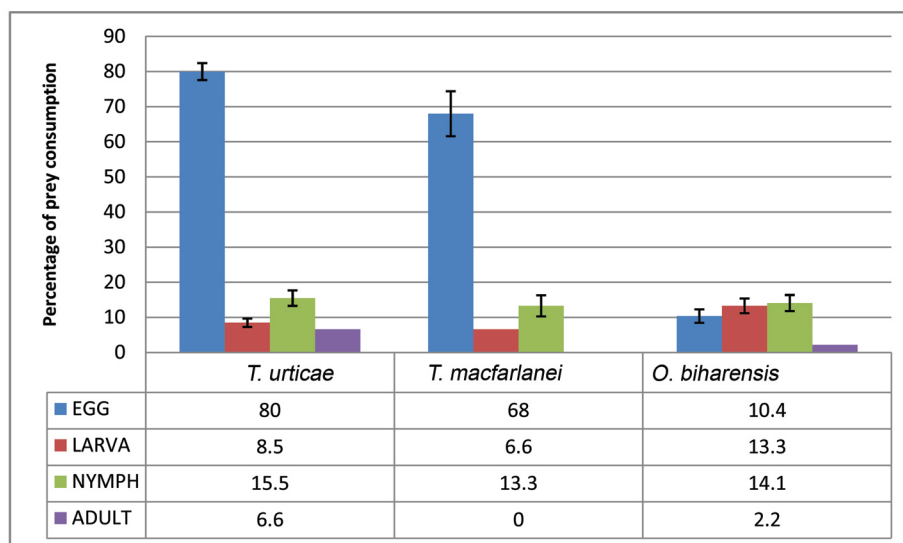


Fig. 7

Mean rate of consumption (%) of nymph of *Neoseiulus longispinosus* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and $70 \pm 5\%$ RH

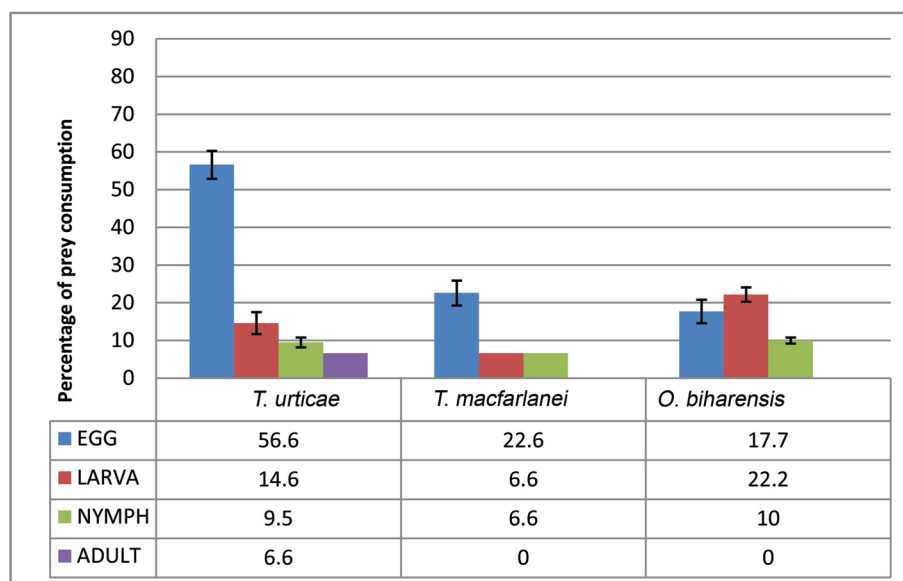
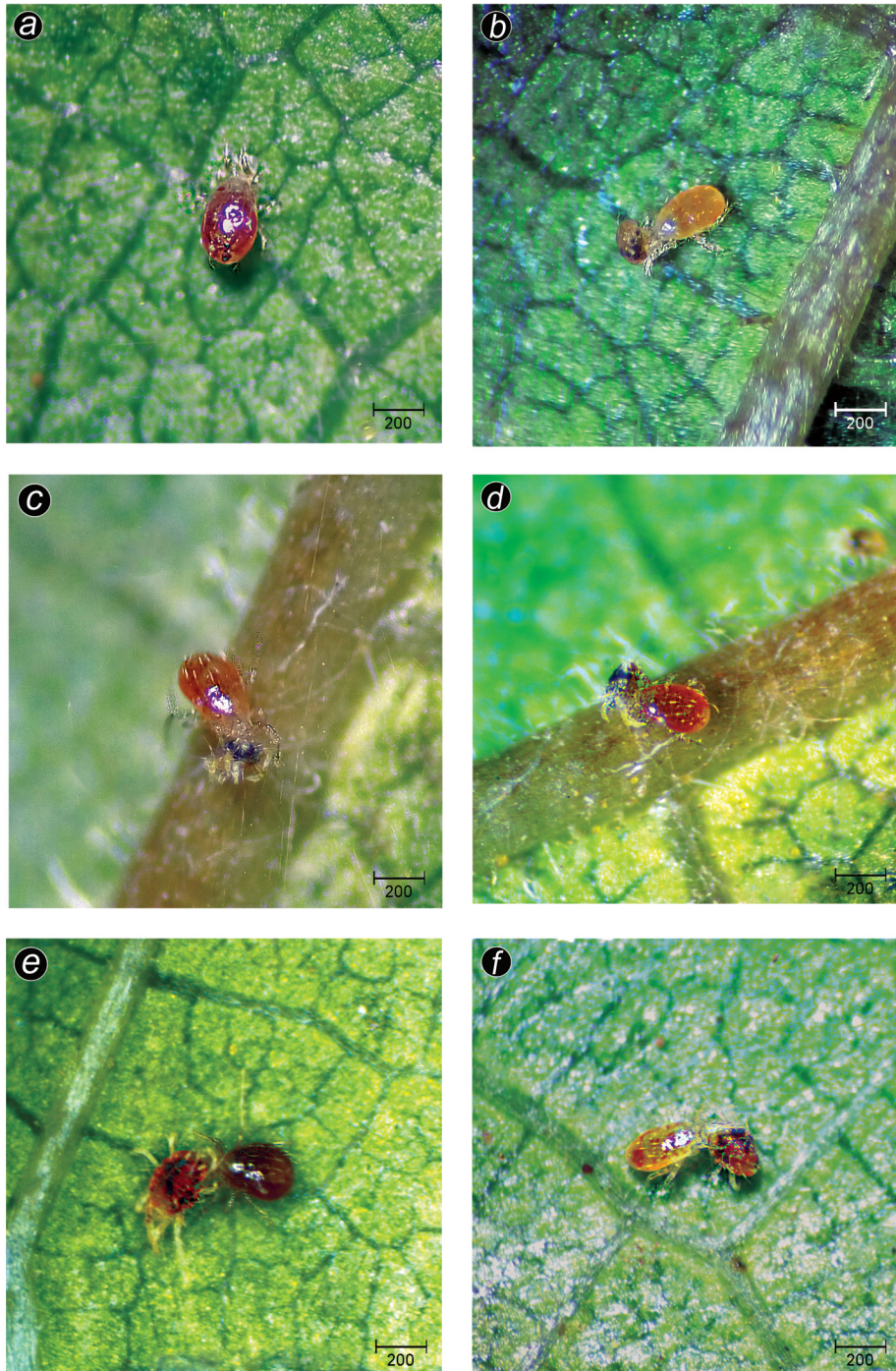


PLATE 22

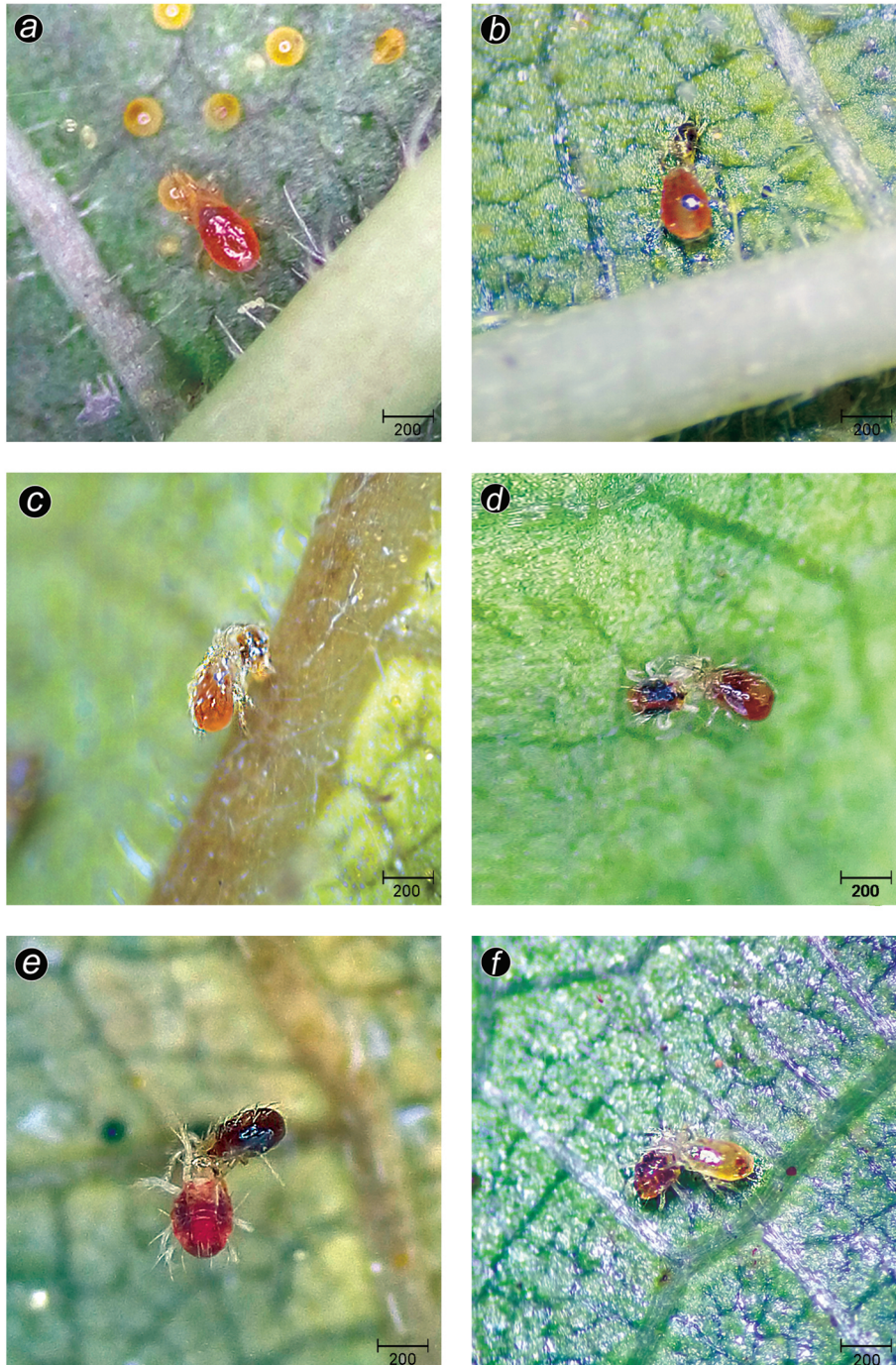
Neoseiulus longispinosus feeding on *Tetranychus urticae*



a. Adult female feeding on egg stage; b. Deutonymph feeding on larva;
c. Adult female feeding on protonymph; d. Adult female feeding on larva ;
e. Adult female feeding on adult (female) prey; f. Deutonymph feeding on
protonymph

PLATE 23

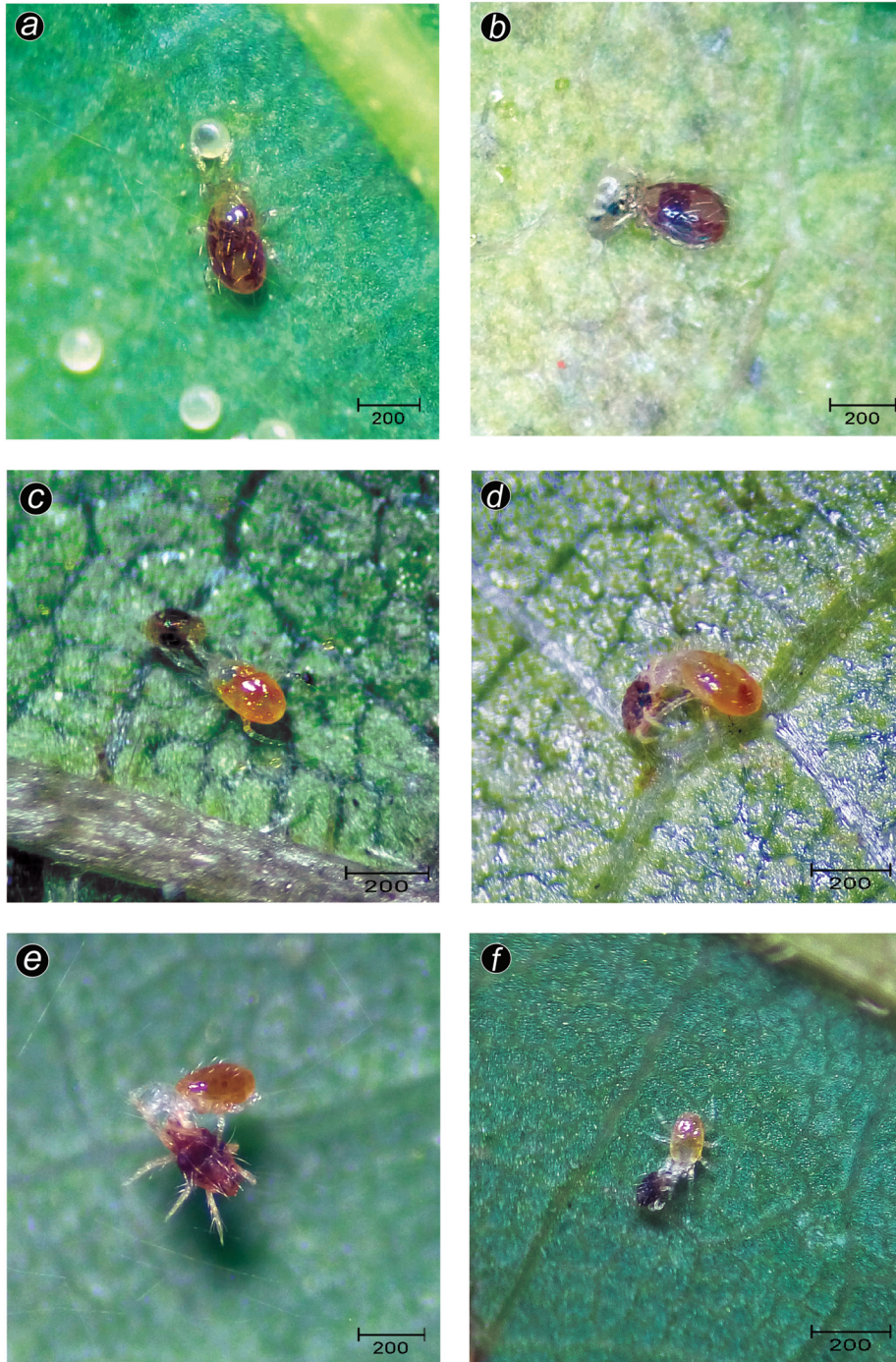
Neoseiulus longispinosus feeding on *Tetranychus macfarlanei*



a. Adult female feeding on egg stage; b. Adult female feeding on larva;
c. Adult female feeding on protonymph; d. Female feeding on deutonymph;
e. Adult female feeding on adult female prey; f. Deutonymph feeding on
deutonymphal stage of the prey.

PLATE 24

Neoseiulus longispinosus feeding on *Oligonychus biharens*



a. Adult female feeding on egg stage; **b.** Adult female feeding on larva; **c.** Adult female feeding on protonymph; **d.** Adult female feeding on deutonymph ; **e.** Adult female feeding on adult female prey; **f.** Protonymph feeding on protonymphal stage of prey.

PLATE 25

Fig. 8

Total rate of consumption (%) of life stages of *Amblyseius paraaerialis* on pest mites, *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

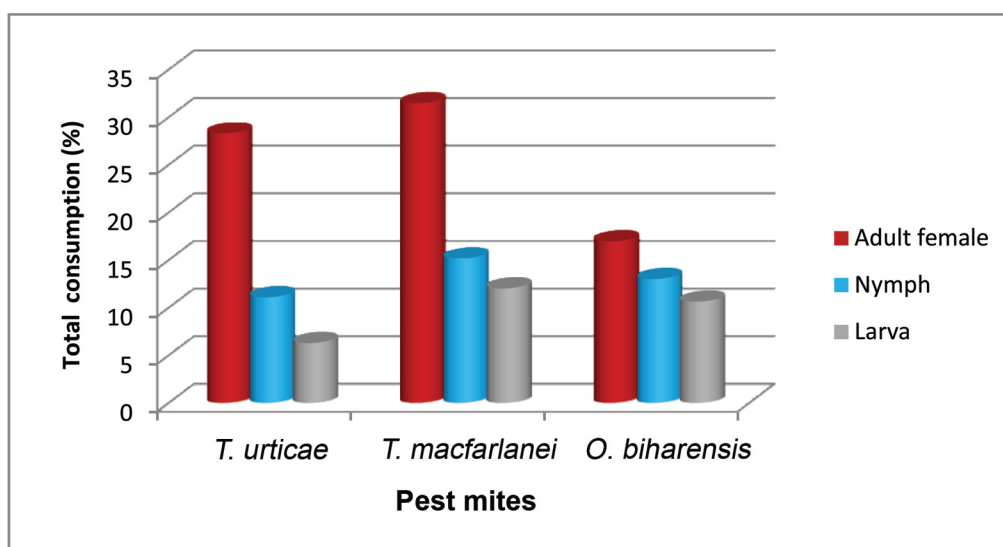


Fig. 7

Mean rate of consumption (%) of adult female of *Amblyseius paraaerialis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

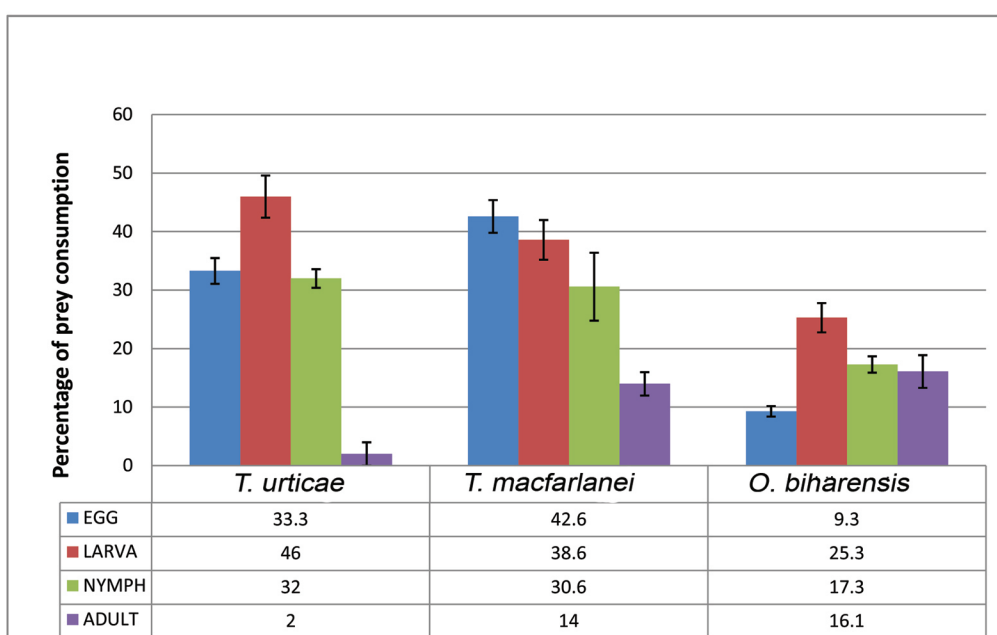


PLATE 26

Fig. 10

Mean rate of consumption (%) of nymph of *Amblyseius paraaerialis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and $70 \pm 5\%$ RH

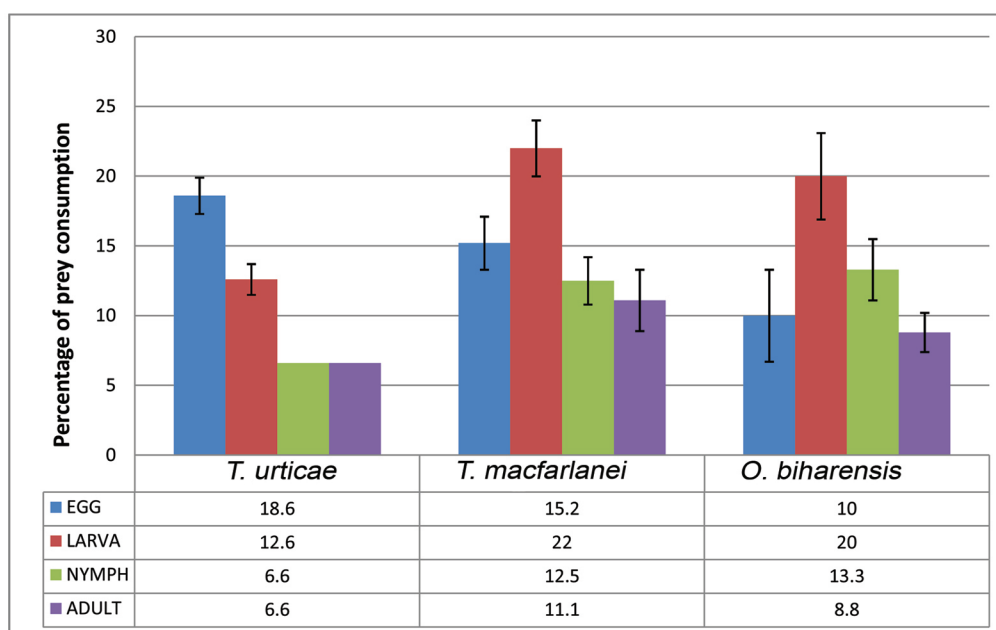


Fig. 11

Mean rate of consumption (%) of larva of *Amblyseius paraaerialis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and $70 \pm 5\%$ RH

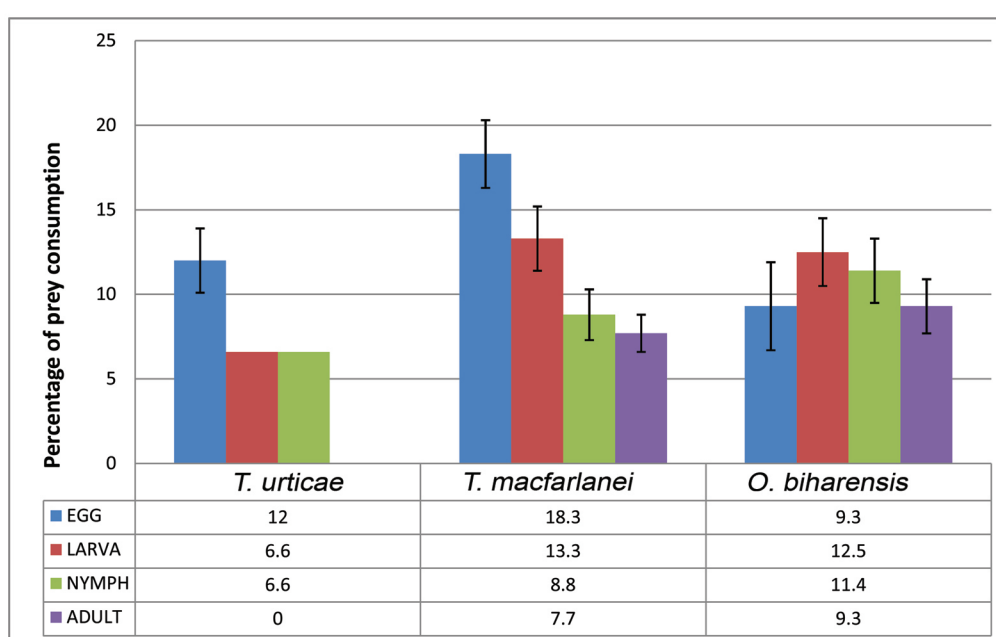
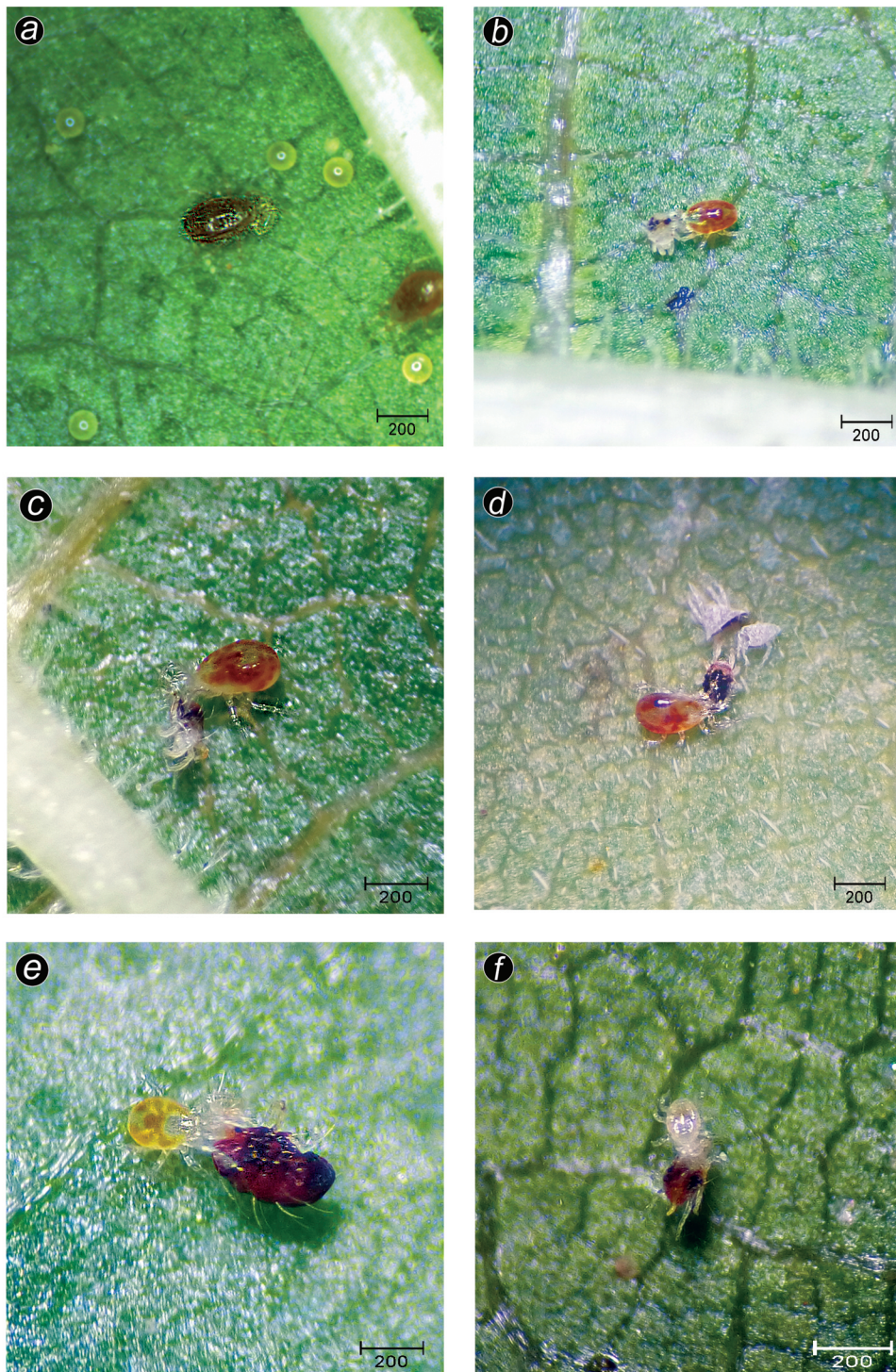


PLATE 27

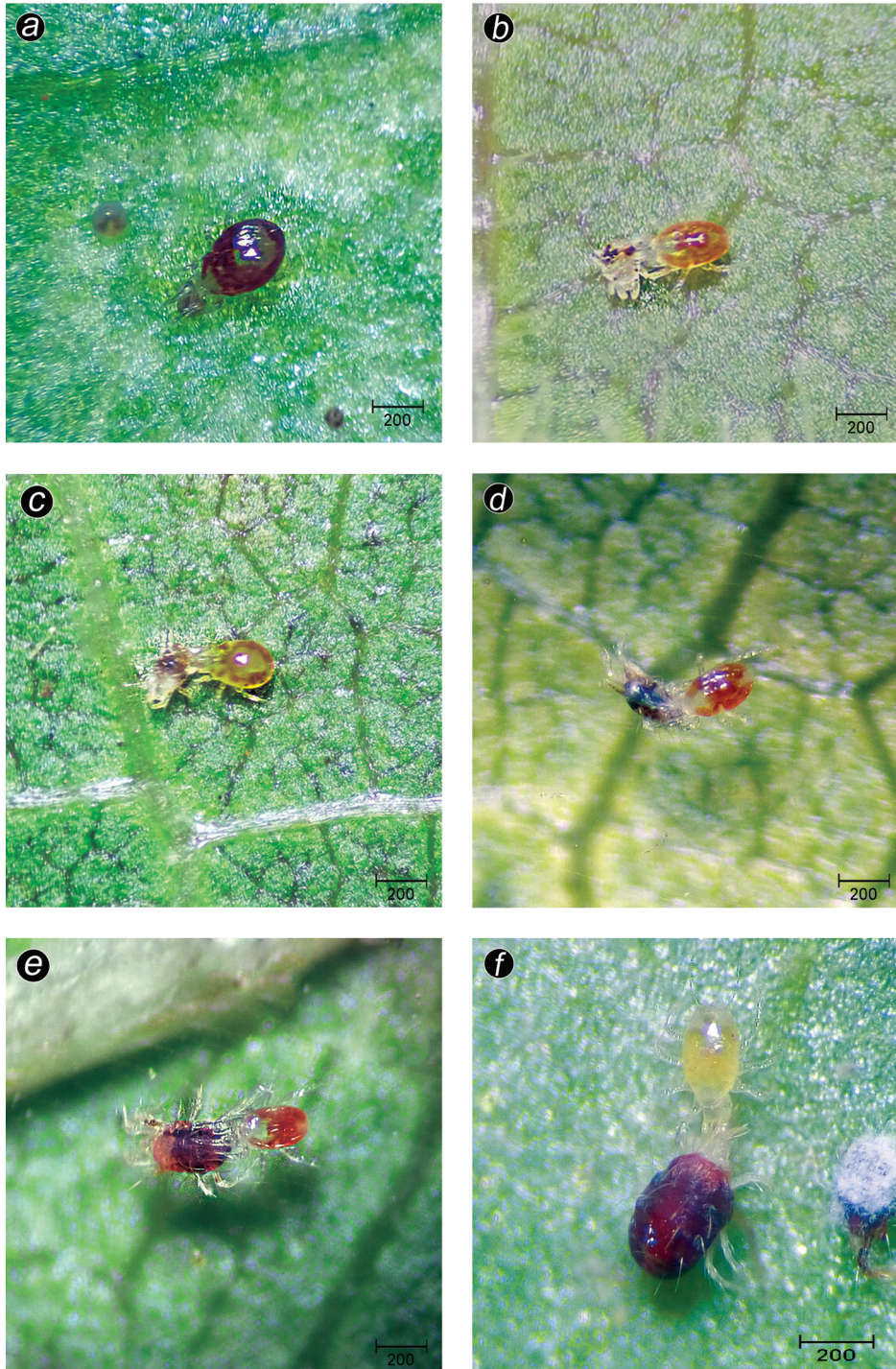
Amblyseius paraaerialis feeding on *Tetranychus urticae*



a. Adult female feeding on egg stage; **b.** Adult female feeding on larva; **c.** Adult female feeding on protonymph; **d.** Adult female feeding on deutonymph ; **e.** Adult female feeding on adult female prey; **f.** Larva feeding on deutonymph

PLATE 28

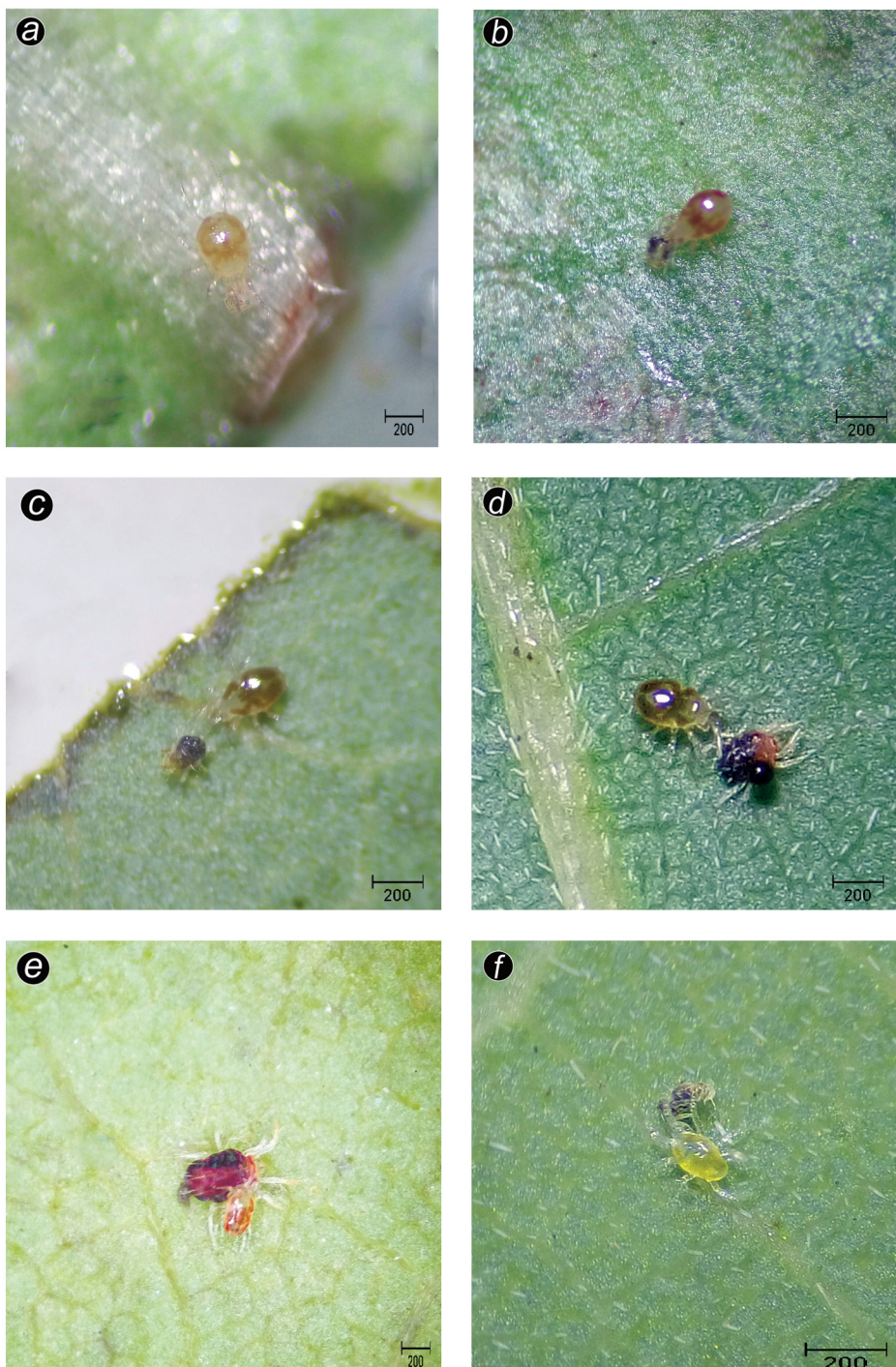
Amblyseius paraaerialis feeding on *Tetranychus macfarlanei*



a. Adult female feeding on egg stage; **b.** Deutonymph feeding on larva; **c.** Adult female feeding on protonymph; **d.** Adult female feeding on deutonymph ; **e.** Adult female feeding on adult female prey; **f.** Protonymph feeding on deutonymph

PLATE 29

Amblyseius paraaerialis feeding on *Oligonychus biharens*



a. Adult female feeding on egg stage; **b.** Adult female feeding on larva; **c.** Adult female feeding on protonymph; **d.** Adult female feeding on deutonymph ; **e.** Adult female feeding on adult female prey; **f.** Protonymph feeding on protonymph of prey mite.

PLATE 30

Fig. 12

Total rate of consumption (%) of life stages of *Euseius rhododendronis* on pest mites, *Tetranychus urticae*, *tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

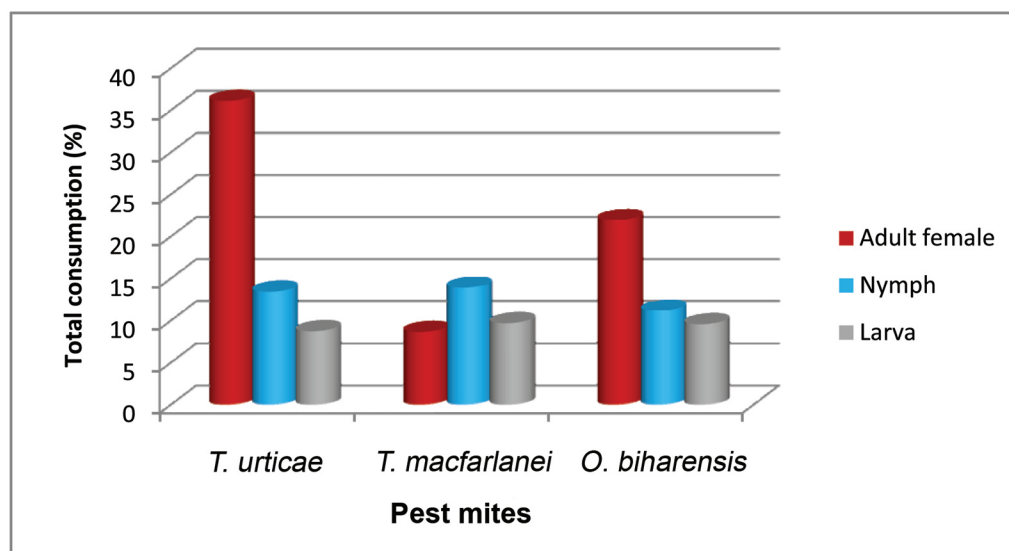


Fig. 13

Mean rate of consumption (%) of adult female of *Euseius rhododendronis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

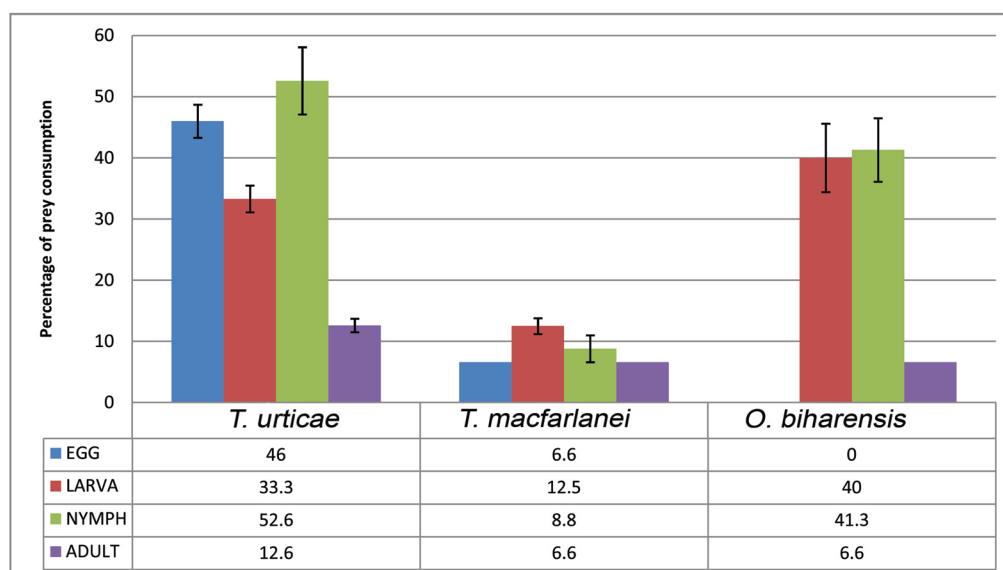


PLATE 31

Fig. 14

Mean rate of consumption (%) of nymph of *Euseius rhododendronis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

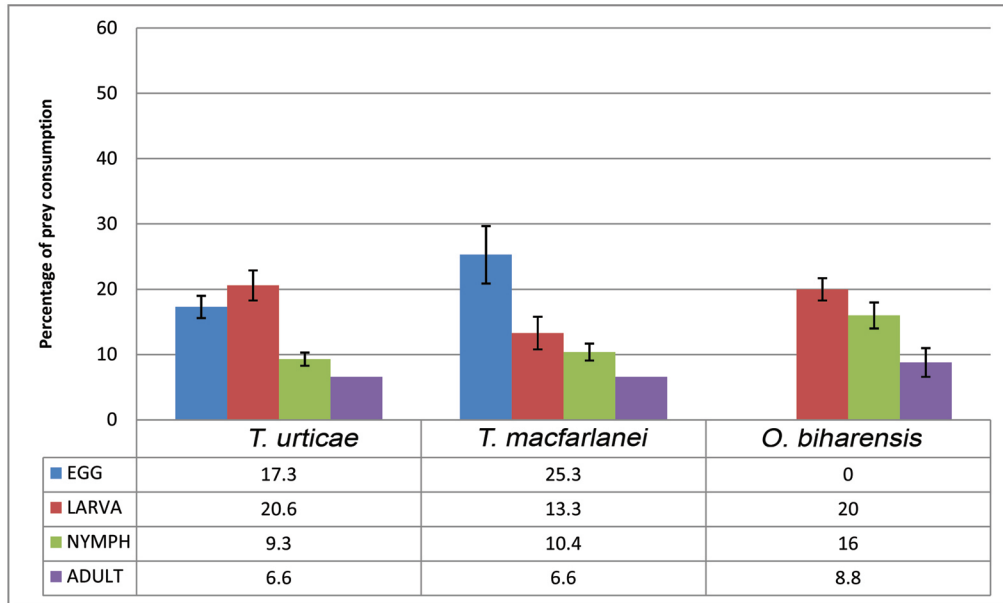


Fig. 15

Mean rate of consumption (%) of larva of *Euseius rhododendronis* on different life stages of *Tetranychus urticae*, *Tetranychus macfarlanei* and *Oligonychus biharensis* at 30 ± 2 °C and 70 ± 5 % RH

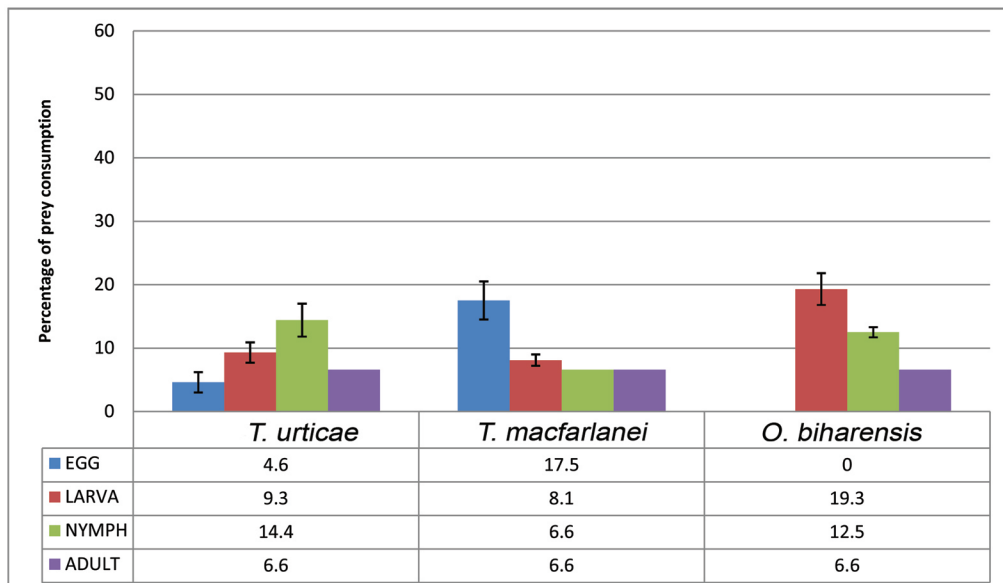
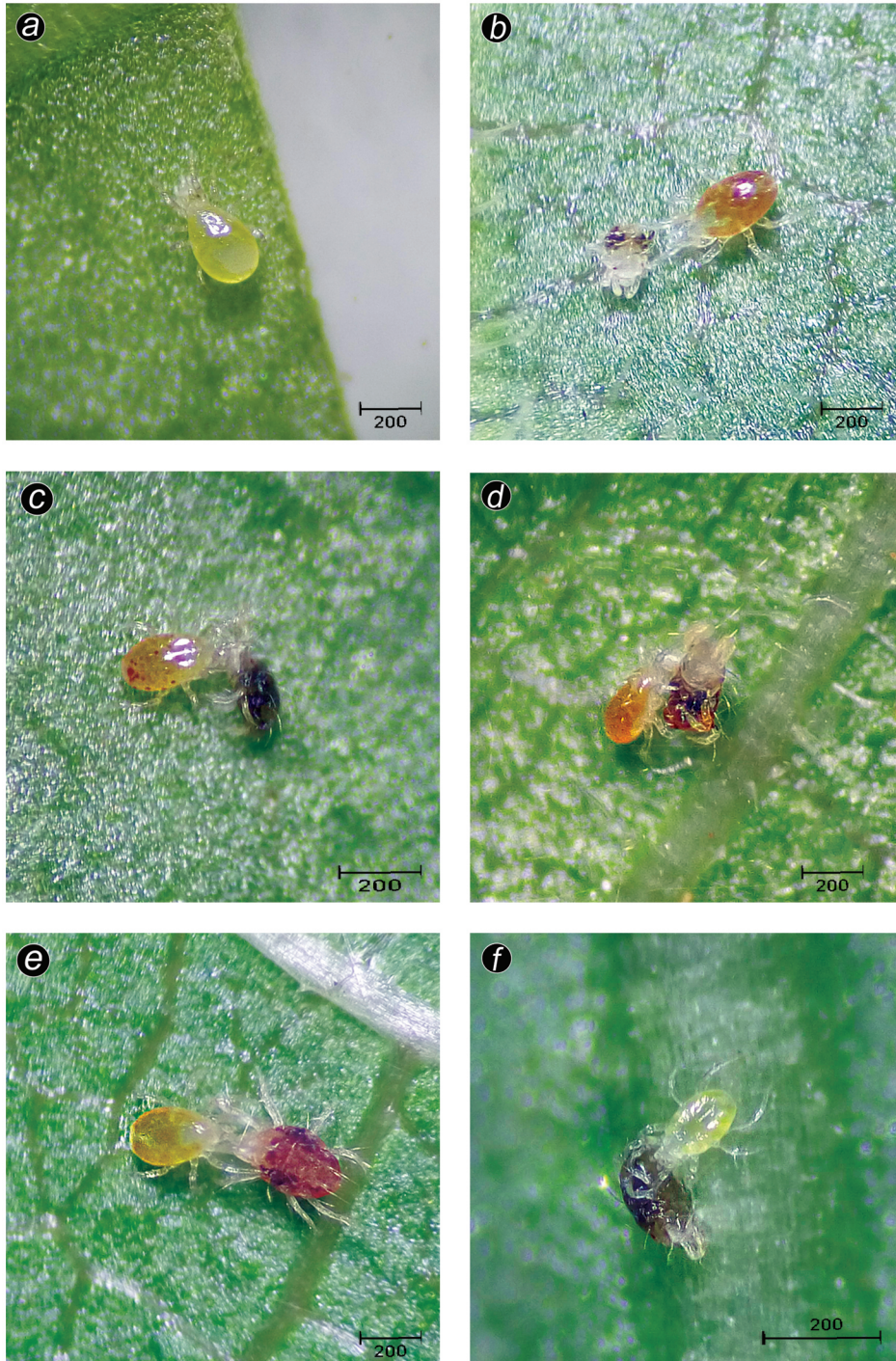


PLATE 32

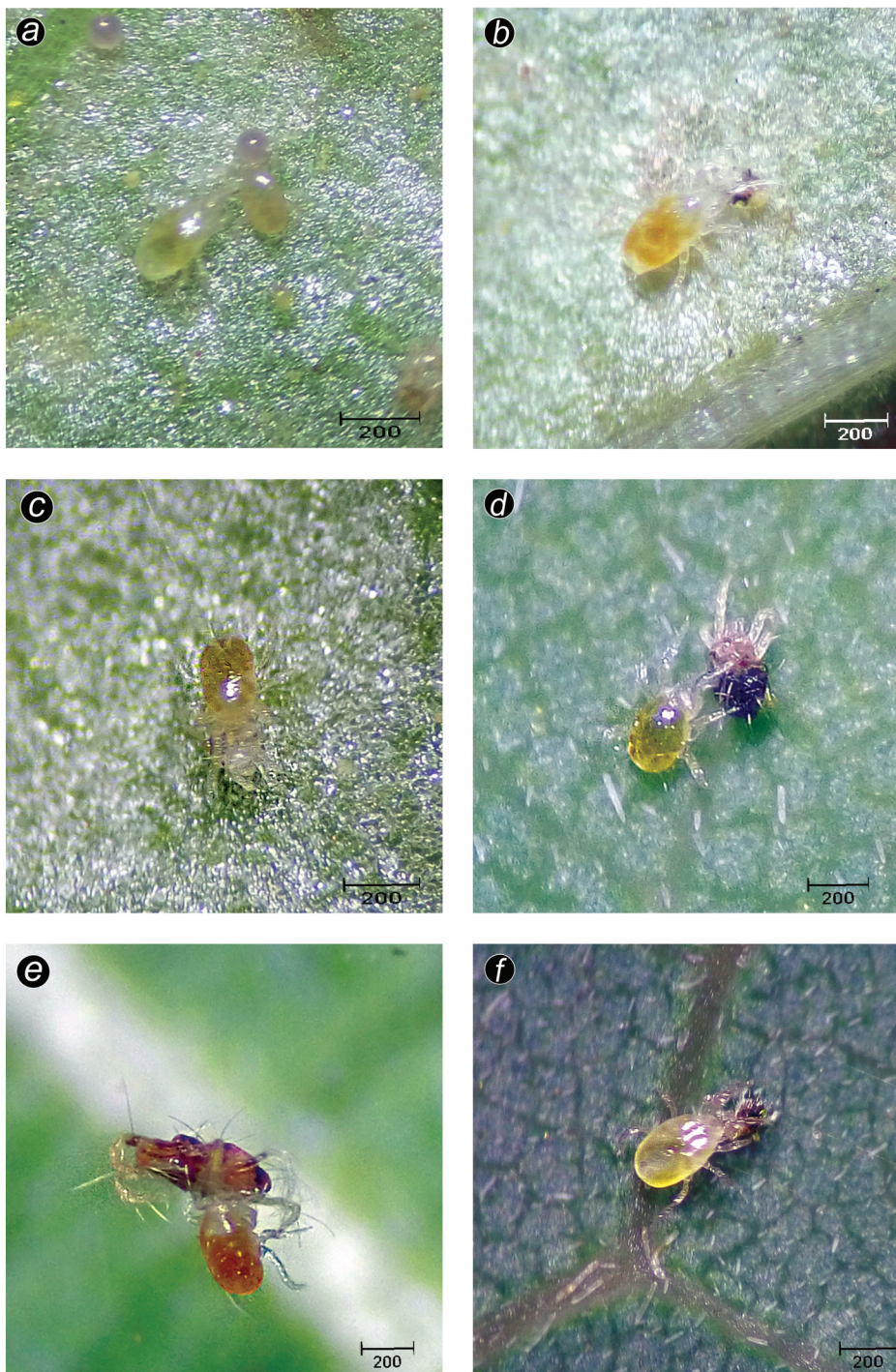
Euseius rhododendronis feeding on *Tetranychus urticae*



a. Adult female feeding on egg stage; **b.** Adult female feeding on larva;
c. Deutonymph feeding on protonymph; **d.** Adult female feeding on deutonymph ;
e. Adult female feeding on adult female prey; **f.** Larva feeding on deutonymph
of prey mite.

PLATE 33

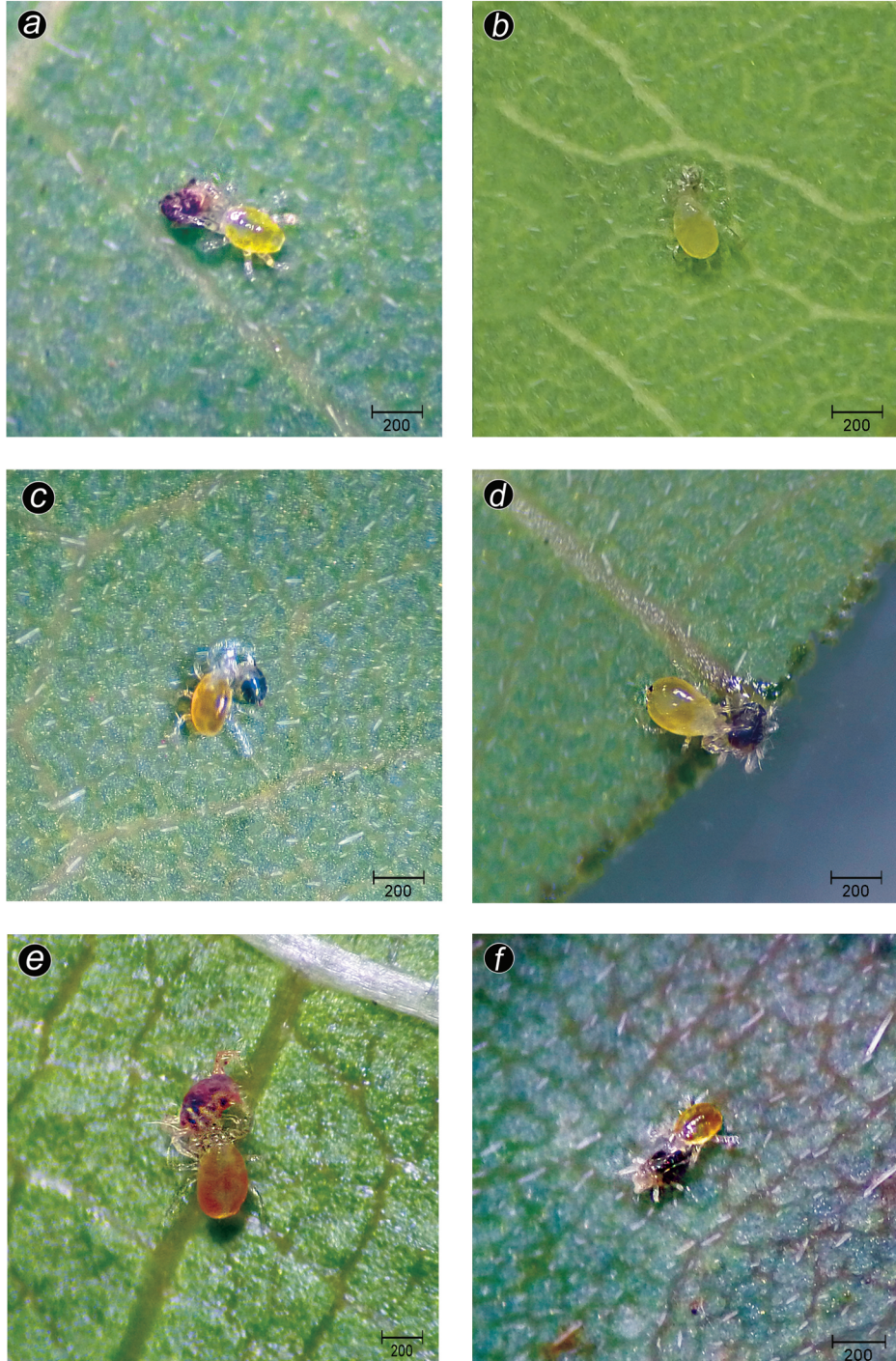
Euseius rhododendronis feeding on *Tetranychus macfarlanei*



a. Adult female feeding on egg stage; **b.** Adult female feeding on larva;
c. Deutonymph feeding on larva; **d.** Deutonymph feeding on deutonymph ;
e. Adult female feeding on adult female prey; **f.** Protonymph feeding on the larva

PLATE 34

Euseius rhododendronis feeding on *Oligonychus biharensis*



a. Protonymph feeding on egg stage; **b.** Adult female feeding on larva;
c. Deutonymph feeding on larva; **d.** Deutonymph feeding on deutonymph ;
e. Adult female feeding on adult female prey; **f.** Protonymph feeding on deutonymph

PLATE 35

Fig. 16

Total rate of consumption (%) of life stages of predatory mites, *Neoseiulus longispinosus*, *Amblyseius paraaerialis* and *Euseius rhododendronis* on different pests at 30 ± 2 °C and $70 \pm 5\%$ RH

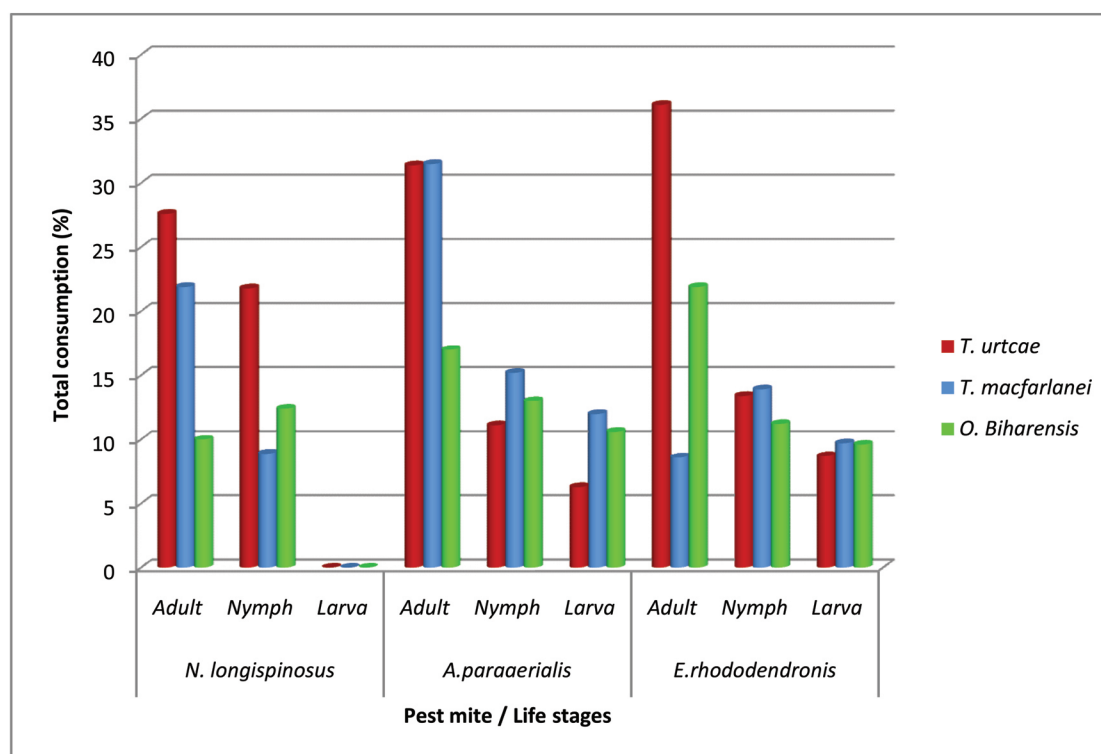


PLATE 36

Fig. 17

Type II functional response curve of *Neoseiulus longispinosus* females to varying egg densities of *Tetranychus urticae* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

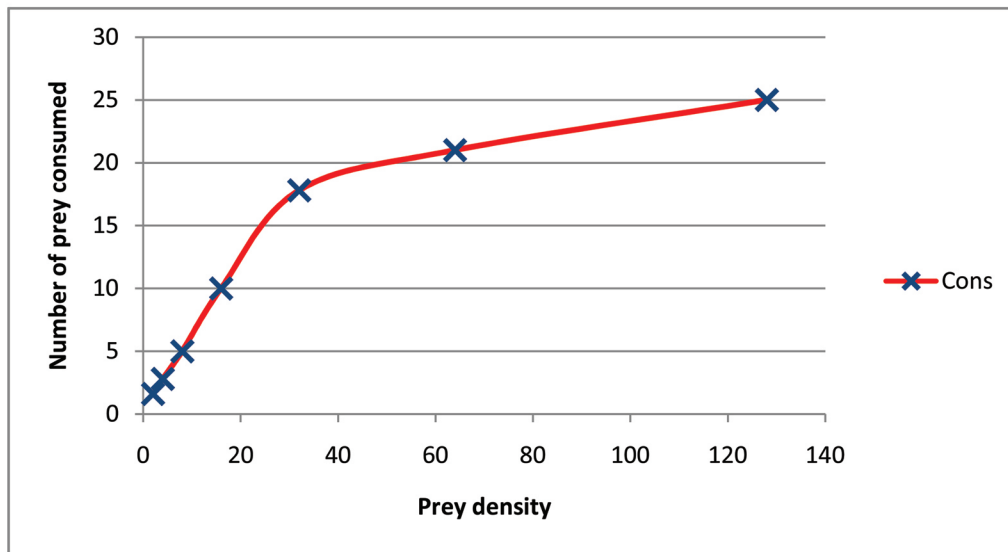


Fig. 18

Functional response of *Neoseiulus longispinosus* females to varying egg densities of *Tetranychus urticae* – Linearisation of Holling's Disc equation through Reciprocal transformation method.

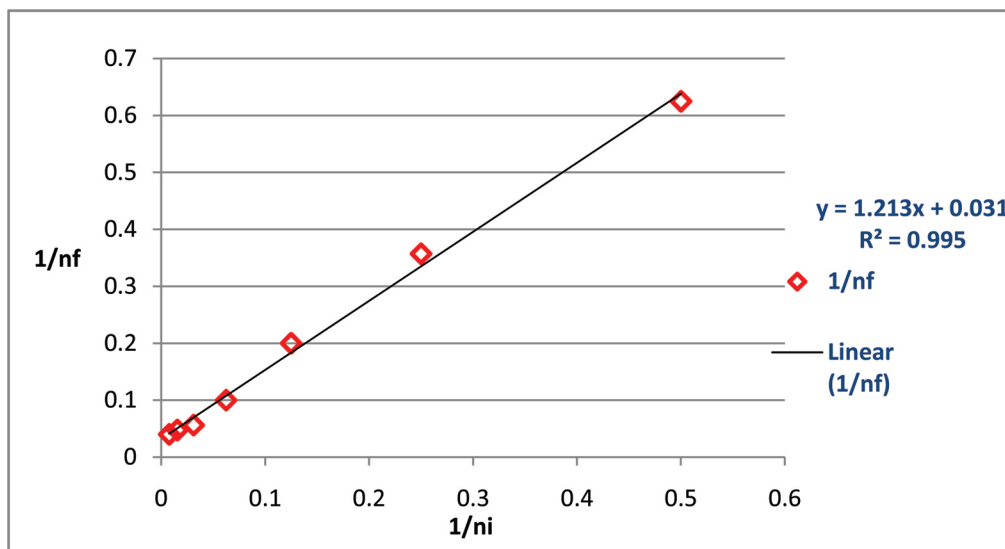


PLATE 37

Fig. 19

Type II functional response curve of *Neoseiulus longispinosus* females to varying egg densities of *Tetranychus macfarlanei* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

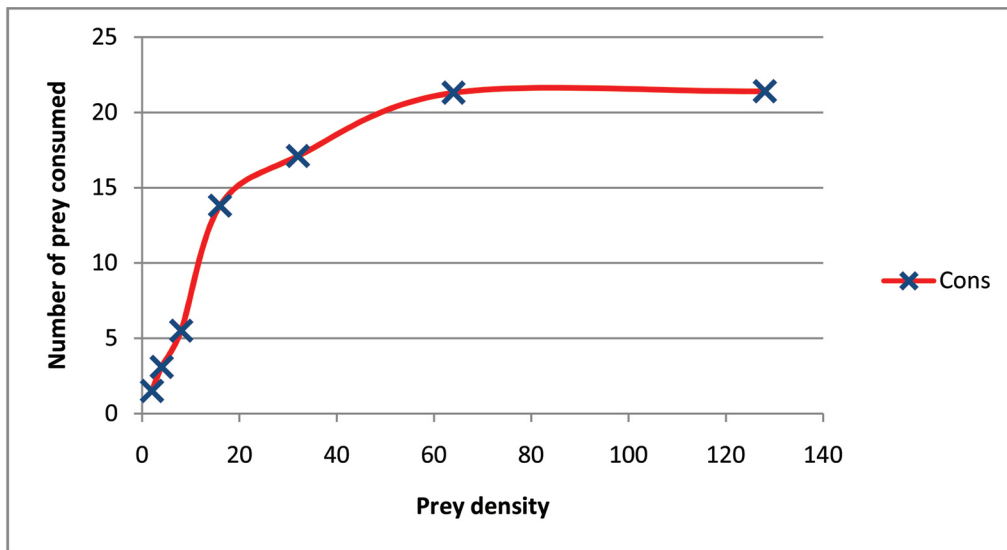


Fig. 20

Functional response of *Neoseiulus longispinosus* females to varying egg densities of *Tetranychus macfarlanei* – Linearisation of Holling's Disc equation through Reciprocal transformation method.

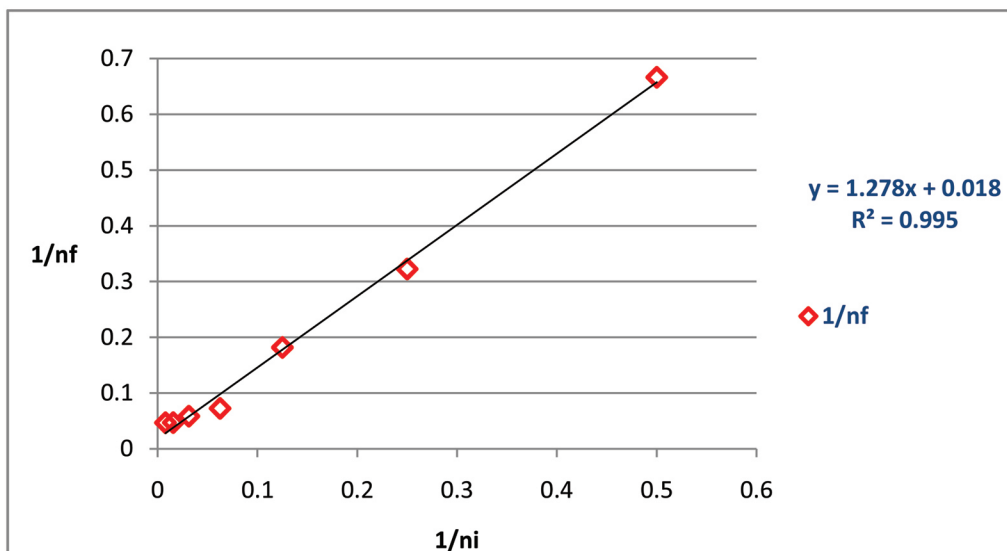


PLATE 38

Fig. 21

Attack rate (a) and Handling time (Th) of adult females of *Neoseiulus longispinosus* on eggs of *Tetranychus urticae* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

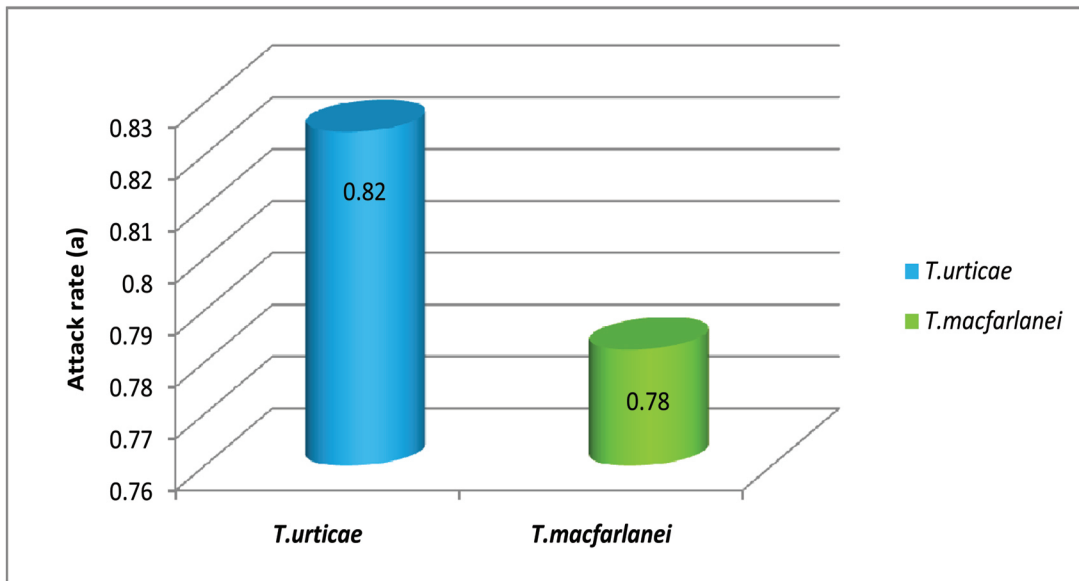


Fig. 22

Attack rate (a) and Handling time (Th) of adult females of *Neoseiulus longispinosus* on eggs of *Tetranychus macfarlanei* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

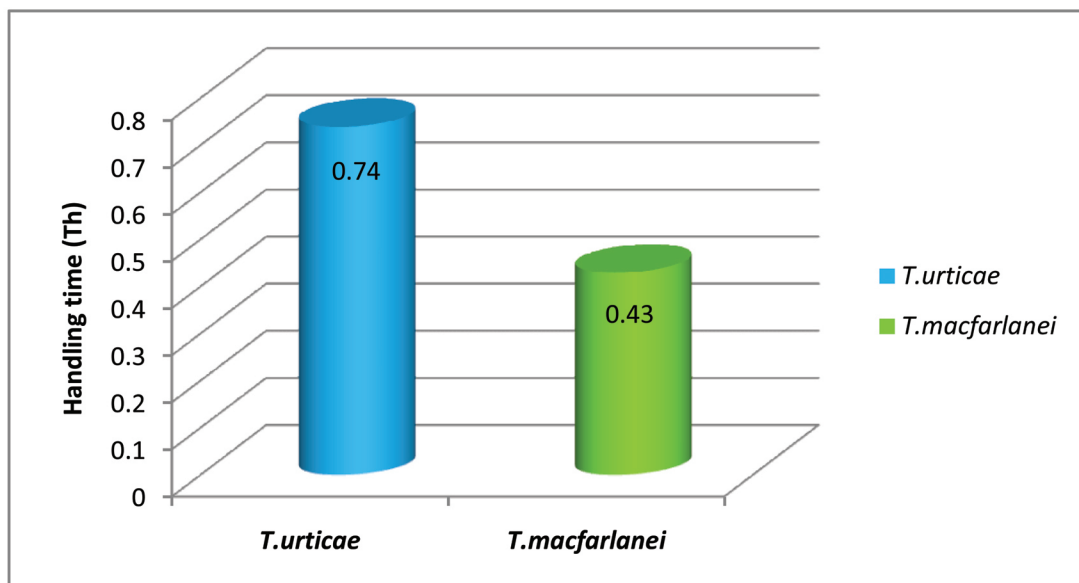
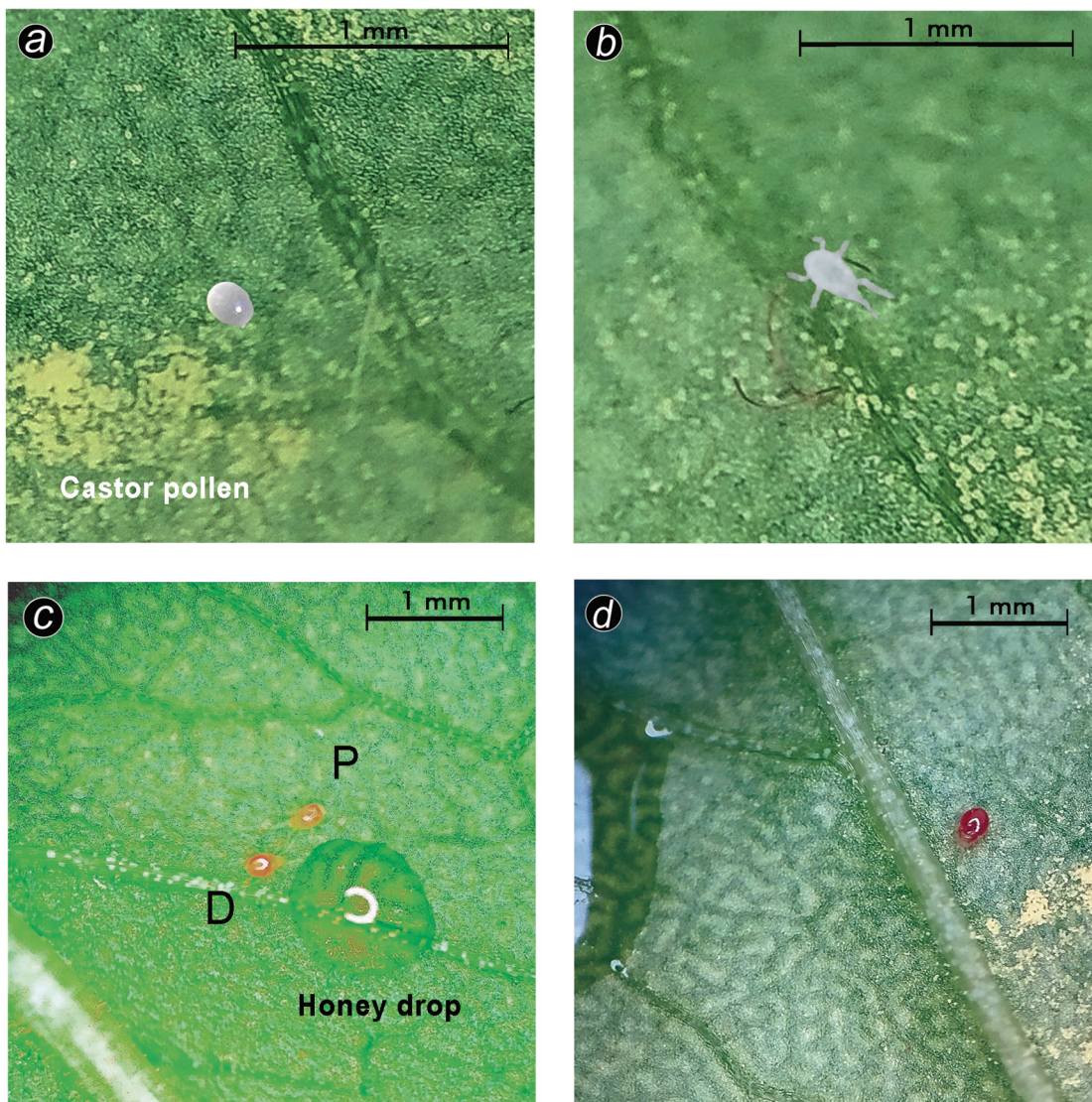


PLATE 39

Developmental stages of *Amblyseius paraaerialis* reared on Honey-Pollen Mixture



a. Egg; b. Larva ; c. Protonymph (P) and deutonymph (D);
d. Adult female

PLATE 40

Fig. 23

Duration of Pre-oviposition, oviposition and post-oviposition periods of *Amblyseius paraaerialis* at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

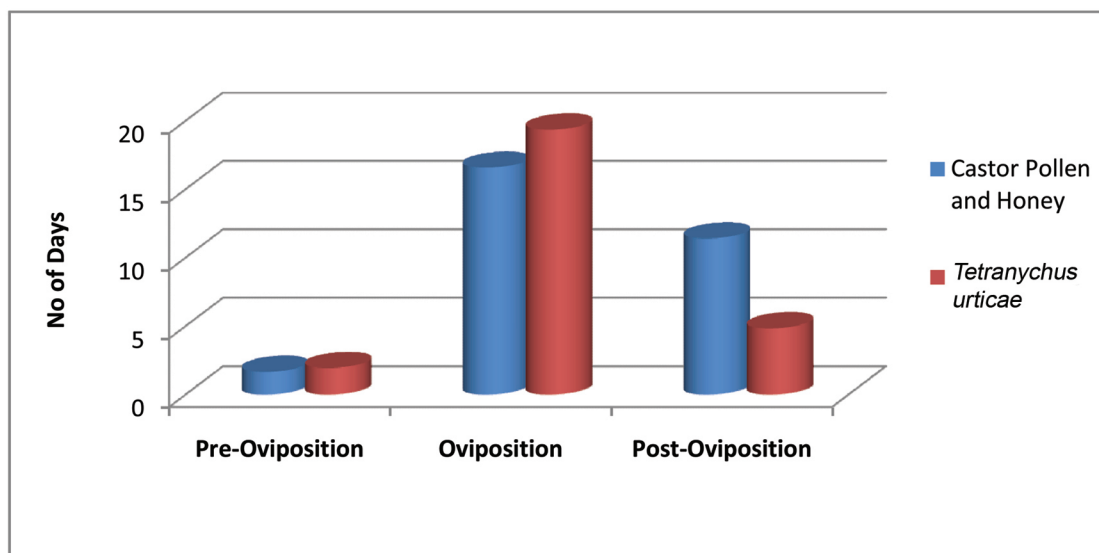


Fig. 24

Developmental duration (in hours) of individual immature stages of *Amblyseius paraaerialis* on different diets provided at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

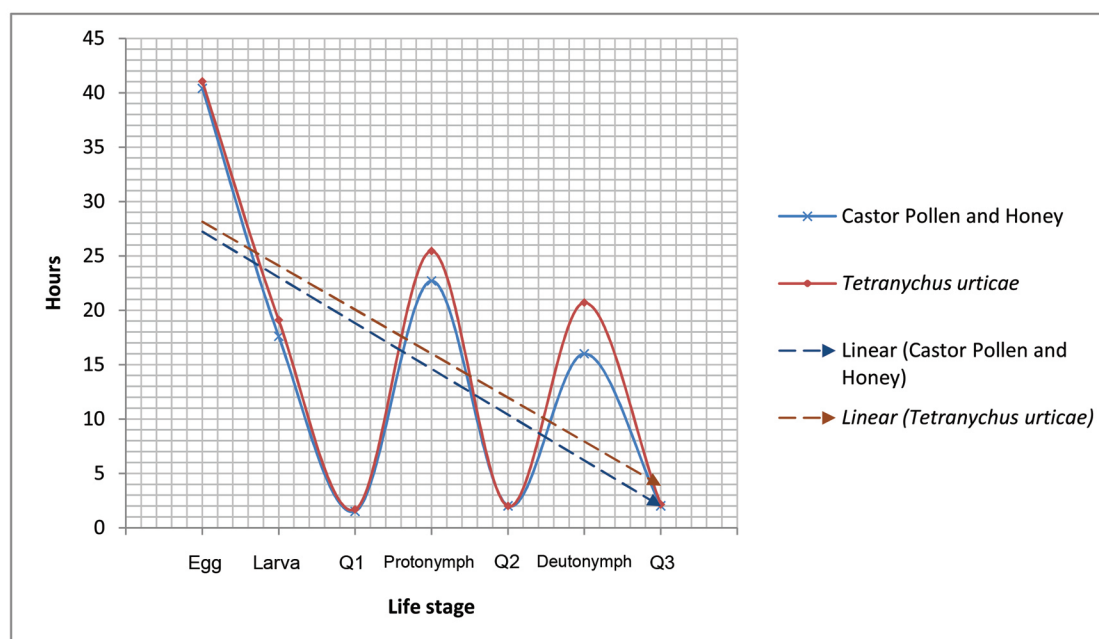


PLATE 41

Fig. 25

Total developmental duration (in hours) of immature stages of *Amblyseius paraaerialis* on different diets provided at $30 \pm 2^\circ\text{C}$ & $70 \pm 5\%$ RH

