STUDIES ON MITES INJURIOUS TO SELECTED MEDICINAL PLANTS OF KERALA

Thesis submitted to the
University of Calicut in partial fulfilment of the
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DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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CERTIFICATE

This is to certify that the thesis entitled **"Studies on mites injurious to selected medicinal plants of Kerala"** is an authentic record of the research work carried out by **Ms. Anitha. K.** under my supervision and guidance in partial fulfilment of the requirements for the degree of **Doctor of Philosophy in Zoology** in the Division of Acarology, Department of Zoology, University of Calicut and that no part thereof has been presented before for any other degree or diploma.

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DECLARATION

I, Anitha. K., do hereby declare that this thesis entitled **"Studies on mites injurious to selected medicinal plants of Kerala"** is an authentic record of the research work carried out by me under the supervision and guidance of **Dr. N. Ramani,** Professor, 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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"Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world"

Louis Pasteur

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Dedicated to…

My family

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PART- I

GENERAL SURVEY ON PHYTOPHAGOUS MITES INFESTING MEDICINAL PLANTS OF KERALA

INTRODUCTION

Mites constitute the most diverse members of an ancient lineage of the Phylum Arthropoda, subphylum Chelicerata and subclass Acari. Being one of the most heterogenous chelicerate group, mites exhibit extreme diversity in morphology, biology, and habits to occupy all available habitats in the terrestrial, aquatic and aerial ecosystems. Together with ticks, mites form the conspicuous group 'Acari' and the latter has attracted the attention of man owing to their multiple roles, which have been categorized in many beneficial and/or injurious/harmful ways. The beneficial categories of mites include the soil dwelling forms, especially the oribatid mites, which owing to their highly diverse feeding habits intensify the processes of organic decomposition and nutrient cycling, lead to enrichment of soil fertility and productivity. The importance of these mites in the indication of various environmental conditions including radioactive pollution, in forensic science for accurate determination of post mortem intervals, in the biological control of plant parasitic nematodes, pests and weeds etc. has also been elucidated. A good sector of mites is known to inhabit our aquatic bodies, where they act as potential indicators of water quality including water pollution, control of vectors like mosquito larvae etc. Despite the beneficial roles mentioned above, many groups of mites have been established as notorious pests of all types of economic crops comprising the vegetables, fruit crops, plantation

crops, medicinal plants, spice crops, garden plants, invasive plants etc. As parasites, pathogens and vectors, large number of mites affects our live stock, wild animals and even man, causing considerable economic loss and health hazards.

Phytophagous habit has been established well among members of superfamilies like Tetranychoidea, Tarsonemoidea and Eriophyoidea. The most economically important groups of phytophagous mites belong to families, Tetranychidae (spider mites), Tenuipalpidae (false spider mites or flat mites), Tarsonemidae (broad mites), Eriophyidae (gall mites), Tuckerellidae, Penthalidae etc. The life cycle of phytophagous mites generally includes various developmental stages like the egg, larva, two nymphal stages and the adult. A physiologically active and physically inactive stage known as the quiescent stage is present in between the larval and the first nymphal stages, between the first and second nymphal stages and between the second nymphal and the adult stages. Most of the phytophagous mites are quite injurious to all types of economically important crops, as they induce both direct and indirect damages on their host plants. While feeding, these mites puncture the plant cell surface by their needle like chelicerae and suck out the cell contents oozing out through the punctured site. Tetranychidae constitutes the largest phytophagous family comprising around 1,200 species, belonging to over 70 genera, and which enjoys worldwide

distribution. The spider mites spin fine webs which cover the leaves or the infested parts of the host plant, partially or completely.

Several species belonging to the genera *Tetranychus*, *Oligonychus*, *Panonychus*, *Eotetranychus*, *Eutetranychus*, *Shizotetranychus*, *Aponychus*, *Neotetranychus* etc. have been recognized as potential pests in agricultural fields and on greenhouse crops. *T. cinnabarinus*, *T. neocaledonicus*, *T. ludeni*, *T. macfarlanei*, *T. fijiensis*, *P. citri*, *P. ulmi*, *O. biharensis*, *O. coffeae*, *O. indicus*, *O. mangiferus*, *O. punicae*, *E. orientalis*, *E. truncatus, S. cajani, A. sulcatus* etc. are the most frequently occurring species on most of our economic crops. Under the family Tenuipalpidae, about 800 species have been described, in over 25 genera. The members of the genera *Tenuipalpus*, *Brevipalpus*, *Raoiella*, *Dolichotetranychus* etc. have been well established as pests of various economic crops. The members of this family play important roles as vectors, by spreading many plant viral diseases. The most common pest species of the family Tenuipalpidae includes *Brevipalpus phoenicis*, *B. obovatus*, *B. californicus*, *B. lewisi*, *B. chilensis*, *Raoiella indica*, *Tenuipalpus micheli*, *T. indicus* etc. The family Tarsonemidae includes 545 species belonging to 45 genera and the two important genera which comprise most of the plant mites are *Tarsonemus* (270 species) and *Steneotarsonemus* (70 species). Eriophyoidea constitutes an important and large superfamily of phytophagous mites, enjoying worldwide distribution. Over 3,000 species belonging to over 250 genera are known to occur in the world. Genera such as

Aceria, Acalitus and *Eriophyes* accommodate most of the injurious species of eriophyid mites.

The present study is an attempt to unravel the common and most injurious species of phytophagous mites inhabiting some selected species of medicinal plants of local importance. As per the estimates of the World Health Organization, 80 per cent of the world population depends on the traditional medicines to meet their primary health care needs (Gupta and Karmakar, 2011). Besides their wide usage as drugs in the Ayurvda, Unani and Sidda systems of medical treatment, an appreciable number of medicinal plants have been extensively used for production of cosmetics, food supplements, phytochemicals, nutraceuticals, colouring and flavoring agents etc. In par with the growing demand on medicinal plants for multipurposes, cultivation practices of which also have experienced an increase with immense funding from the Government and private sectors. Concomitant with the increase in cultivation practices, the medicinal plants, like other agricultural and horticultural plants, also have experienced increasing pest problems, resulting from the changed agricultural practices, indiscriminate use of pesticides and application of synthetic fertilizers.

Among the various kinds of pests which pose serious threat to our valuable medicinal flora, the arthropod pests, dominated by the insects and mites come in the forefront. Of these, mite pests have received relatively little

attention from both the public and scientific sectors, despite of the considerable damage induced by them. This is especially true, as far as South India, especially Kerala is concerned, where majority of the people rely on the ayurvedic and unani systems of treatment to meet their healthcare demands. The system of Ayurveda, which depends on the extracts of medicinal plants to a large extent, has attracted the fascination of foreigners. Kerala, being a state which is blessed with a creditable number of ayurvedic hospitals and nursing homes has made a tremendous raise in its economy out of this mode of treatment. Because of its wide acceptance among the people as the safe mode of treatment, Ayurveda has become an integral part of the routine life style of the people of Kerala and presently, it has become the practice of Keralites to maintain herbal gardens in their homeyards. However, despite the pivotal role played by medicinal plants in the maintenance of health care of people of Kerala, no adequate attention has been received so far for the conservation of this valuable group of floral entity and its protection from the increasing incidence of pest attack, experienced for the last few decades.

At present, only very scattered information is available on the pests, especially on the mite pests infesting our valuable medicinal flora. Formulation of control strategies against any pest requires acquisition of knowledge on varied aspects like the correct identity of the pest, the type of damage induced by the pest, distribution pattern and seasonal incidence, favourable conditions for population build up, pattern of development,

morphological features of the life stages, and the potential natural enemies, if any in the field which could be effectively used for management of pest in instances of pest outbreak etc. With these incentives, the present research project was undertaken to gather knowledge on the mite fauna infesting selected species of medicinal plants of local importance, distribution pattern and seasonal pattern of most injurious species, extent of damage induced by selected species on respective host plants, biological parameters of selected species, impact of temperature-humidity-host plant parameters on life cycle of selected species and also to charter possible measures for effective suppression of selected injurious species under controlled conditions, using natural enemies and biopesticides.

REVIEW OF LITERATURE

Currently, our knowledge on the phytophagous mites inhabiting medicinal plants is very much limited as this forms a poorly explored aspect. Hence, the present review has been extended to incorporate research work carried out on mite pests/associates of other crop plants also, apart from that of the medicinal plants.

The earliest record of phytophagous mites was made by Peal (1868) who first observed mite incidence on tea plants in Assam and named it as red-spider. Later, Wood-Mason (1884) described it as *Tetranychus bioculatus* which formed the first published reference on Indian plant mites of agricultural importance. The impact of climatic factors on the population density of the spruce spider mite, *Oligonychus ununguis* was studied by Garman (1923) and he noted an abundance of the species during the period of May to October. Baker and Pritchard (1953) listed five families belonging to the spider mite superfamily Tetranychoidea as strictly phytophagous on higher plants. Kadzhaja (1955) reported the infestation of *T. rosae* on *Rosa* sp. from USSR. Knowledge on the faunal diversity of Indian eriophyid mites infesting some economically important plants was enhanced by Channabasavanna (1966), who provided data on the role of these mites in gall formation on host plants. Oatman and McMurtry (1966) observed that the

phytophagous mite population on strawberry in southern California was reduced drastically in relation to low temperature and rainfall. Swirski *et al*. (1967) revealed that high temperature and low relative humidity would increase the growth of the mite population while high humidity would accelerate the natural enemy population, especially of the fungi which successfully suppress the mite population. Incidence of the spider mite, *Neotetranychus gloriosus* on medicinal plants like *Pscidia piscipula* and *Piper* sp. was recorded by Estebanes-Gonzalez and Baker (1968). Haramoto (1969) enlisted 37 species of plants belonging to 27 families as hosts for *B. phoenicis* in Hawaii and clearly demonstrated aerial dispersal in females of the species which showed heavy infestation on papaya. Van de Vrie *et al*. (1972) confirmed that the population size of spider mites was greatly affected by the differences in the host plant species or cultivars and these differences might be associated with the nutritional value of the host plants. Studies made by Keetch (1972) revealed that *P. citri* preferred humid and cooler conditions to build up its population to the peak level in spring months and the hot and dry conditions in the summer months supported low population densities of the mite. Tuttle *et al*. (1974) recorded the incidence of *N. gloriosus* on an economically important plant, *Agave tequilana* in northwestern and north central Mexico. Nageshchandra and Channabasavanna (1974) listed 36 species of economically important plants as hosts for *B. phoenicis* in India. Jeppson *et al*. (1975) provided an elaborate account on the injurious species

of phytophagous mites of the family Tetranychidae, Tenuipalpidae and Eriophyidae infesting common economic crops like vegetables, medicinal plants, and fruit trees. Tuttle *et al*. (1976) provided evidence on infestation by *N. gloriosus* on medicinal plants like *Croton ciliatogalnduliferus*, *Croton* sp., *Sida* sp. and *Solanum* sp. Lal (1977) conducted studies on the biology of *Eutetranychus orientalis* on two medicinally important host plants, *viz. Bauhinia variegata* and *Rauvolfia serpentina* under two different temperatures like 28.64^{o}C and 23.61^{o}C. Lal and Mukharji (1977) conducted an indepth study on the phytophagous mites infesting medicinal plants in Uttar Pradesh, India. The same authors (1979) recorded that hot dry wind favoured the population of *E. orientalis* on *citrus* in Varanasi, India. Smith-Meyer (1979) described the morphological variations between different populations of *B. phoenicis*, *B. californicus* and *B. obovatus* and also reported that each species had more than 50 host plant species on a global level.

Lal and Mukharji (1980) carried out studies on the seasonal distribution pattern of *E. orientalis* and *E. uncatus* on their host plants and observed that high temperature with low humidity and sunny days favoured the population buildup of *E. orientalis* while moderate temperature with moderate to high humidity favoured the development of *E. uncatus*. The population of *E. orientalis* was found abundant during summer months (March-June), low during the winter (December- February) and totally absent during rainy season (July-September). Pillai *et al.*, (1980) conducted studies

on the seasonal distribution of population of *T. equitorius* on mulberry in India and recorded maximum population of the mite during March to June and a decline during August and which remained at a lower level up to January-February. The sudden fall in mite population experienced from August onwards was attributed to the heavy rain fall. Smith-Meyer (1981) found that infestation by *E. orientalis* on economically important crops in Southern Africa initiated in February, and attained the peak level during the months of March and April. Dhooria (1982) studied the host range, seasonal incidence and ovipositional preference of *E. orientalis* on 45 species of plants. Lal (1982) recorded the effect of meteorological parameters *viz*. temperature, relative humidity and rainfall on the population of spider mite species like *E. orientalis, T. neocaledonicus* and *T. cinnabarinus* on cassava plant and observed a significant correlation between population increase and relative humidity and non-significant correlation between population size and temperature. Gutierrez' and Schicha (1983) examined 251 mite samples collected from cultivated plants and weeds in New South Wales and identified 25 species of tetranychid mites under 9 genera, of which 5 species *viz*. *Aplonobia citri*, *Schizotetranychus celarius*, *O. grypus*, *O. tiwakae* and *T. lombardinii* formed the first report from the Australian continent. Dhooria and Butani (1983) observed a positive correlation between *E. orientalis* population and high temperature on orange tree. The authors recorded highest population of *E. orientalis* on orange during the period from May to

September and a negligible population during December to March. Incidence of three species of false spider mites (*B. californicus*, *B. obovatus* and *B. phoenicis*) on citrus was reported by Denmark (1984) in Florida. Nageshchandra and Channabasavanna (1984) recorded a peak population density of *Raoiella indica* in February on guava in the months of March and April on coconut. The authors established a positive correlation between mite population and temperature and a negative correlation with relative humidity and rainfall. Sharma and Kushwaha (1984) conducted studies on the varietal preference of the vegetable spider mite, *T. neocaledonicus* on 4 varieties of brinjal in Rajasthan and recorded high incidence of the mite on Black beauty variety. Hoy *et al*. (1985) proved aerial dispersal of spider mites by catching live individuals of *T. urticae* on aerial panels kept 200 m away from infested almond trees, and reported that aerial dispersal was higher in the afternoon and evening, when prevailing winds were stronger. Nagraj and Reddy (1985) provided information on the various pests attacking the most important traditional medicinal plant, *Withania somnifera* in India. Van de Vrie (1985) recorded that the two-spotted spider mite, *T. urticae* was the major pest of greenhouse roses (*Rosa* sp.), a highly significant crop in Mexico.

Studies on the population dynamics of the oriental red mite of citrus, *E. orientalis* on coorg mandarin were carried out in India by Bhumannavar and Singh (1986). Karuppuchamy and Mohanasundaram (1987) conducted studies on the bioecology and control of the chilli muranai mite,

Polyphagotarsonemus latus in India. Mohanasundaram (1990) made observations on the association of members of the genus *Aceria* with some economically important plants in South India. Studies made by Ho (1991) observed that feeding by *P. latus* resulted in high economic loss on host plants like lemon, tea and pepper. Joshi *et al*. (1992) carried out studies on the leaf galls of *Pongamia glabra* induced by *A. pongamiae* in Delhi and found that leaf size and relative humidity had a significant positive correlation with the number of galls and mites. Khanjani and Kamali (1993) conducted studies on mites associated with some economically important plants of the family Fabaceae in Hamadan. Infestation by *T. urticae* on the lima beans, *Phaseolus lunatus* was reported in India by Gupta and Gupta (1994) and the authors also observed the presence of *O. mangiferus* on medicinal plants like castor and pomegranate. Childers (1994) showed that *B. phoenicis*, *B. californicus* and *B. obovatus* could severe potential vectors of leprosis on Florida citrus, causing heavy economic loss. Ochoa *et al.* (1994) listed a total of 177 species of plant hosts for *B. phoenicis*, *B. californicus* and *B. obovatus* in Central America, which included 114 hosts for *B. phoenicis*, 29 hosts for *B. californicus* and 34 hosts for *B. obovatus*. The authors also noted considerable morphological variations between the populations of *B. californicus* collected from Costa Rica. Kumari and Sadana (1995) recorded peak population of *B. phoenicis* on guava during the months of November-December. Chen *et al*. (1996) recorded the infestation of *T. truncatus* on *Sophora japonica* in China

and observed peak population of the mite during July-August with a mean relative humidity of 67 per cent and temperature of 28^{o}C. Rai and Singh (1997) analysed the population trend of *B. phoenicis* on *W. somnifera* (Ashwagandha) in relation to weather factors in Varanasi, India. Gotoh (1997) conducted studies on the population of *T. urticae* in four different Japanese pear orchards and found that the mite population varied depending upon the season. He observed two types of seasonal population trends in *T. urticae*, with peak population from September to early October in one pear orchard and two peaks in July and September, in the other orchard.

Lehman (1998) distinguished the spruce spider mite, *O. ununguis* as a "cool season" mite because it generally reached peak populations during the spring and fall. Salazar *et al.* (1998) carried out biological observations on the two spotted spider mite, *T. urticae* infesting raspberry crop and found that the mite population was highest in February. Bolland *et al*. (1998) prepared a World Catalogue of the spider mite family infesting several economically important crops, by listing 1189 species of spider mites categorized under 71 genera. The authors reported that species like *Oligonychus biharensis* and *Tetranychus desertorum* were polyphagous generalists infesting 53 and 193 species of host plants respectively and the two-spotted spider mite, *T. urticae* could infest on more than 900 species of host plants. Karmakar *et al*. (1998) observed seasonal abundance of *Panonychus ulmi* population in mulberry gardens of West Bengal. The authors reported that the mean population of *P.*

ulmi attained peak levels during the second fortnight of March (19.74/leaf). Roy *et al*. (1999) studied the seasonal abundance of spider mites and their predators on red raspberry in the years 1993 and 1994 at two agricultural locations near Quebec city, Canada. Bhagat and Singh (1999) observed that the population of *T. cinnabarinus* remained high during August to February on brinjal, due to the prevalence of congenial weather factors.

Khanjani and Kamali (2000) conducted studies on the pest mites associated with beans (*Phaseolus vulgaris*) in Hamadan province. Navajas *et al*. (2001) recorded data on the distribution of *T. kanzawai* throughout Asia, Oceania, North America and Mexico, where it acquired the status of a severe pest in agricultural fields. Childers *et al.* (2001) identified 10 species of *Brevipalpus*, 5 species of *Tenuipalpus*, *Pentamerismus tauricus* and *Ultratenuipalpus gonianensis* infesting on citrus worldwide. Gallo *et al*. (2002) detected infestation by *T. urticae* on various crops like cotton, strawberry, rose, tomato, beans, soybeans and peach in Brazil. Ghosh and Gupta (2003) conducted a survey on mites associated with medicinal plants in West Bengal, India and recorded the occurrence of both pest and predatory mites. The authors reported 54 species belonging to 27 genera under 14 families and three orders from West Bengal, of which 23 species were phytophagous, two species were fungivorous and remaining 29 species were predatory in habit. Hall and Simms. (2003) evaluated the damage induced by the Texas citrus mite, *E. banksi* to citrus and its impact on leaf longevity in

irrigated citrus orchard. Prasad and Singh (2003) studied the influence of abiotic factors on the incidence of *T. macfarlanei* on pumpkin. The authors observed a significant positive correlation between mite population and temperature. Zhang (2003) recorded infestation by the two spotted spider mite on 1200 species of plants and found that its infestation was mainly confined to vegetables, medicinal plants, ornamental plants and other economically important plants. Childers *et al.* (2003) provided a consolidated account on the plant mites of agricultural importance and listed that *B. californicus*, *B. obovatus* and *B. phoenicis* had a host range comprised of 316, 451 and 486 species of plants respectively. Data on morphological variations within the three species of *Brevipalpus viz*. *B. californicus*, *B. obovatus* and *B. phoenicis* were provided by Welbourn *et al.* (2003). Kitajima *et al.* (2003) reported that *B. phoenicis* was the only known vector of the passion fruit green spot virus in Brazil.

Yadav Babu (2004) observed an increase in areca mite populations during the months of March-April. Ghosh (2004) conducted a study on the mites occurring on medicinal plants in the Northeast India and recorded the presence of 45 species of mites on 21 species of medicinal plants belonging to 14 plant families. He recorded the incidence of both predatory and phytophagous mites of the families Phytoseiidae, Bdellidae, Cunaxidae, Stigmaeidae, Eupopidae, Cheyletidae, Tydeidae, Tetranychidae and Tenuipalpidae. Evidences for infestation by *B. phoenicis* on citrus and coffee

were provided by Teodoro and Reis (2004). Feres *et al*. (2005) observed the presence of several phytophagous mite species belonging to the genera *Eotetranychus*, *Neotetranychus*, *Oligonychus* and *Tetranychus* on various groups of economically important plants in Brazil. Nahar (2005) recorded the highest population of the two spotted spider mite, *T. urticae* during April and August period on the bean plants. Lahiri *et al*. (2005) conducted a survey on mites present on 35 species of plants of high medicinal value in Kolkata metropolis and recorded a total of 48 species of mites. Among these, 17 species were phytophagous in nature, causing considerable economic loss to their respective host plants while 31 species were predatory in habit, feeding upon phytophagous mites and other harmful insects. The phytophagous mites belonged to four families *viz*. Tetranychidae (11 spp., 5 gen.), Tenuipalpidae (3 spp., 1 gen.), Tarsenomidae (2 spp., 2 gen.) and Eriophyidae (1sp.). Among the pest mites, *T. urticae*, *P. citri*, *Schizotetranychus cajani* and *P. latus* were the most common species causing severe damage to the host plants and *Datura metel* was the host which harboured the maximum number of mite species (13 spp., 10 gen., 7 fam.) followed by *Justicia adhatoda* (6 spp., 5 gen., 5 fam).

Ghoshal *et al*. (2006) recorded the peak population of various pest mites on *Psidium guajava* during February and the minimum population during July. The authors also observed a positive correlation between mite population and temperature and relative humidity and negative correlation

with rainfall. Rolania and Sharma (2007) reported that population of *T. urticae* on Aswagandha peaked in the third week of December due to prevalence of fairly high temperature, and the population declined from the last week of December to a negligible level in the third week of January due to the prevalence of high relative humidity and rainfall. Gupta *et al*., (2007) evaluated the bioefficacy of some plant extracts to control population of the false spider mite, *B. phoenicis* on a medicinal plant, *J. adhatoda* in India. Mani *et al*. (2007) observed that population density of *T. urticae* increased in December and reached the peak in April on grapewine at Pune due to high temperature and low relative humidty. Sheeja and Ramani (2007) conducted studies on the spatial distribution pattern and seasonal abundance of an eriophyid vagrant species, *Anthocoptes vitexae* on the medicinal shrub, *Vitex negundo* in Kerala. Sangeetha and Ramani (2007a) conducted studies on the developmental biology of the vegetable mite, *T. neocaledonicus* on a nutrient rich vegetable cum medicinal crop, *Moringa oleifera.* The authors observed that respective durations of life cycle of the males and females were 9.5 ± 0 days and 10.9 ± 0.15 under the sexual mode where as those of the parthenogenetic progeny were 8.875 ± 0.04 days .The same authors (2007b) recorded significant loss ($p<0.01$) in chlorophyll content of *M. oleifera* leaves due to infestation by *T. neocaledonicus*. Data on the species composition and seasonal occurrence of tetranychoid mites like *T. urticae*, *Eotetranychus uncatus*, *Amphitetranychus viennensis*, *P. ulmi*, *Bryobia rubrioculus* and

Cenopalpus pulcher and their predators of the family Phytoseiidae and Stigmaeidae in insecticide sprayed and unsprayed apple orchards in Turkey during the period of April to November were provided by Yanar and Ecevit (2008). The predatory mites of unsprayed orchards were found to have more potential in controlling the pest population when compared to the sprayed orchards. Osman and Mahmoud (2008) recorded the patterns of seasonal abundance of phytophagous mites like *T. urticae* and *C. pulcher* on pear trees during the blooming and fruiting season of 2005-2006, in Egypt. Among the two species studied, *C. pulcher* and its life stages were present on its host during the entire period of study and *T. urticae* induced less economic damage on pear trees.

Vasquez *et al*. (2009) surveyed the phytophagous mites of the family Tetranychidae and Tenuipalpidae infesting natural vegetation, comprising mostly the medicinally important plants in Lara, Venezuela and the authors identified a total of eight tetranychid and two tenuipalpid mite species. The tenuipalpid species recovered were *B. phoenicis* and *Tenuipalpus* sp., of which the former species was identified from hosts such as *Cassia siamea*, *Capparis linearis*, *Spathodae campanulata*, *Randia* sp. and *Melicoccus bijugatus* whereas the latter was found to infest *Spondias mombin.* Plants like *C. siamea*, *S. campanulata*, *Randia* sp. and *M. bijugatus* were recorded as new hosts for *B. phoenicis* in Venezuela. The tetranychid species recovered

were *T. urticae*, *O. biharensis*, *Oligonychus* sp., *Neotetranychus gloriosus*, *T. cinnabarinus*, *E. banksi* and *E. willamettei.*

Rachana *et al*. (2009) observed the seasonal incidence of *T. neocaledonicus* and its natural enemies on okra leaves in Shimoga, India during the period from April, 2006 to March, 2007. The authors recorded high population of *T. neocaledonicus* during March and April months and the species showed a significant positive correlation with mean temperature and a significant negative correlation with the two spotted spider mite, *T. urticae* on brinjal during the period of October, 2008 to April, 2009 and the results of which revealed that the maximum temperature had a significant positive correlation (r = + 0.701) with the *T. urticae* population, whereas the relative humidity (r = - 0.471) and rainfall (r = - 0.398) had significant negative correlations. The average maximum temperature of 24-25^{o}C and above, with relative humidity of around 70 per cent and above was found favourable for the multiplication of *P. latus* on mulberry under Nilgiri hill conditions, as reported by Rajalakshmi *et al.* (2009).

The mite exhibited peak population in May and June. From October onwards when the average minimum temperature fell below 20^{o}C, the population started to decline. Shahini *et al*. (2009) conducted studies on the population dynamics of some eriophyid mites infesting Olive trees in Albania and found that the most common eriophyid mites were *Aceria oleae*,

Dirtymacus athiasella and *Tegolophus hassani*, of which the most predominant species was *Aceria oleae.* The highest population density of eriophyids was observed during April and later on, the mites moved on to the flowers. Yousuf and Chouhan (2009) recorded the incidence of seven species of mites belonging to genus *Tetranychus viz*. *T. hydrangea*, *T. neocaledonicus*, *T. urticae*, *T. ludeni*, *T. sayedi*, *T. fijiensis* and *T. macfarlanei* on forest trees in northern part of India.

Sharma and Agarwal (2010) pointed out that the two spotted spider mite, *T. urticae* had emerged as a new threat to the medicinal plants in India. Prabheena and Ramani (2010) conducted biological studies on the flat mite, *B. phoenicis* infesting the medicinal shrub, *Ocimum gratissimum* at 30^{o}C and 65% relative humidity and recorded that the average durations of preoviposition, oviposition and post oviposition periods of the species were 4.3, 8.9 and 7.2 days respectively. The species was found to complete its development from egg to adult stage with an average of 22.8 days. Sheela and Haq (2010) conducted studies on the breeding biology of an eriophyid species, *A. vitifoliae,* attacking the medicinal shrub, *Hibiscus vitifolius* in the laboratoty at a range of 28-30^{o}C, in northern Kerala and found that the species completed its development from egg to adult within 13-16 days. Ramanna *et al.* (2010) recorded that the period of infestation by *T. urticae* on the medicinal plant, *Withania somnifera* (Aswagandha) was from August 2008 to March 2009. Sudo *et al*. (2010) observed the co-existence of *B. obovatus* with

phytoseiid mites, mainly with *Phytoseius* spp. on the deciduous shrub, *Viburnum erosum* var. *punctatum* in Kyoto, West-central Japan, from the late summer to the mid-autumn (late August to October) period. Vacante (2010) conducted detailed studies on the citrus mites and reported 104 species belonging to various families like Phytoptidae, Eriophyidae, Diptilomiopidae, Tarsonemidae, Tenuipalpidae, Tuckerellidae and Tetranychidae.

Data on the seasonal abundance and feeding efficiency of the false spider mite, *Tenuipalpus pernicis* infesting guava were supplemented by Ghoshal *et al*. (2011). The mite population density was found averaged from November, 2007 to January, 2008 (17.9 ± 0.33 mites/6.25 cm^2 and 15.4 ± 0.43 mites/6.25 cm^2 respectively) with a peak density during May, 2008 (32.8 ± 0.28/6.25 cm^2) and a minimum population density in August 2008 (4.5 ± 0.51 mites/6.25 cm^2). The authors established a positive correlation between mite population density and temperature and relative humidity and a negative correlation with rainfall. Masoudian (2011) identified the mite fauna, mainly of the predatory mites of the family Phytoseiidae associated with some medicinal plants of the family Asteracae in Iran. Reddy *et al*. (2011) described new species of mites inhabiting three economically important plants like the eggplant (*Solanum melongena*), cycad (*Cycas micronesica*) and guava (*P. guajava*). The authors recorded that *T. marianae* and the predatory mite, *P. horridus* were the most dominant species on eggplant, *B. californicus* and the predator, *Cunaxa* sp. were the dominant species on guava and *B.*

californicus and *Amblyseius obtusus* were the dominant species on cycad. Haque *et al*. (2011) observed the seasonal abundance of *T. urticae* on 20 species of vegetable crops and 24 species of ornamental plants in Rajshahi during the period from August 2010 to January 2011. The authors noted that the increase in pest mite population was directly related with the increase in temperature and pest mite population attained peak level during August. Singh and Raghuraman (2011) identified *E. orientalis* as a major pest of citrus in India, and it was also found infesting other host plants like pear, peach, ber, cucurbits and cotton.

Badieritakis *et al*. (2012) surveyed the mite fauna inhabiting the foliage and litter of 10 species of *Medicago* of the family Fabaceae in Greece and the results of their study revealed 83 mite taxa from the foliage of herbaceous and shrub medicinal plants and 85 mite taxa from the litter samples of *M. strsseri*, *M. sativa* and *M. arborea.* The most common phytophagous mites identified during the survey were *A. medicaginis*, *Brevipalpus* sp., and *Pentamerismus* sp. A large number of predatory mites belonging to families Bdellidae, Cunaxidae, Cheyletidae, Stigmaeidae etc. were also identified. A survey conducted by Anitha and Ramani (2012) on the mite fauna associated with medicinal plants *viz*. *J. adhatoda*, *Cardiospermum halicacabum*, *Vitex negundo*, *O. sanctum* and *O. gratissimum* revealed the association of members of three families of the phytophagous mites *viz*. Tetranychidae, Tenuipalpidae and Eriophyidae. It was found that *C.*

halicacabum was infested by *T. neocaledonicus* and *B. phoenicis*; *A. vasica* was infested by *T. cinnabarinus* and *Brevipalpus* sp; *V. negundo* and *O. sanctum* were infested by *B. phoenicis* and *B. obovatus* respectively. A general abundance of tetranychid and tenuipalpid mites was recorded on the surveyed plants and the authors also reported the degree of infestation by individual species on its specific host plant. Sharma and Pati (2012) recorded the occurrence of the carmine spider mite, *T. urticae*, infesting the Ashwagangha, *W. somnifera* in Punjab, India. The mite population was found to occupy the aerial parts of the host and through their feeding activity the host leaves got transformed to shiny white in color, which gradually dried off and shed later. Sheela and Ramani (2012) provided information on the phytophagous mites infesting medicinal plants of Kerala by collecting 6 species of mites *viz*. *B. phoenicis*, *T. urticae*, *A. vitexae*, *Paratetra murrayae*, *Aceria* sp. nov. I and *Aceria* sp. nov. II which induced damage on 5 species of important medicinal plants such as *H. rosasinensis*, *J. adhatoda*, *V. negundo*, *Murraya koenigii* and *Ixora coccinia* respectively. The damage symptoms induced by these species included chlorosis, leaf crinkling, bud malformation, shoot deformity, and reduction in leaf size. Ghoshal and Barman (2012) conducted studies on population dynamics and feeding potential of *T. pernicis* infesting guava during the period of November, 2009 to October, 2011 and found that the mite population attained the peak level during June, in both the years (27.50 ± 0.16 mites/6.25 cm^2). The mean temperature, relative

humidity and rainfall recorded during this period were 31.01 ± 1.40^{o}C, 82.95 ± 2.45%, and 0.35 ± 0.22 mm respectively. The lowest mite population was recorded during November in both the years (0.02 ± 0.07 mites6.25 cm^{2}) when the mean temperature, relative humidity and rainfall were recorded as 26.31 ± 2.50^{o}C, 76.56 ± 4.72% and 0.81 ± 0.78 mm respectively.

Rekha *et al*. (2013) conducted studies on the incidence and damage symptoms induced by the spider mite, *T. macfarlanei* on the vegetable crop, *Abelmoschus esculentus* and they quantified the population density of the mite by adopting per leaf counting method and recorded the maximum population during the summer season, with peak density. The results of a survey carried out by Masoudian and Khanjani (2013) on the mites associated with some medicinal plants of the family Asteraceae, in Hamedan, Iran during the period of 2008-2009 enabled to record a total of 23 species of mites belonging to 18 genera and 15 families. The most abundant species was recognized as *T. urticae* during the survey period. Flores *et al*. (2013) studied demographic parameters of *T. urticae* on 4 cultivars of *Rosa* sp. Meynard *et al*. (2013) observed the seasonal abundance of *B. lewisi* on *Metasequoia glyptostroboides* (dawn redwood) in China. Prabheena and Ramani (2013) made a quantitative estimation of the chlorophyll loss induced by *B. phoenicis* on the medicinal shrub, *O. gratissimum* and recorded a marked reduction in the amounts of both chlorophyll *a* and *b* pigments. Nasareen *et al*., (2013) studied the seasonal variations in the population density of the gall mite,

Aceria doctersi within the leaf galls of *Cinnamomum verum* and found that factors like temperature, humidity and rainfall exerted an important role in regulating the population density of the mite. Temperature and humidity exhibited a positive impact (r = 0.58 & r = 0.237) on the population density of *A. doctersi* where as rainfall showed a negative impact (r = - 0.182). Ghoshal (2013) while surveying the mites infesting the tulsi plant recorded *T. neocaledonicus* as one of the dominant species throughout the period of his study.

Variations in the population distribution of two species of tenuipalpid mites on their specific host medicinal plants *viz*. *O. sanctum, O. gratissimum* and *J. adhatoda* grown in various localities of the Malappuram district of Kerala were studied by Anitha and Ramani (2014) during the period from September to December of 2011. It was found that *J. adhatoda* and *O. gratissimum* were infested by *B. phoenicis* and *O. sanctum* was infested by *B. obovatus* and the total number of adults and nymphal stages of *B. obovatus* on *O. sanctum* was high (3561) when compared to that of *B. pheonicis* on *O. gartissimum* (2327) and *J. adhatoda* (1445). Tsagkarakis *et al*. (2014) conducted studies on the faunal composition and seasonal abundance of mites on three species of citrus in Greece and recorded 15 taxa of mites belonging to three orders during the two year period of sampling. The mites collected included nine predatory taxa under three families *viz*. Phytoseiidae, Cheyletidae and Bdellidae and two phytophagous taxa under families

Tetranychidae and Eriophyidae. Nasareen and Ramani (2014) conducted studies on the seasonal variation in the population density of the gall mite, *A. pongamiae* within the leaf galls of *Pongamia pinnata* and observed a significant positive correlation between population density and temperature. The authors reported a negative correlation between number of mites and rain fall. Results of field studies made by Al-Nasser (2014) on the population density of phytophagous mites infesting the grape vine, *V. vinifera* in Makkah, KSA revealed the incidence of species *viz*. *B. californicus*, *Eriophyes vitis*, *T. urticae* and *Tarsonemus* sp., *Tydeus* sp. and three species of predatory mites, *Amblyseius andersoni*, *Typhlodromus pyri* and *Agistemus exsertus*, with the highest mean population density of *E. vitis* (225.4 individuals/10 leaves) on this host. Jafari *et al*. (2014) studied the population changes of *C. irani* and showed that the mite population rapidly increased to a high density during the summer season. Study on seasonal abundance of *O. coffeae* on tea in Assam was carried out by Mazid *et al*. (2015). The authors observed the highest population of the mite in the second week of June and lowest mite population was observed in December. The authors found a moderate positive correlation with humidity and maximum temperature and significant positive correlation with minimum temperature and rainfall. Nasareen and Ramani (2015) recorded the variation in the carbohydrate contents in the leaf galls on *C. verum* induced by *A. doctersi* by analyzing the carbohydrate contents in 10 and 35 days old galls as well as that of the

uninfested leaves. A significant increase in carbohydrate contents was observed in both the young and mature gall tissue when compared to the uninfested leaf tissues (P<.0001). Ahmed *et al*. (2015) conducted studies on the insects and mites infesting some medicinal plants used in the Unani system in India and recorded the presence of eight species of insects belonging to eight genera, eight families and two orders and twenty two species of mites belonging to seven families, ten genera and three orders on these plants. The authors also assessed the bioefficacy of some green pesticides prepared with the extracts of black tulsi (*O. tenuiflorum*), *karanja* (*P. pinnata*) and *palash (Butea monosperma*), for the control of the pseudococcid insect pest, *Ferrisia virgata* infesting the medicinal shrub, *D. metel*.

MATERIALS AND METHODS

During the present study, attempts were made to gain knowledge on the faunal diversity of phytophagous mites infesting the medicinal plants of local importance. This was achieved by undertaking general surveys on mites inhabiting a variety of medicinal plants grown/cultivated in various localities distributed over ten districts of Kerala. The state of Kerala, geographically has been divided into three climatically distinct regions *viz*. eastern highlands with rugged and cool mountainous terrain, the central midlands with rolling hills, and the western lowlands with coastal plains and it lies between north latitudes 8°17'30" N and 12°47'40" N and east longitudes 74°27'47" E and 77°37'12" E.

1. Sampling localities

For procuring of mite specimens from various medicinal plants, surveys were carried out to collect mite infested plant parts from various botanical/herbal gardens and other localities such as the urban and rural areas, sacred groves, agricultural fields, etc. While collecting, random sampling of aerial plant parts like the leaves, leaflets, twigs, inflorescence etc. was carried out from various species of plants growing in different localities. A total of seven botanical/herbal gardens and 29 sampling localities distributed in northern, central and southern districts of Kerala were surveyed during the present study. Of these, Kasaragode, Kannur, Wayanad, Kozhikode and

Malappuram represented the Northern districts, Thrissur, Palakkad and Eranakulam represented the districts of Central Kerala while Thiruvananthapuram and Pathanamthitta formed the Southern districts of Kerala.

1.1. Botanical / Herbal gardens

During the present study, mite infested plant parts were collected from a total of five botanical gardens and two herbal gardens (Table. 1; Plate. 1).

a) Calicut University Botanical Garden (CUBG)

Calicut University Botanical Garden, situated in the Malappuram district of Kerala formed one of the major collection site for the regular collection of mite infested plant samples. The garden lies within the latitude 11^{o} 35'-45' and longitude 75^{o} 40'-50'. Altitude of the place is 40-60 m. It is established in 1972 with an area of 19.5 ha and average altitude of 45.5 m from the sea level. It is an excellent centre of biodiversity and ex-situ conservation of tropical Indian flora and exotic species and the motto of the garden is to promote cultivation and maintenance of rare, endangered and threatened species of plants of south India. The garden has more than 300 species of medicinal plants of various groups *viz*. herbs, shrubs and trees in 19.5 ha of the total space of the garden. The soil here is lateritic in nature with

an average rainfall of 300 cm which is concentrated mostly in the monsoon season and the temperature ranges from 17-35^{o}C.

b). Kottakal Arya Vaidya Sala Botanical Garden (KAVSBG)

Kottakal Arya Vaidya Sala is located at Kottakal in the Malappuram district of Kerala. This botanical garden is located at 10^{o}59'48" N and 76^{o} 0'38" E. The main aim of this garden is exploration, identification, collection and documentation of all the groups of the plants used in Ayurvedic system of traditional medicine from various localities of the southern states of India. The herbal garden is set up in an eight acre plot at Kottakal. The garden supports live collection of more than 700 species of plants.

c). Parapanangadi Herbal Garden (PHG)

The Parapanangadi herbal garden is a private garden situated at Kodappali (11^{o}3'0" N and 75^{o}52'0" E) in the Malappuram district of Kerala. This herbal garden contains more than 250 species of medicinal plants. The aim of this herbal garden is to promote the knowledge and interest in the field of plant cultivation and to maintain the natural resources, mainly the medicinal herbs. The seeds and nurseries of various groups of medicinal plants are available in the garden.

d). Malabar Botanical Garden (MBG)

Malabar botanical garden and institute of plant sciences, Calicut is located in a serene sub urban area, Pokkunnu in the Olavanna village, about 10 km away from the Calicut city. It is located at 11^{o}14'24"N and 75^{o} 49'38" E. It is a center of research in biodiversity conservation and the main aim of this institution is the ex situ conservation of the endangered aquatic and wetland plants. The garden sprawls over 16 ha area with 6 ha wetland which is transformed into a placid lake, during monsoon and it is ideal for wetland flora conservation. The garden has eight green houses for medicinal plants, orchids, aquatic plants etc.

e). Thekumthara (Syam) Herbal Garden (SHG)

Syam Herbal Garden is a private garden located in the Thekumthara village in Kalpetta (11.622550^{o} N and 76.081252^{o} E), Wayanad district of Kerala. The garden is maintained in an area of 5 acres and has more than 400 species of medicinal plants categorized of herbs, shrubs, climbers and trees.

f). Kerala Forest Research Institute (KFRI)

KFRI is situated at Peechi, in the Thrissur district of Kerala. The institute is located at 10^{o}31'48" N and 76^{o}20'50" E. It is a research organization founded in 1975 and the institute is meant for conservation, sustainable utilization and scientific management of natural resources. The

institute is engaged in active research on tropical forests and forestry under the guidance of a multidisciplinary team of experts. The medicinal plant garden of the KFRI embraces more than 400 species of medicinal plants comprising herbs, shrubs, trees and climbers. The raw materials used in the Indian Materia Medica have been assembled as a reference collection in this Institute.

g). Jawaharlal Nehru Tropical Botanical Garden and Research Institute (JNTBGRI)

The Jawaharlal Nehru Tropical Botanical Garden and Research Institute is situated at 8^{o} 45'47" N and 77^{o}2'15" E at Palode, 40 km away from Thiruvananthapuram. It was founded in 1979 with the major objective of establishing a conservatory Botanical garden of tropical plant resources in general of the country and the Kerala state in particular and also to promote sustainable utilization of resources. The JNTBGRI organization maintains 300 acres of land for conservation of wild tropical plant genetic resources of the country. In includes 121 ha of forest land with hills and hillocks and evergreen, deciduous, marshy and rocky areas, which provides different microclimatic conditions for the profusion of the tropical species. The institute is currently conserving about 4000 species of flowering plants and about 300 species of non-flowering angiosperms.

1.2. Other collection localities in various districts of Kerala

Mite infested aerial parts (leaves/twigs) were collected from locally grown/cultivated species of medicinal plants from 29 localities distributed over 10 districts of Kerala (Table. 2). The sampling localities selected for the present study included rural and urban area, semi-forest area, temple premises and sacred groves, agricultural fields, home yards, etc. Species level identification of the locally available medicinal plants was done with the help of expert plant taxonomists in the Department of Botany, University of Calicut.

a) Sampling localities in Kasaragode district:

Two localities *viz*. Kanhangad (KSD-1) and Cheruvathur (KSD-2) were selected from the Kasaragode district for the survey of mite infested plants. The district is located at 12.5^{o} N and 75.0^{o} E and its landscape is dominated by the characteristic coconut palms, locally available medicinal plants and accompanied by rolling hills and streams flowing into the sea.

b) Sampling localities in Kannur district:

Kannur is located at 11.86^{o} N and 75.35^{o} E. Kannur has an elevation of 1.02 metres (2.98 ft) along the coast of the Laccadive sea, with a sandy coastal area. The two localities selected in the Kannur district for collection of mite infested plants were Edakkad (KAN-1) and Anjarakandi (KAN-2).

c) Sampling localities in Wayanad district:

Wayanad is located at 11.60^{o} N and 76.08^{o} E. The district has only 3.8 per cent urbanized area and the remaining area includes forests or villages. The district is home to many endangered species. Wayanad has a cool weather throughout the year except for April and May which reaches the peak summer, a maximum to 31^{o}C. The flora of Wayanad is characteristic of the Western Ghats and the plantation crops are grown in the cool climate. The mite infested leaves were collected from three localities of the district *viz*. Ambalavayal (WAY-1), Meenangadi (WAY-2), and Pookode (WAY-3).

d) Sampling localities in Kozhikode district:

Kozhikode is located at 11.25^{o} N and 75.77^{o} E. The city has 15 km (9.3 mi) long shoreline and small hills. A few kilometres from the sea to the east, the surface gathers into slopes and clustering hills with numerous valleys in between formed due to floods and sediment transport. Six localities *viz*. Feroke (KOZ-1), Ramanattukara (KOZ -2), Kadalundi (KOZ -3), Nadakkavu (KOZ -4), Kunnamangalam (KOZ -5) and Perambra (KOZ -6) were selected from the Kozhikode district for the purpose of sampling of mite infested plant parts.

e) Sampling localities in Malappuram district:

Malappurm is located at 11.04º N and 76.08º E and the district situated in the mid land area of the state. The district is comprised of small hills and fresh water streams. The climate is generally mild, hot and humid in nature. Six localities *viz*. Thenjipalam (MLP-1), Tirur (MLP-2), Thavanoor (MLP-3), Thirunavaya (MLP-4), Kanjiramukku (MLP-5), and Nilamboor (MLP-6) were considered for collection of plant samples.

f) Sampling localities in Palakkad district:

Palakkad is located at 10.77^{o} N and 76.65^{o} E and has got a tropical wet and dry climate. Temperature remains moderate throughout the year, with exceptions in March and April, which being the hottest months. The localities selected in this district for the collection of mite infested plants were Peringode (PKD-1), Mannarkad (PKD -2) and Nelliyampathi (PKD -3).

g) Sampling localities in Thrissur district:

This region lies in the south western coastal state of Kerala, and is located at 10.52^{o} N and 76.21^{o} E. The climate is generally tropical. Winter is experienced from December to February, which is slightly cooler, and windy, due to winds from the Western Ghats. Two localities *viz***.** Cheruvathani (TCR-1) and Mundoor (TCR-2) were surveyed during the present study for surveying mite infested plant parts.

h) Sampling localities in Ernakulam district:

Ernakulam District is located at 9.98^{o} N and 76.28^{o} E. It has an average elevation of 4 m (13 ft). The two localities selected from this district for collection of mite infested leaves were Edappally (ERK-1) and Paravoor (ERK-2).

i) Sampling localities in Pathanamthitta district:

Pathanamthitta district, located at 9.27^{o} N and 76.78^{o} E is characterized by three kinds of natural geographical regions *viz*. highland, the midland and the lowland. The district has tropical biodiversity with forest, plantations and rivers. About 50 per cent of the total area of the district is covered with thick forest. The collection localities selected from this district were Elanthur (PTM-1) and Parakode (PTM-2).

j) Sampling localities in Thiruvananthapuram District:

Thiruvananthapuram district is located at 8.29^{o} N and 76.57^{o} E, on the west coast of India, near the extreme south of the mainland. The average elevation is 16 ft (4.9 m) above sea level. The city has a climate that borders between a tropical savanna climate and tropical monsoon climate. Mite infested leaf samples were collected from two localities of this district *viz*. Pattom (TVM-1) and Perroorkada (TVM-2).

2. Medicinal plants surveyed

A total of 136 species of medicinal plants belonging to 114 genera and 50 families were surveyed during the present study for locating the incidence of phytophagous mite infestation and also to understand the most injurious and economically important groups of phytophagous mites (Table.3). Based on their habits, these plant species could be categorized in to shrubs (48), herbs (42), trees (31) and climbers (15).

3. Collection and identification of phytophagous mites

3.1. Collection of mite infested leaf/twig samples

During the period of survey, mite infested aerial parts like the twigs and leaves of the various species of medicinal plants were collected from the localities mentioned above, based on visual symptoms of infestation. In the field, both adaxial (upper) and abaxial (lower) surfaces of the leaves or leaflets of medicinal plants showing the symptoms of mite infestation were examined. The aerial parts of plants which showed characteristic symptoms of mite incidence like the presence of chlorotic spots, yellowing, white patches, crinkling etc. were plucked/cut with a fine scissors/blade and transferred to separate polythene bags, loosely tied with rubber bands, labelled and transported to the laboratory for further study.

3.2. Segregation of mite specimens:

In the laboratory, the leaf samples collected from various species of medicinal plants were screened under a stereo zoom microscope (Make:

Macro Vis, USA, Model No: MVNSZ-405). While screening, both the adaxial and abaxial surfaces were thoroughly examined under the microscope to locate the various life stages of the mite, the nature of feeding, damage symptoms produced etc. by the individual species. Mites belonging to the various groups were picked up using a moistened fine camel hair brush and preserved separately in 70 per cent alcohol containing 5 per cent glycerine contained in specimen vials. The specimen vials containing the various species were labeled and subjected to further processing for taxonomic studies. Adult males and females of each group were preserved in separate vials for the purpose of identification.

3.3. Clearing and mounting of mite specimens

The specimens preserved in 70 per cent alcohol were dehydrated by passing through different alcohol grades such as 80 per cent, 90 per cent and absolute alcohol in cavity blocks. The dehydrated specimens were transferred to a clearing medium (prepared by 1:1 ratio of absolute alcohol and lactic acid). The cleared specimens were mounted on microscopic slides by placing a drop of Hoyer's medium at the center of the Microslide. The slide mounted specimens were oven dried at 50-55^{o}C for 2-3 days, sealed and labeled for further study.

1) Preparation of mounting medium - Hoyer's medium

Hoyer's medium was prepared by mixing the ingredients listed below in the following proportion:

Gum Arabic	:	30 gm
Chloral hydrate	:	200 gm
Distilled water	:	50 ml
Glycerol	:	20 ml

1. Added 30 gm of Gum Arabic to 50 ml distilled water in a beaker and heated the solution at 60^{o}C, and stirred well with a glass rod.

2. Slowly added 200 gm of Chloral hydrate and stirred well.

3. After dissolving the Chloral hydrate, added 20 ml of Glycerol.

4. Filtered the solution with a glass wool and stored in a tightly sealed amber glass bottle at room temperature.

3.4. Identification of mite specimens

Identification of the cleared specimens up to the family, generic and species levels was made under the higher magnification (40X) of a research microscope (Axioscope) following the keys available in books (Jeppson *et al*., 1975; Krantz, 1978; Gupta, 1985, 2003; Ehara and Gotoh, 2009, Zhang, 2003), by referring the relevant papers and also by seeking help from experts in plant mites.

4. Study on faunal diversity, seasonal abundance and relative distribution of phytophagous mites

Data on the faunal diversity of phytophagous mites inhabiting various species of medicinal plants cultivated/grown in different localities of Kerala were recorded in Table -3. Based on the intensity of incidence/number of injurious families of mites, the mite infestation on the host plants were categorized in to four *viz*. high (+ + +), moderate (+ +), low (+) and absent (0). The above four categories were based on the number of mites representing a particular group present per leaf of the host plant, in the field condition. The mite incidence was categorized as high when the number of adult mites was more than 10, moderate when the number was in the range of 5-10, low when the number was 1-5 and absent when the number was 0. During the present study, the species level identification was made only for those species which showed frequent occurrence on respective host plants, inducing severe damage. The species of mites collected and identified from various medicinal plants were recorded and presented. The major host plants of most injurious species of mites were also recorded during the period of study. The major host plant status for a pest mite was considered based on their number of various life stages present per leaf (20-30) and severity/intensity of heavy visible damages produced. Occurrence of the pest mite on the same species of host plants in both the seasons surveyed during

the year 2011-2012 was another criteria used for the selection of major host plant.

Data on the seasonal abundance and relative distribution pattern of the most frequently occurring and most injurious species of phytophagous mites (*T. neocaledonicus* on *Cardiospermum halicacabum*; *O. biharensis* on *Justicia adhatoda*; *B. phoenicis* on *Vitex negundo*) were collected by regular sampling of host plants. Studies on seasonal abundance and relative distribution pattern of selected species of phytophagous mites on their respective host medicinal plants were carried out for a period of two years (2011 & 2012). For studying the seasonal abundance of selected species of phytophagous mites, mite infested middle aged leaves (n=10) were collected randomly from their respective host medicinal plants, in every month from various localities of Malappuram (Thenjipalam, Tirur & Kanjiramukku) and Kozhikode (Ramanattukara, Nadakkavu & Kadalundi) districts of Kerala. The meteorological parameters *viz*. temperature and relative humidity of these collection sites were recorded using Thermo Hygrometer. For studying the relative distribution pattern of selected species of phytophagous mites, mite infested middle aged leaves (n=10) were collected from their respective host plants from various localities of Kerala (Table. 4) during the dry period (January to May) of the year 2011 & 2012.

For collecting data on seasonal abundance and relative distribution pattern of the selected species, the population density of the mites was

recorded following per leaf counting method. While doing per leaf counting, 1-2 adult mites from each field collected leaf sample were mounted for species confirmation. When the mite population was low on the leaves, the number of life stages present on both surfaces of the leaves were counted directly under a stereo zoom microscope and pooled together. In cases of high infestation, the leaf samples were immersed in a petri dish (100 mm dia. x 15 mm H) containing 70 per cent alcohol for 5-7 min. and the leaves were slightly washed in alcohol to remove the entire life stages of the mites from the leaf surface. The life stages of individual species on each leaf sample in the Petri dish were thoroughly examined under a stereo zoom microscope in the laboratory. The excess alcohol was removed from the Petri dish with the help of a 1 ml syringe and the number of life stages of each species present per leaf in a Petri dish was counted. For seasonal abundance study, the data on the average number of mites present on infested leaves collected from above mentioned localities for every month was recorded. The data regarding relative distribution of the pest mites under study was recorded based on the population density of the pest mites in various collection localities. The population density of the pest mites was categorized into four *viz*. high, moderate, low and absent for the average number of mites as above 50, 20-50, below 20, and 0 respectively.

OBSERVATIONS

During the period of research, general surveys were carried out on the mites infesting medicinal plants grown/cultivated in various localities, distributed over ten districts *viz*. Kasaragode, Kannur, Kozhikode, Wayanad, Malappuram, Thrissur, Palakkad, Eranakulam, Pathanamthita and Thiruvananthapuram of Kerala.

1. Faunal diversity of phytophagous mites on various medicinal plants

Detailed examination of the systematic position of the mites recovered from the medicinal plants revealed the incidence of members of three acarine orders *viz*. Prostigmata, Mesostigmata and Oribatida. A total of 136 species of plants belonging to 114 genera and 50 families showed the incidence of mite infestation by disclosing members of the order Prostigmata (Table. 4). Members of the suborder Prostigmata were found to induce heavy, clearly visible damages on their host plants and hence theses mites were selected for detailed studies. Of the various species of plants screened, 59 per cent were recognized as hosts for the members of most injurious groups of mites. The members of three superfamilies *viz*. Tetranychoidea, Tarsonemoidea and Eriophyoidea of the order Prostigmata showed infestation on medicinal plants in almost all the seasons surveyed, inducing heavy damage. The pest mites which showed common occurrence on the plants surveyed were members of

four phytophagous families *viz*. Tetranychidae, Tenuipalpidae, Tarsonemidae and Eriophyidae (Fig. 1). The major genera of the pest mites recovered during the survey were *Tetranychus*, *Oligonychus*, *Eutetranychus*, *Eotetranychus*, *Panonychus*, *Bryobia*, *Aponychus* and *Schizotetranychus* of the family Tetranychidae; *Brevipalpus* and *Tenuipalpus* of the family Tenuipalpidae; *Polyphagotarsonemus*, *Tarsonemus* and *Steneotarsonemus* of the family Tarsonemidae; *Aceria*, *Anthocoptes*, *Acalitus*, *Acaphylla*, *Metaculus*, *Diptilomiopus* and *Eriophyes* of the family Eriophyidae. Among the 136 species of plants surveyed, 112, 84, 37 and 18 species of plants showed mite infestation by members of Tenuipalpidae, Tetranychidae, Eriophyidae and Tarsonemidae respectively (Fig. 2). Nineteen species of plants showed multiple infestation by members of more than two phytophagous mite families.

The major genera of most injurious pest mites recovered during the survey were *Tetranychus*, *Oligonychus*, *Eutetranychus*, *Eotetranychus*, and *Panonychus* of the family Tetranychidae; *Brevipalpus* of the family Tenuipalpidae; *Polyphagotarsonemus* of the family Tarsonemidae; *Aceria*, *Anthocoptes*, *Acalitus*, and *Eriophyes* of the family Eriophyidae. Among the pest mites recovered during the study, the dominant members of Tetranychidae belonged to the genera *Tetranychus* (23%) and *Oligonychus* (9%), while Tenuipalpidae was represented by *Brevipalpus* (27%) and others constituted 41% (Fig. 3.)

A total of 24 species belonging to 11 genera could be recognized as most injurious groups of pest mites on the medicinal plants surveyed. The most common injurious species recorded on various host medicinal plants during the study period were *Tetranychus neocaledonicus* Andre, *T. cinnabarinus* (Biosduval) (Plate. 2; Fig. A), *T. ludeni* Zacher, *T. macfarlanei* Baker & Pritchard, *T. fijiensis* Hirst, *Oligonychus biharensis* (Hirst), *O. coffeae* (Nietner) (Plate. 2; Fig. B & C), *O. indicus* (Hirst), *O. mangiferus* (Rahman & Sapra), *Eutetranychus orientalis* (Klien), *E. banksi* (McGregor), *Panonychus ulmi* (Koch) (Plate. 2; Fig. D), *P. citri* (McGregor) (Plate. 2; Fig. E), *Brevipalpus phoenicis* (Geijskes) (Plate. 2; Fig. E), *B. obovatus* Donnadieu, *B. californicus* (Banks), *Polyphagotarsonemus latus* (Banks) (Plate. 2; Fig. G & H, Plate. 3; Fig. A, B & C), *Eotetranychus* sp., (Plate. 3; Fig. E & F), *Aceria pongamiae* (L.), *Anthocoptes vitexae* Mohanasundaram, *A. docterci* (Nalepa), *Aceria* sp., (Plate. 3; Fig. D), *A. clerodendronis* (Farkas) and *Acalitus hibisci* Mondal & Chakrabarti (Table. 5).

Data were also collected on the host range of selected species of injurious mites infesting common medicinal plants of local importance. Data regarding the incidence of most injurious species of phytophagous mites along with details of host plants are presented in Table. 5. The results of the survey also helped to add new host records for 11 species of mites *viz*. *T. neocaledonicus* (*Leucas lavendulifolia*, *Acalyha indica*, *Gloriosa superba*, *Mussaenda frondosa*, *Dalbergia lanceolaria*, *Desmodium gangeticum*,

Adenanthera pavonina, and *Scoparia dulcis*); *T. cinnabarinus* (*C. halicacabum*, *Biophytum reinwardtii*, *Pseudarthria viscida*, *Emilia sonchifolia*, *D. motorium*, and *A. pavonina*); *O. biharensis* (*Justicia adhathoda*, *B. reinwardtii*, *Bauhinia accuminata* and *D. motorium*); *O. indicus* (*Artocarpus hirsutus* and *Demostachya bipinnata*); *E. orientalis* (*M. frondosa* and *Momordica charantia*); *P. citri* (*Mitragyna parvifolia*); *P. ulmi* (*B. acuminata*); *B. phoenicis* (*Premna corymbosa*, *Lawsonia inermis*, *Vitex trifolia*, *Mentha rotundifolia*, *C. halicacabum*, *L. lavendulifolia*, *Abrus precatorius*, *Rauvolfia serpentia*, *V. cinera*, *W. somnifera* and *Andrographis paniculata*); *B. obovatus* (*Oroxylum indicum*; *P. latus* (*C. halicacabum*, *L. lavendulifolia*, *A. paniculata*, *S. dulcis*, *Vernonia cinera*, *C. prostrata* and *Salacia reticulata*); *Aceria* sp. (*Ceriscoides turgida* and *Ecobolium viride*). The host range of the species recovered could be listed as *T. neocaledonicus* (20 plants), *T. cinnabarinus* (22 plants), *T. ludeni* (11 plants), *O. biharensis* (17 plants), *B. phoenicis* (28 plants) and *P. latus* (17 plants) (Table. 5).

The major host plants recorded for the pest mites were, *T. neocaledonicus* (*C. halicacabum*, *L. lavendulifolia*, *A. precatorius*, *A. indica*, *C. retusa*, *M. oliefera*, *A. pavonina*, *C. fistula*, *I. tinctoria* & *R. communis*); *T. cinnabarinus* (*J. adhatoda*, *D. metel*, *C. halicacabum*, *M. rotundifolia*, *M. frondosa*, *A. indica*, *C. ternatea*, *P. viscida* & *S. rhombifolia*); *T. ludeni* (*Hibiscus aculeatus*, *A. esculentus* & *D. metel*); *T. macfarlanei* (*S. indicum*, *Solanum nigrum* & *A. esculentus*); *T. fijiensis* (*I. racemosa*, C. *papya* & *H.*

annus); *O. biharensis* (*J. adhatoda*, *B. reinwardtii*, *B. acuminata* & *D. motorium*); *O. coffeae* (*C. arabica*, *M. sylvestris*, *T. sinensis* & *R. indica*); *O. indicus* (*A. hirsutus*); *O. mangiferus* (*V. vinifera* & *A. squamosal*); *P. harti* (*O. corniculata*); *E. orientalis* (*A. indica*, *C. papya* & *M. frondosa*); *E. banksi* (*P. reticulatus*); *Eotetranychus* sp. (*R. communis*); *P. citri* (*C. papya*, *C. lemon* & *M. parvifolia*); *P. ulmi* (*M. sylvestris*); *B. phoenicis* (*V. negundo*, *L. inermis*, *V. trifolia* & *P. guajava*); *B. obovatus* (*O. sanctum*, *D. metel* & *P. amarus*); *B. californicus* (*B. variegata*, *H. rosa-sinensis* & *H. annus*); *P. latus* (*D. metel*, *C. halicacabum*, *V. cinera* & *L. lavendulifolia*); *A. pongamiae* (*Pongamia pinnata*); *A. vitexae* (*V. negundo*); *Aceria* sp. (*C. turgida* & *Ecobolium viride*); *A. clerodendronis* (*C. inerme*); *Acalitus hibisci* (*H. vitifolius*); *Eriophyes alangii* (*Alangium salvifolium*) (Table. 5).

2. Seasonal abundance and relative distribution of phytophagous pest mites

Results of studies on seasonal distribution pattern revealed that the phytophagous mites exhibited peak population (3-4 months) during the dry period of the year, usually from February to May, a low population (2-3 months) during the rainy season from June to August and a moderate density (4-5 months) during September to January months (Table. 6). During field sampling, species like *T. neocaledonicus* and *O. biharensis* were found to occur in peak densities during the months of March to May, and average number of mites per leaf was observed as 163.25 ± 2.72 and 196.45 ± 3.07

respectively for the two species in the month of April. A marked reduction in the number of mites was observed during the rainy season, and average number of mites per leaf was recorded as 27.61 ± 1.52 and 32.41 ± 1.73 respectively for *T. neocaledonicus* and *O. biharensis* in the month of July. Subsequent to the rainy season, the mite population showed a slight tendency to increase and from September onwards, mite population showed a moderate level of distribution up to February. In the case of the false spider mite, *B. phoenicis*, the maximum mite population was observed in May and the number of mites per leaf was recorded as 179.58 ± 2.85. The lowest population (43.03 ± 2.17 mites per leaf) was recorded in the month of July. *B. phoenicis* also showed a moderate population during the period of September to February. Results of statistical analysis of the population density of the pest mites with respect to the meteorological parameters *viz*. temperature, relative humidity and rainfall revealed a significant positive correlation between mite population and the average temperature and a significant negative correlation between the mite population and average humidity and rainfall.

Table. 7 presents the data on relative distribution of species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* on host plants surveyed in various localities of Kerala. Based on the relative distribution pattern of the pest mites in the various herbal/botanical gardens and other localities of Kerala four categories were distinguished to represent mite population density such as high, moderate, low and absent. The vegetable

mite, *T. neocaledonicus* was found to occur in high population on plants grown in 25 sites (4 botanical/herbal gardens & 21 localities), in moderate population on plants screened from 7 sites (3 botanical/herbal gardens & 4 localities), in low density on plants surveyed in 3 sites and showed a total absence on plants collected from 2 localities. Meanwhile, *O. biharensis* showed high population density on plants collected from 21 sites (4 botanical/herbal gardens & 17 localities), moderate occurrence on plants collected from 10 sites (2 botanical/herbal gardens & 8 localities), low population on plants collected from 4 sites (1 botanical & 3 localities) and a total absence on plants grown in 2 sites (localities). Of the three species of pest mites studied, the false spider mite, *B. phoenicis* showed its high population density on plants collected from 28 sites (7 botanical/herbal gardens & 21 localities) and moderate population on plants collected from 7 sites (localities), low population on plants screened from 2 sites (localities). The species showed its presence in all the localities surveyed and its population was high in all the botanical/herbal gardens screened.

PART – II

STUDY ON BIOLOGICAL PARAMETERS OF SELECTED SPECIES OF PEST MITES

INTRODUCTION

One of the most essential aspect for chartering effective integrated control measures of a pest population is a precise knowledge on its biological parameters like the food and feeding habits, seasonal abundance and host range of the pest species, the breeding cycle, duration of life cycle, feeding habits of immature stages, effect of various factors like temperature, humidity, type of host plant, natural enemies with potential to regulate pest population in field etc. Taking in to consideration of these facts, in the present study attempts were made to conduct detailed observation studies on feeding and breeding biology of three species of pest mites, which induced significant loss both qualitatively and quantitatively to some of the most vital medicinal plants of local importance. The pest species selected for detailed biological studies were *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* and their respective host plants were *Cardiospermum halicacabum*, *Leucas lavendulifolia*, *Justicia adhatoda*, *Biophytum reinwardtii*, *Bauhinia acuminata*, *Mentha rotundufolia* and *Vitex negundo*.

The pest mite species selected for biological studies during the present Ph.D. work represent the most injurious phytophagous families like the Tetranychidae and Tenuipalpidae. Members of these phytophagous families are well known notorious pests which induce heavy damages at the cellular level, tissue level and organ level on their host plants. As a result of feeding,

the leaf surface area for photosynthesis and transpiration would become greatly reduced, leading to improper functioning of normal plant physiological processes. Heavy infestation by these mites would generally result in both physiological and morphological aberrations which become visible in the form of clear white chlorotic spots, white patches, necrotic spots and patches, yellowing, brown colouration, crinkiling and shrunken appearance and early leaf abscission, thereby declining the vigor of the host plants. Moreover, various biochemical alterations also result from the mite infestation which include the loss in photosynthetic pigments, enhanced production of stress proteins, polyphenols etc. thereby greatly affecting the photosynthetic machinery and biomass of the host plants.

The members of Tetranychidae, the commonly called 'spider mites' are small, red, green, yellow or brown coloured with the females generally larger than the males. The gnathosoma is provided with a capsule like structure known as the stylophore, which is formed by the fusion of the cheliceral body. The chelicerae are well suited for piercing the plant tissue and sucking up the cell sap, thereby leading to drastic reduction in the number of mesophyll tissues of the leaves of the host plant. The infested leaves show distorted epidermal cells, reduced number of chloroplast cells and collapsed palisade parenchyma cells. The webs produced by the spider mites cover the infested part of the host plant and this in turn would act as a barrier for normal physiological processes of the host plant *viz*. photosynthesis and gas

exchange. The most common mite feeding symptoms include chlorotic spots, necrotic spots, stippling, crinkling, bronzing, defoliation etc. The damage of mesophyll layer on the lower surface of the leaves due to feeding causes bronzing. Among the spider mites the members of two genera *viz*. *Tetranychus* and *Oligonychus* are known to induce wide spread damages on almost all categories of economic plants and hence considered for conducting detailed studies on feeding and breeding parameters.

T. neocaledonicus has become a serious threat to vegetable crops and it shows a wide range of distribution throughout the world. This species is found to colonize the lower surface of the leaves generally, but may infest both surfaces of host leaves, depending up on the size of the host plant and the severity of infestation. Feeding by this mite leads to varying damage symptoms like the appearance of chlorotic spots, chlorotic patches, yellowing and drying up of leaves. During heavy infestation the premature leaf drop also has been observed. *O. biharensis* is a serious pest of agricultural, vegetable, fruit, ornamental and medicinal crops. The life stages of this species are usually found confined to the upper surface of the leaves and during heavy infestation extend their infestation to both surfaces. Infestation by this mite leads to the development of characteristic yellowing, bronzing, crinkling and drying up of leaves and thereby resulting in severe loss to crop yield. Herbaceous plants, up on infestation by this species would get completely

destroyed while mite infested shrubs and trees show a decline in plant vigor and reduced yield.

Members of Tenuipalpidae, resemble the spider mites in several respects but are unable to spin silken webs like the spider mites and hence are known by the common name 'false spider mites'. Apart from inflicting direct feeding injury with their relatively long mouth parts, tenuipalpid mites cause indirect damage also by injecting toxic saliva into the leaves, stem, bud tissues and fruits of the host plants. Members of tenuipalpid genera *viz*. *Brevipalpus*, *Cenopalpus*, *Dolichotetranychus*, *Raoiella* and *Tenuipalpus* are recognized as serious economic plant pests, causing many direct (feeding injury) and indirect (viral diseases) damages on their host plants. *B. phoenicis* is a dorso-ventrally flattened, slow moving, red coloured small sized mite, infesting the lower surface of the host plant leaves, mainly along the midrib region. The visible damage symptoms induced by this species include necrotic and leprotic spots and patches and development of yellow and brown colouration of infested leaves. This species acts as vector for a number of phytopathogenic viruses like Citrus leprosis virus, Citrus necrotic spot virus and Hibiscus green spot virus.

The life history of the spider mites and false spider mites includes five stages *viz*. egg, larva, protonymph, deutonymph and adult. In between each of the active life stages, there is an immobile but physiologically active stage

known as the quiescent stage. These mites exhibit both sexual and parthenogenetic modes of reproduction, as evidenced during the present study in species like *T. neocaledonicus* and *O. biharensis*. Most of the spider mites exhibit arrhenotoky in which the unfertilized eggs develop into male individuals. Many species of the genus *Brevipalpus* including *B. californicus*, *B. obovatus* and *B. phoenicis* though have been established as sexual species with low frequencies of male individuals, quite often are reported to be solely parthenogenetic with thelytokous reproductive mode, under the feminizing effect of various bacterial symbionts of the genera *Wolbachia*, *Cardinium* etc. The longevity of tenuipalpid mites, especially members of *Brevipalpus* is far superior, reaching 2-3 times greater than that of the longevity of the Tetranychid mites.

Estimation of mite induced feeding damage is expected to provide a general awareness on the nature and extent of economic loss on a particular crop, resulting from the most injurious group of mites. Measurements of the variations in the level of biochemical compounds induced by mite infestation on respective host plants would give a clear indication on the severity of pest attack. Measuring the intensity of feeding damage would become a useful tool for fast estimation of severity of infestation and predicting yield loss. With this intention, in the present study, both qualitative and quantitative estimations were carried out to record the cellular levels of damage,

photosynthetic efficiency of host plants as well as the variations in the biochemical constituents like the stress proteins and polyphenols.

Mite populations, generally show an increase or decrease depending upon the prevailing environmental factors especially like the temperature, relative humidity and type of host plant/source of food. On the availability of optimum conditions, mite populations exhibit rapid increase to assume peak proportions on respective host plants, causing extensive damage. In order to find out the optimum temperature-humidity conditions which support the maximum rate of reproduction of pest mites, three temperature-humidity combinations and varied host plants were selected to conduct studies on breeding parameters of the three selected species of pest mites. This would help to identify the most favoured temperature humidity conditions and the most preferred food plant of the various species to build up the mite population density in rapid rates.

REVIEW OF LITERATURE

In par with the biological parameters of pest mites included in the present study, the review of literature presented here has been divided into two sections *viz*. feeding biology and breeding biology. In the feeding biology section, research works done on various feeding parameters like the damage symptoms induced by pest mites, most preferred feeding sites, morphological and anatomical structural alterations produced, mite induced biochemical and physiological variations in the normal functioning of host plant, contamination with the fecal pellets and webs of the pest mites on their host plants etc. variations in the biochemical compounds and physiological functions. The breeding biology section of the review include the research works concentrated on aspects such as two modes of reproduction (sexual and parthenogenetic), oviposition periods, fecundity, female longevity, egg viability, developmental durations of the immature life stages, immature survivability, moulting, adult duration, mating and sex ratio of various pest mites.

1. Feeding biology

The association of *Brevipalpus* mites with leprosis and their involvement in the transmission of the disease in Argentina was brought to light through the studies carried out by Frezzi (1940). Vergani (1945) designated that the feeding injury produced by *B. obovatus* to citrus leaves,

fruits and twigs could be defined as "Lepra explosive" or "Leprosis". Bodenheimer (1951) observed that *E. orientalis* infested citrus leaves would weaken and drop, and during heavy infestation led to dieback of twigs and branches. The author also observed that the stressed plants were more prone to damage by the mite. Blair and Groves (1952) recorded that the leaves of fruit trees infested by the red spider mite presented a flattening of epidermal cells. The feeding injury on citrus fruits by *B. lewisi* in California was found to result in the development of scab-like isolated depressions and subsequent formation of scars as observed by Elmer and Jeppson (1957). Knorr and Price (1958) referred the leprotic disease as “nailhead rust” in Florida and the symptoms were observed on both surfaces of leaves. Biochemical studies were carried out by Boulanger (1958) to assess the alterations induced in the metabolic activities of red delicious apple leaves as a result of infestation by the European red mite.

Knorr (1959) observed that *B. californicus* was the only species associated with leprosis disease on citrus in Florida. Knorr *et al*. (1960) reported that the intensity of infestation by *B. phoenicis* on leaves and stems of citrus was comparatively high than that of *B. obovatus*, when they co-existed on the same plant. Liesering (1960) observed that the feeding punctures produced by *T. urticae* could exhaust 18 to 22 cells per minute and the puncturing of the cells proceeded from one spot to another in the form of a circle, thereby resulting in the formation of typical, small round suction spots.

Dean and Maxwell (1967) reported that large populations of *B*. *californicus* and *B*. *phoenicis* were responsible for causing rind spotting or leprosis like spotting on grape fruits in Texas. *B. californicus* was found to attack grape fruits and orange in Texas and Florida and the symptoms on twigs and branches were referred as "Florida scaly bark". The species produced smaller necrotic lesions on the surface of infested leaves and fruits and which were called as "Leprosis-like spotting" or "nail head rust". The brown necrotic area or spot ultimately turned to darker with a corky texture and the damage to fruits usually occurred in the lower tree canopy, below the level of two meters. Gonzalez (1968) recognized *B. chilensis* as a polyphagous species which did not transmit any diseases and its infestation was recorded in the Oriental and Neotropical regions where it caused silvering of citrus fruits. According to Knorr *et al*. (1968), the incidence of leprosis was first observed in Florida in the 1860's and it gradually spread to 17 counties. The prevalence of leprosis and the infestation of *B*. *californicus* greatly destroyed the citrus industry in Florida. Avery and Briggs, (1968a, b) provided information on the damages caused by the fruit tree red spider mite, *P. ulmi* on the leaves and fruits of its host plum and apple.

Knorr and Denmark (1970) observed that the feeding activity of *B*. *phoenicis* on citrus seedlings resulted in the formation of "Brevipalpus gall" or "nodal galling". Symptoms of leprosis were found developed on the fruits, leaves, shoots and large limbs of citrus as reported by Knorr (1973). Chestnut-

brown spots of pinhead size to 6 mm in diameter were found to occur on oranges as a result of mite infestation. Rajagopalan (1974) reported that *T. ludeni* was the only spider mite species in India which vectored the plant viral disease, Dolichos Enation Mosaic Virus (DEMV) and this highly polyphagous mite showed occurrence in the field almost throughout the year. Hazan *et al*. (1974 & 1975) observed that the heavy webs spun by spider mites on leaves would reduce the photosynthesis and transpiration rates of plants. Jeppson *et al*. (1975) designated the feeding damage induced by the reddish black flat mite as "phoenicis blotch" in Florida and the authors reported that feeding by *B. lewisi* and *B. californicus* on citrus fruit induced 'silvering' of affected tissues. Hall and Ferree (1975) estimated the damage induced by *T. urticae* on its host plant through biochemical studies. Sandhu and Gupta (1977) reported that *T. urticae* could infest a large number of vegetables and the infested leaves first showed yellow colouration and then bronzing and stunted growth, leading to reduction in yield and quality of marketable flowers.

Ultrastructural elucidation of leaf damage induced by *T. mcdanieli* to 'Red Delicious' apple was made by Tanigoshi and Davis (1978) and the authors observed that mite infestation resulted in the coagulation of protoplasts and the chloroplasts inturn leading to a swollen appearance with cup-shaped thylakoids. Kolodoziej *et al.* (1979) observed depletion of chlorophyll content in plants infested by *T. urticae.* Sances (1979 a & b)

studied the morphological and physiological responses of strawberry leaves to infestation by the two spotted spider mite. A reduction in photosynthetic rate induced by the pacific spider mite was reported by Andrews and La Pre´ (1979) in almond leaves. Buchanan *et al*. (1980) recorded *B. lewisi* as a polyphagous species, showing worldwide distribution trend. Mattson (1980) observed that nitrogen formed an important, and often limiting, nutrient for herbivores. *T. urticae* on apple was found to result in a reduction in CO_2 assimilation, stomatal conductance, and leaf transpiration thereby leading to reduced yield as shown by Ferree and Hall (1980).

Studies made by Rice and Weinberger (1981) showed that *B. lewisi* caused necrotic spots on pistachios in California and the mite was found to feed on the petioles, stems, and nuts and as a result dark, irregular and roughened scab-like blotches were formed on the surface where the mites aggregated and fed along the edges of damaged tissue. Pettersson (1981) reported that infestation by *B. obovatus* on its host ultimately led to heavy leaf drop. Garcı´a-Marı´ and Del Rivero (1981) recorded that the feeding damage induced by *P. citri* on their host plant included webbing and silvering on both leaves and fruits. Severe infestation by this species caused defoliation followed by twig dieback. Chiavegato *et al*. (1982) conducted transmission studies on the virus causing leprosis and its vector, *B. phoenicis*. Mothes and Seitz (1982) observed the fine structural alterations developed in bean plant leaves infested by *T. urticae*. Hanna *et al*. (1982) established a positive

correlation between nitrogen levels in leaf tissues and rates of mite development and fecundity.

De Angelis *et al*. (1983) studied the impact of spider mite infestation on photosynthesis, leaf conductance, and leaf chlorophyll content of peppermint leaves. Meena and Sadana (1983) assessed the quantitative changes in the biochemical components of *Coleus* sp. in response to infestation by *B. obovatus.* Chiavegato and Salibe (1984) reported that leprosis was transmitted by larvae of *B*. *phoenicis* after a 24 h acquisition period but the nymphs and adults were less efficient in transmitting the disease. Di Martino (1985) reported that *B. californicus* caused severe damage to orange in the Mediterranean region. It produced brown to bronze colored and corky scab-like spots on rind of sweet orange. Tomczyk and Kropczynska (1985) observed that the typical symptoms produced by spider mites on tomatoes were small and light-colored spots and which hindered tomato production. Goff (1986) reported that the red spider mite exhibited a polyphagous trend and had a wide range of distribution. Schafferb *et al*. (1986) assessed the net photosynthesis, transpiration, and stomatal conductance of avocado leaves infested by the avocado red mites. Brito *et al*. (1986) observed that feeding injury induced by three species of spider mites resulted in a reduction in the leaf stomatal conductance, CO_2 assimilation and transpiration in cotton plants. Youngman *et al*. (1986) carried out a comparative study on the feeding damage induced by four species of

tetranychid mites on almond leaves. The authors observed that spider mite infestation on almond leaves reduced gas exchange, photosynthetic processes and leaf transpiration. Brandenburg and Kennedy (1987) reported that pest mites induced both direct and indirect damages to host plants and the direct damages included defoliation and leaf burning while the indirect damage included decreased rate of photosynthesis.

Garnsey *et al.* (1988) reported that the causative agent of leprosis would be a bacilliform virus and which was vectored by a mite. Weston *et al*. (1989) reported the repellent effect of terpenoids against the spider mites and the authors also mentioned the association of *B*. *obovatus* with leprosis in Argentina and Venezuela. Infestation by the tomato russet mite, *Aculops lycopersici* was known to cause a decrease in gas exchange and leaf transpiration and 50 per cent reduction in the photosynthetic rate as reported by Royalty and Perring (1989) in tomato leaves. Cameron *et al*. (1990) observed the effect of feeding by the two-spotted spider mite on some physiological activities of the leaves of raspberry. Wilson and O'Dowd (1990) studied the impact of the gall mite, *Phytoptus emarginatae* on leaf size and shoot length of *Prunus americana* and recorded 38 per cent reduction in the photosynthetic area of the host leave*s*. Berenhaum & Zangerl (1991) observed that the host plants of spider mites differed in the degree of food quality, and suggested that the difference was dependent either up on the level of primary plant metabolites, or on the quantity and nature of secondary

metabolites. Ananthakrishnan *et al.* (1992) recorded an increase in the amount of phenol in plants like cassava, castor and eucalyptus during pest attack and suggested that the increase in total phenols would be a mode of host resistance against pest attack. The impact of feeding by the two-spotted spider mite, *T. urticae* on gas exchange in the leaves of Pinot noire grapevine was studied by Candolfi *et al.* (1992).

Tomkiewicz *et al*. (1993) quantified the average chlorophyll content per cm^2 of leaf area, by measuring the absorption of chlorophyll extract in a spectrophotometer and the calibration curve on cassava green mite injured leaves. Candolfi *et al*. (1993) observed a reduction in the rate of photosynthesis in grapevine leaves infested by the European red mite, *P. ulmi*. Kaiser (1993) suggested that mite induced nitrogen-containing volatile compounds like oximes and nitriles were synthesized from amino acids. Bennett and Wallsgrove (1994) reported that the secondary metabolites produced by plants would play a major role in defense mechanism. Childers (1994) reported that the larvae, nymphs and adults of the false spider mites, *B. phoenicis* and *B. obovatus* would feed on the ventral surface of 'Robinson' tangerine leaves, along the midrib and the feeding damages induced by these mites were well visible on the upper leaf surface, opposite to the injured areas on the lower leaf surface. A reduction in the quality of the flowers owing to pest mite infestation was recorded by Karlik *et al*. (1995). Chiavegato (1995) found that all the feeding stages of *B. phoenicis* were equally responsible for

transmission of leprosis. Studies made by Colariccio *et al*. (1995) revealed the role of *Brevipalpus* mites in the mechanical transmission of citrus leprosis and the ultrastructural aspects of the disease. Iatrou *et al*. (1995) observed that spider mite infestation on bean leaves induced a depletion in chlorophyll fluorescence and chlorophyll content.

Studies of Francesconi *et al*. (1996) revealed the adverse impact of the feeding damage induced by the European red mite on the physiological processes of the host plant, apple. Lindquist *et al*. (1996) observed that eriophyid mites would use the cytoplasmic contents present on the adaxial or abaxial epidermis of leaves of respective host plants as their food. Being very small in size and equipped with short stylets, eriophyoid mites were found to damage mainly the first cell layer under the cuticle or parenchyma cells of the leaf. Koel and Gupta (1997) recorded more than 30 per cent loss in chlorophyll content of leaves of the sponge gourd (*Luffa acutangula*) infested by *T. ludeni*. The authors also observed a depletion in iron and zinc in mite infested host plants. Larson (1998) revealed a notable decrease in the photosynthetic rate of cherry plant leaves as a result of eriophyoid mite infestation. Spieser *et al*. (1998) observed that feeding by the apple rust mite induced leaf tissue changes such as the altered leaf color and gas exchange on apple leaves. The authors confirmed a significant negative relationship between the cumulative leaf damage induced by the eriophyid species, *Aculus schlechtendali* and the net CO_2 exchange by a single-leaf as well as

transpiration rate on apple trees. Kondo and Hiramatsu (1999) reported that infestation by the peach silver mite, *A. fockeui* on peach tree caused heavy damage to the photosynthetic apparatus thereby reducing the photosynthetic rate. Ripa and Rodriguez (1999) noted that the feeding injury induced by *B. chilensis* resulted in a roughened silvering of the rind on lemons in Chile. Nangia *et al.* (1999) observed a marked reduction in the amount of total protein in mulberry leaves infested by *E. suginamensis*. Krips *et al*. (1999) reported that in some plant species, mite infestation induced production of nitrogen-containing compounds such as oximes and nitriles and the presence of both these compounds was reported in spider mite-infested Gerbera plants. Hoffland *et al*. (1999) observed that as a result of spider mite attack, C/ N ratio was increased with a decreasing nitrogen availability. Usha *et al*. (1999) recorded a marked reduction in the amount of total sugars in *T. urticae* infested leaves of french beans. Sumangala and Haq (2000) provided a detailed account on the injurious effects caused by the spider mite pest, *T. ludeni* on the noxious aquatic weed, *Eichhornia crassipes*. Hoffland *et al*. (2000) conducted studies on the effects of nitrogen availability on the defensive chemistry of tomato plants as well as on its preference shown by the two-spotted spider mite, *T. urticae.* The authors reported that during mite attack, carbohydrates got accumulated at decreased nutrient availability, and the C/N ratio in the tissues also got increased.

Childers *et al*. (2001) observed that the reddish black flat mite, *B. phoenicis* was responsible for the transmission of a viral disease commonly known as "Lepra explosive" or "Leprosis" in the American Continent. *Brevipalpus* mites were found to transfer the disease causing virus mechanically from one host to another and the major host observed was citrus. Information on the occurrence of citrus leprosis throughout the Caribbean, Central America, North America and Panama was provided by Dominguez *et al.* (2001). Kielkiewicz (2002) studied the ultrastructural changes induced as a result of infestation by the two-spotted spider mite on strawberry leaves. Gallo *et al*. (2002) found that *T. urticae* mainly fed and colonised on the lower surface of leaves of the host plant, where it sucked out the cell contents and produced many chlorotic spots. Prolonged feeding resulted in the premature leaf fall and reduction in the number of flowers produced. Park and Lee (2002) reported that the leaf chlorophyll content in cucumber got decreased with increase in spider mite population density and its intensity of infestation. Bounfour *et al*. (2002) observed a reduction in the chlorophyll content and chlorophyll fluorescence in red raspberry leaves infested with *T. urticae* and *E. carpini.*

Rodrigues *et al*. (2003) reported that citrus leprosis was caused by two different viruses, *viz*. the nuclear and cytoplasmic viruses, which differed morphologically but induced similar disease symptoms in citrus. Kitajima *et al.* (2003) mentioned that *B. phoenicis* was the only known vector of passion

fruit green spot virus in Brazil, and high populations of this mite induced the cytoplasmic viral disease resulting in considerable leaf and fruit drop. The damage symptoms appeared as characteristic green spotting on matured yellow fruits and the most serious damage was due to development of necrotic lesions that girdled the stems and killed the plants. Chagas *et al.* (2003) reported that *B. phoenicis* acted as vector for the coffee ring spot virus which caused nuclear type of viral disease in coffee plants in Brazil and Costa Rica. The damage was observed as conspicuous, localized ring spot lesions which occurred on both leaves and berries, ultimately leading to leaf and fruit dropping. Kondo *et al.* (2003) pointed out that *B. californicus* was the known vector of the orchid fleck virus (OFV) and the OFV particles accumulated in the nucleus of infected orchid plants. Childers *et al*. (2003a, b) recorded *B. californicus, B. obovatus* and *B. phoenicis* as major pests of citrus varieties in Texas and during the initial stages of infestation, the mite populations were found crowded on the lower leaf surface, along the mid vein. During heavy infestation, the mites were found on the outer margins of the leaves and at the base adjacent to the petiole. The authors observed that *B. obovatus* injected toxic saliva into the fruits, new shoots, twigs, leaves, stems and bud tissues of its host plants, which might cause severe stunting in new shoots with the formation of corky swollen buds, severely stunted leaves with symptoms of chlorosis, blistering, bronzing, or necrotic areas and ultimately leading to premature leaf drop. Van Den Boom *et al*. (2003) showed that several species

of plants belonging to different families had developed different degrees of direct defense against infestation by the spider mite, *T. urticae.* The chlorophyll content of the leaves could be regarded as one of the parameters determining the photosynthetic efficiency of plants as opined by Lahai *et al.* (2003). Studies conducted by Balkema-Boomstra (2003) revealed that many secondary metabolites found in plants served as defense materials against spider mites, by performing as toxins, deterrents, digestibility reducers or as precursors to physical defense systems. Haile and Higley (2003) studied the impact of spider mite infestation on soybean and found that it caused severe damages, mainly reducing the stomatal conductance and transipiration process in their hosts. Nogueira *et al*. (2003; 2004) provided information on the diseases borne by *Brevipalpus* mites and their symptoms in many ornamental plants.

Landeros *et al*. (2004) assessed the physiological responses such as CO_2 assimilation, stomatal behaviour and transpiration rate of rose leaves infested by *T. urticae.* The authors recorded that infestation by this mite caused heavy damage to the photosynthetic apparatus and thereby affected the primary physiological processes of the plant. Reddall *et al*. (2004) found that severe mechanical damage induced by *T. urticae* on its host plant, cotton resulted in reduction in the rate of photosynthesis. Landeros *et al*. (2004) recorded the effect of different densities of the two-spotted spider mite, *T. urticae* on CO_2 assimilation, transpiration and stomatal behavior in rose

leaves. Flechtmann and Etienne (2004; 2005) reported that mite infested leaves became disfigured with scattered yellow spots, which later turned to give a fully yellowish appearance to the entire leaves. Based on their studies, Chen *et al.* (2005) stated that spider mites possessed an extraordinary ability to colonise vegetable plants, to replenish all the available nutrients and to cause serious injuries to the hosts. Ghoshal *et al*. (2005) recorded an increase in the amount of phenol compounds in jute plants due to infestation by the mite, *P. latus.* Childers and Rodrigues (2005) found that citrus leprosis spread into the United States from Central America mainly via illegal movement of infected plants or movement of infested live ornamental plant materials.

Pascon *et al*. (2006) confirmed that *B. phoenicis* transmited the virus throughout its different biological stages, but not transovarially, and in order to become infective, each mite had to acquire the virus separately. Rodrigues (2006) showed that *B. phoenicis* induced leprosis with a marked reduction in the citrus yields in Brazil and millions of dollars were spent to eradicate this pest mite. Kondo *et al.* (2006) recorded that OFV produced chlorotic or necrotic spots and rings on the leaf fronds of many genera of Orchidaceae. Reddy and Baskaran (2006) reported that infestation by *T. ludeni* induced heavy damage on four varieties of eggplants. Attack by this mite was so severe that the whole plants appeared to be crinkled due to water loss, and which ultimately led to poor yield. Klamkowski *et al*. (2006) studied the impact of *T. urticae* infestation on the rates of gas exchange, water

consumption and growth in strawberry plants. Studies made by Puchalska (2006) showed that feeding by the spider mite, *O. ununguis* on 'Conica' leaves caused an increase in the amount of phenolic content and during heavy infestation of the mite, the accumulation of phenolic compounds caused a reduction in the photosynthentic rate. Palmieri *et al.* (2007) showed that both *B. californicus* and *B. phoenicis* could serve as vectors of citrus leprosis in Guatemala. Zhang (2008) observed that spider mites with their needle-like mouthparts pierced the leaves of host plants and fed on the plant sap by sucking out the fluids from the plant cells. He further recorded that leaves turned to a bronzy appearance during heavy infestation. Kazak and Kibritci (2008) pointed out that feeding by *T. cinnabarinus* on strawberry cultivars severely affected the growth, flowering and fruit formation.

Pena *et al.* (2009) described how the attacked pinnae displayed uneven dark patches on the on the upper surface of the leaflet corresponding to the area where the mites were located on the underside. Darbemamieh *et al*. (2009) reported that the false spider mite, *C. irani* showed a wide distribution trend in apple orchards in the Western regions of Iran. Sivritepe *et al*. (2009) reported that the total chlorophyll contents in spider mite infested leaves of grapevines showed marked reduction thereby resulting in severe oxidative stress on the host plant. The decrease in chlorophyll content was possibly due to mechanical damage to the chloroplast during mite infestation. Bueno *et al*. (2009) studied the effect of spider mite attack on the photosynthetic response

of soybean plants in Portuguese. The authors reported a significant reduction in the photosynthetic rate due to stomatal limitation but no significant reduction in leaf chlorophyll content was observed in mite infested leaves. Moreover, the mite induced injury did not impair the function of light harvesting and photoelectron transport. Rodrigues *et al.* (2010) provided information on the devastating effect of the tenuipalpid mite pest*, R. indica* on the economies of many countries within the Caribbean region. Kitajima *et al.* (2010) reported 37 ornamental plant species, including orchids as hosts for *Brevipalpus* transmitted viruses. Both *B. obovatus* and *B. phoenicis* were identified as vectors of *Cestrum* ring spot virus on *Cestrum nocturum* and *Solanum violaefolium* ring spot virus on *S. violaefolium* in Brazil. Fan *et al.* (2010) confirmed the infestation of *B. lewisi* on its host plant, *Metasequoia glyptostroboides* by recording symptoms like leaf spots, color change from yellowish to brownish, and the presence of large number of mite exuviae on mite infested leaves. Petanovic and Kielkiewicz (2010) reviewed the symptoms as well as the biochemical and physiological changes induced by eriophyoid mites on their specific host plants. Jayasinghe and Mallik (2010) observed the feeding damages induced by *T. urticae* population on tomato plants and they observed that mite induced leaf injury resulted in chloroplast destruction and thereby exerted a negative impact on photosynthesis and altered carbon allocation patterns in tissues of the host plant.

Biochemical studies were conducted by Sangeetha and Ramani (2011a) to elucidate the feeding damage of *O. biharensis* in terms of phenol, chlorophyll and protein contents of cassava leaves and which provided a better insight on cellular levels of damage. Childers and Rodrigues (2011) presented an overview of *Brevipalpus* mites and their role as vectors in transmitting cytoplasmic and nuclear type plant viruses. Abdel-Khalek *et al*. (2011) noted the development of necrotic spots in advanced stages of leaf damage that resulted from the infestation by *E. orientalis.* Sangeetha *et al*., (2011) made observations on the feeding habits of *O. biharensis* on cassava plants and included the mite under the category of 'leaf suckers. The adults, larvae and nymphal stages of the mite exhibited active feeding by piercing the leaf tissue with their stylets set on protrusible stylophore that could be seen moving back and forth during feeding and sucking the tissue fluids out from the leaves. The authors also mentioned that initial symptoms of feeding damage were manifested in the form of numerous white spots at the points of feeding on the leaf surface which upon progressive feeding, merged together to form chlorotic patches and severely infested leaves appeared yellowish and crinkled, bearing dark brown patches. Evaristo *et al*. (2013) studied the physiological responses induced by the broad mite, *P. latus* on *Jatropha curcas* and recorded that the infested plants showed reductions in the photosynthetic rate, stomatal conductance and leaf transpiration. The authors

could not record a marked reduction in the chlorophyll content owing to mite infestation.

Tehri *et al.* (2014) performed studies on the phyiological impact of *T. urticae* infestation on cucumber plant and found that the infestation caused enormous loss in the total photosynthates of the host plant. Hsu *et al*. (2015) investigated the photosynthetic responses of *Jatropha* to infestation by the spider mite, *T. urticae* and found that leaf CO_2 assimilation rate, stomatal conductance, transpiration, instantaneous carboxylation efficiency and intracellular CO_2 concentration were significantly decreased in mite-infested leaves when compared to the uninfested leaves. Besides these, infested leaves exhibited a reduction in soluble protein and soluble sugar, but no measurable reductions in chlorophyll or carotenoid contents were observed. Investigation carried out by Vibija and Ramani (2015) on the impact of spider mite infestation on the photosynthetic pigments of Indian Thorny Bamboos, *Bambusa bambos*, showed that mite infestation induced significant reduction in the chlorophyll content. The percentage reductions in chlorophyll content were recorded as 77, 75, 85.03 and 47.8 for total chlorophyll, chlorophyll *a*, chlorophyll *b* and carotenoids.

2. Breeding biology

Srivastava and Mathur (1962) conducted studies on the postembryonic development of *T. cinnabarinus* on the leaves of castor and recorded that the mite completed its development with an average of 14.3 days and the adult longevity was found to range from 8 to 14 days. Haramoto (1969) observed that the developmental rates of *B. phoenicis* on the leaves of *Carica papaya* were greatly influenced by temperature, relative humidity, and nature of host plants. Beavers and Hampton (1971) reported that the duration of life cycle of *B. phoenicis* was 20.7 days at 27^{o}C. Hazan *et al*. (1973) successfully completed the life history studies and prepared the life tables of the carmine spider mite at four constant temperatures between 19^{o}C and 35^{o}C and six relative humidities from 0 per cent of saturation. The authors recorded highest fecundity at 24^{o}C and 38 per cent RH and lowest mortality at 30^{o}C and 38 per cent or 63 per cent RH. Tanigoshi *et al*. (1975) studied the influence of temperature on population increase of *T. macdanieli* and the authors observed that the mean generation time got decreased as the temperature increased. The authors recorded the mean generation time of *T. mcdanieli* as 14.31 and 10.50 days at 32 and 35°C respectively. Jeppson *et al.* (1975) recorded the developmental rates of *B. obovatus* at 27^{o}C and 30^{o}C as 5.3 and 3.5 days for the larvae, 4.0 and 4.1 days for the protonymph and 4.0 and 2.7 days for the deutonymph respectively. A total of 54.3 or 32.1 eggs per female was produced over adult life spans of 38.1 and 23.4 days respectively.

Shih *et al*. (1976) conducted studies on the biology, life table and intrinsic rate of increase of *T. urticae* on beans (*Phaseolus vulgaris*). According to the authors, the oviposition rate of *T.urticae* attained peak level on the 7th day and the developmental durations of egg, larva, protonymph and deutonymph were 2.3, 0.6, 0.4 and 1.9 days respectively. Lal (1977) made biological observations on *E. orientalis* infesting *Bauhinia variegata* and *Rauvolfia serpentina* at 28.64^{o}C and 23.61^{o}C. The author recorded a longer duration for the development of the mite on both hosts at lower temperature and he concluded that the life cycle of the mite was affected by temperature but not by the host plants. Lal and Mukharji (1978) carried out studies on the biology of *E. uncatus* on *B. variegata* at 26.6^{o}C to 22.47^{o}C, and observed that the life cycle of *E. uncatus* was completed in 8.01 days and 20.32 days at an average of the temperatures selected for the study. The influence of temperature and relative humidity on the postembryonic development of *P. citri* infesting *C. papaya* was studied by Maity and Chakrabarti (1978) at various temperature-humidity conditions *viz*. 23.6 ± 1^{o}C & 64.5 per cent RH, 26.7 ± 1^{o}C & 51.5 per cent RH and 30.6 ± 1^{o}C & 48.7 per cent RH. The authors recorded that 30.6 ± 1^{o}C & 48.7 per cent RH was the most favorable condition for the development of *P. citri*. Lal (1978) conducted studies on the developmental biology of *B. phoenicis* on two host plants *viz*. *Oroxylum indicum* and *Clerodendron siphonanthus* and found that it was strongly influenced by temperature, relative humidity and host plant. The duration of

development from egg to adult period of the mite was recorded as 20.7 and 20.2 days respectively on *O. indicum* and *C. siphonanthus* at 26.6°C. Saito (1979a) successfully performed a comparative study on the developmental durations of three species of tetranychids *viz*. *O. ununguis, T. urticae* and *P. citri* and observed that *T. urticae* had a higher fecundity level and shorter duration of development when compared to other two species of spider mites studied.

Buchanan *et al*. (1980) made studies on the population growth of *B. lewisi* on vine leaves (*V. champini*) and reported that the juvenile development of *B. lewisi* varied from 16.8 to 27.9 days at 34°C & 35 per cent RH and 22°C & 70 per cent RH respectively. According to the authors, the development of larva and protonymph of the mite was faster when compared to that of the detonymph and egg stages. The mite population was found to comprise only female individuals. Helle *et al*. (1980) observed the types of parthenogenesis occurring in the false spider mites and reported that *B. phoenicis* reproduced mainly by thelytokous type of parthenogenesis in which the females laid eggs and produced the female young ones without the involvement of males in the process of reproduction. Puttaswamy and Channabasavanna (1980a) studied the effect of temperature and relative humidity on the development and oviposition of *T. ludeni* infesting French beans. The authors found that the most favorable temperature-humidity conditions for the development and maximum survival of eggs of the species

were between 32 ± 1 & 35 ± 1°C and 65 ± 3 per cent & 75 ± 3 per cent RH. High humidity (95 ± 3 % RH) was found to reduce the fecundity of adults irrespective of temperature ranges. The same authors (1980b) reported that *T. ludeni* required 12.48 ± 0.16 days and 11.96 ± 0.38 days respectively to complete the life cycles of females and males. Oviposition periods of unmated and mated females were 1.43 ± 0.11 and 1.54 ± 0.30 days respectively and they laid on an average 165.88 ± 47.04 eggs and 132.00 ± 28.54 eggs during respective ovipositional periods of 22.83 ± 4.56 days and 27.41 ± 4.75 days. Herbert (1981) recorded 10.6°C as the threshold temperature for the development of *P. ulmi* and observed that the duration of development from egg to adult required 31.2, 20.5 and 14 days for females and 21.9, 19.6 and 12.8 days for males at 15, 18 and 21°C respectively.

Biological studies on *T. neocaledonicus* infesting okra leaves were performed by Ray and Rai (1981) and the authors observed that the pre-oviposition period of the mite lasted for 12 hours and eggs were laid singly on both surfaces of leaves. The development of larval and protonymphal stages of the mite required 1 and 1.5-2 days respectively. They further recorded that the life cycle of the mite was completed within 4-5 days which often extended to 8 days. Puttaswamy and Channabasavanna (1981a) observed that the population of *T. ludeni* on the host plant was high during the period from May to July. The same authors (1981b) studied the influence of host plants on the development, fecundity and longevity of *T. ludeni* and recorded the shortest

developmental period for *T. ludeni* on brinjal (9.24 days), maximum fecundity on okra (149.40 eggs) and French bean (148.90 eggs) and highest longevity on South American cucurbit (26.91 days) and French bean (21.08 days). The same authors (1981c) observed the effect of three species of *Amaranthus viz., A. tricolor*, *A. spinosus* and *A. viridis* on the developmental biology of *T. neocaledonicus* at different temperature-relative humidity conditions ranging from 23-26^{o}C and 74-81 per cent respectively. The authors recorded that *A. spinosus* and *A. viridis* were the most suitable hosts preferred by the mite. Oomen (1982) reported that in the scarlet mite, *B. phoenicis* infesting tea plants in India, the maximum egg production occurred between 8 and 20 days after the onset of oviposition. The author also mentioned that the eggs and chrysalis stages of the mite remained attached to the plant surfaces of the host. The egg to adult period was observed as 33.5 days at 19.1-23.4^{o}C. Puttaswamy and Channabasavanna (1982b) studied the life history of *T. neocaledonicus* on different host plants like castor, tapioca, mulberry and slender amaranth. The authors observed that duration of development from egg to adult was longer on tapioca (12.11 days) than that on castor (10.48 days), *A. viridis* (10.20 days) and mulberry (10.14 days).

Mallik and Channabasavanna (1983) successfully traced the life history and prepared life tables of *T. ludeni* and recorded the respective durations of egg, larva, protonymph and deutonymph of *T. ludeni* on French bean as 106, 32.5, 34.5 and 49 hours. Jackson *et al.* (1983) conducted

biological studies of the pecan leaf scorch mite, *E. hicoriae* and recorded that temperatures like 18.3°C and 35°C inhibited hatching process and increased mortality of the immature stages. Helle and Pijnacker (1985) reported that the sex ratio in *T. urticae* was usually biased towards female mites. Dhooria (1985) studied development of the citrus mite, *E. orientalis* based on the age and surface nature of leaves of different hosts. While studying the effect of temperature on the development of *B. obovatus* on *Solidago Canadensis*. Goyal *et al*. (1985) observed that the rate of development of this mite was influenced by temperature, relative humidity and host plant species. Pande and Sharma (1986) recorded the effect of temperature on the biology of the red cucurbit mite, *T. neocaledonicus* at five different temperatures and found that the mite did not survive at a temperature beyond 37°C. Chiavegato (1986) reported that *B. phoenicis* had a faster developmental rate on citrus fruits than that on citrus leaves and he observed an average period of incubation of 7.71 ± 0.48 days on citric fruit at 25 ± 1°C. Life history studies on the carmine spider mite, *T. cinnabarinus* at three temperatures (22.7, 26.6 and 30.5°C) were made by Northcraft and Watson (1987) and they constructed the life tables also. Gotoh (1987) conducted a study on the life history parameters of *P. ulmi* and recorded that the net reproductive rate of the species was 49.01. Dubitzki and Gerson (1987) recorded the mean development time and longevity of females of *P. harti* on detached leaves of *O. corniculata* as 12 and 14.3 days respectively and the authors observed that the mean fecundity

per female mite was 17.5. Sardar and Sarkar (1987) traced the life history of the red mite, *T. bioculatus* and reported that the fecundity of the mite was 64.4 eggs per female on the host plant, black gram (*Vigna mungo*). Based on the life history studies of the red spider mite *T. bioculatus*, Ali and Sarkar (1987) reported that the mite required 15 days to complete its development from egg to adult stage. The longevity of the adult males and females of the mite was on an average of 18.3 and 20.7 days respectively.

Dhooria and Sagar (1989) conducted biological observations on the carmine spider mite, *T. cinnabarinus* on four varieties of Japanese mint at Ludhiana, India and reported that the larval and nymphal development was completed in 6 days. The respective durations of pre-oviposition, oviposition and post-oviposition periods were recorded as 1-3 days, 2-17 days and 0-6 days. Longevity of the adult female ranged from 3-19 days while the fecundity ranged from 0-77 eggs. Manjunatha and Puttaswamy (1989) studied the developmental biology of *T. neocaledonicus* and found that the females and males of this species completed life cycle in an average of 10.44 ± 0.97 days and 10.19 ± 0.84 days respectively on French bean under greenhouse condition. The influence of temperature on the life-history parameters of the yellow grape-vine mite, *E. carpini* was studied by Bonato *et al*. (1990) and the results of the study revealed that an increase in temperature resulted in a subsequent decrease in the total development time from 28.4 to 9.7 days and an increase in the mean oviposition rate (3.2 eggs/day). Trinidade and

Chiavegato (1990) observed that *B. phoenicis* had a higher reproductive rate when compared to that of *B. californicus* and *B. obovatus* on citrus fruits. Rosero *et al*. (1990) traced the embryological development of the carnation mite, *T. cinnabarinus* infesting *Dianthus caryophyllus*. Sabelis (1991) provided an extensive review on the evolution of life-history of spider mites. Childers *et al*. (1991) observed the impact of different temperatures on the breeding biology of *E. banksi* infesting the 'marsh' grapefruit leaves. Das and Gupta (1991) performed biological studies on the citrus mite, *E. orientalis* under field condition in West Bengal, India.

Gotoh *et al*. (1993) mentioned that the speciation processes in *T. urticae* happened based on the host-plant specialization. Trinidade and Chiavegato (1994) could not find any significant differences in the developmental rates of *B. californicus*, *B. obovatus*, and *B. phoenicis* reared on Azalea (*Rhododendron* sp.) at 23 and 27^{o}C. Studies made by Wilson (1994) revealed that the developmental time, pre-oviposition period, reproductive period, and life span of *Tetranychus* mites were influenced by leaf age or stage of plant development. Shaw and Devroy (1995) conducted studies on the biology of the vegetable red spider mite *T. neocaledonicus* on brinjal. Bonato *et al.* (1995) studied the effect of five constant temperatures like 16, 22, 26, 31 and 36 ^{o}C on biological and demographic parameters of *M. progresivus* and *O. gossypii* infesting cassava. It was found that both the species could be successfully reared at a temperature range of 22-36^{o}C. The

shortest development time of 7.2 days was recorded at 31°C for *M. progresivus* and 8.2 days for *O. gossypii*. The maximum fecundity was recorded at 26°C with 42.1 and 36.3 eggs for *M. progresivus* and *O. gossypii* respectively. Nandagopal and Gedia (1995) recorded the durations of larva, protonymph and deutonymph of male and female of *T. cinnabarinus* on groundnut as 1.09, 1.11 and 3.17 days and 1.12, 1.08 and 5.04 days respectively.

Bonato and Gutierrez (1996) studied the reproductive strategy of two spider mite species on cow pea in Africa. They recorded that the unmated females of *O. gossypii* on cow pea lived longer than the mated ones. Kennedy *et al.* (1996) observed that the longevity of individual *Brevipalpus* mites was two to three times greater than the corresponding longevities of most of the tetranychid mites. The total duration of life cycle of the species was 41.68 ± 5.92 days. Aponte and McMurtry (1997) studied the biology, life table and mating behavior of *O. perseae* at four different temperatures *viz*. 15, 20, 25 and 30°C and observed that the net reproduction rate was highest at 25°C. Huaguo *et al.* (1998) traced the duration of development, fecundity and hatching rate of *T. kanzawai* at different temperature-humidity conditions like 15°C & 80 per cent RH, 20°C & 75 per cent RH, 25°C & 70 per cent RH, 30°C & 65 per cent RH and 35°C & 60 per cent RH. The authors observed that the optimum temperature for the development of the mite was within a range of 25-30°C. Liu and Tsai (1998) conducted studies on the development,

survivorship and reproduction of the tumid spider mite, *T. tumidus* on coconut palm at six constant temperatures *viz*. 10, 15, 20, 25, 30 and 35^{o}C and it was found that 30^{o}C was the optimum temperature for the population growth of the mite. Saha *et al*. (1999) studied the effect of temperature and relative humidity on the rate of development, longevity and fecundity of the red spider mite, *O. coffeae* and recorded 8.88 ± 0.6 days as the mean longevity of the mite. Bonato and Gutierrez (1999) recorded the effect of mating status on the fecundity and longevity of four species of spider mites and found that the life span of *O. biharensis* on cow pea was 10.1 ± 0.18 days, and the mated females had a shorter life span than that of the virgin females.

Gotoh and Nagata (2001) conducted studies on the development and reproduction of *O. coffeae* on tea and provided data on the hatchability of eggs, sex ratio of the offsprings and survivorship of immature stages. The threshold temperature for development of the species was found to be 10^{o}C and a marked decline in the developmental time with increase in temperature was observed. Weeks *et al.* (2001) stated that the haploid *B. phoenicis* females were sustained as a result of infection by an unidentified species of endosymbiotic bacterium. The authors reported that the bacterium feminized the genetic males and induced parthenogenesis. Bounfour and Tanigoshi (2001) studied the effect of temperature on the development and demographic parameters of *Tetranychus* and *Eotetranychus carpini* and recorded a life time fecundity of 121.1 and a daily oviposition rate of 7.1 in *T. urticae*. Fu *et al*.

(2002) recorded the effects of temperature on the development and reproduction of *T. piercei* on banana and observed that a shorter generation time of 8.5 and 7.2 days was required by the species at 32 and 36^{o}C respectively. Thongtab *et al.* (2002) explored the bionomics of the citrus yellow mite, *E. cendani* on five different host plants at a temperature of 28 ± 1^{o}C and relative humidity of 58 ± 5 per cent. The respective durations of egg, larva and nymphal stages were found to range from 4.9–5.8, 1.9-3, 1.9-2.6 and 1.8-2.7 days. Khan and Sengonca (2002) studied the development, longevity and reproduction of the European red mite, *P. ulmi*, and found that the mean total fecundity ranged from 80 to 51 eggs per female at 25 and 30^{o}C, respectively and the sex ratio of the mite was observed as 0.75.

Kazak *et al.* (2003) recorded the developmental time of *T. cinnabarinus* on different strawberry cultivars. Badii *et al.* (2003) conducted a study on the life history and life table parameters of the Texas citrus mite, *E. banksi* on orange and recorded that the durations of immature stages were found to decline with rising temperature up to 32.5 and increased at 35^{o}C. A temperature range of 28-31^{o}C was found to be optimal for the development of *E. banksi.* Gotoh *et al*. (2003) traced the life history traits of six species of *Panonychus viz*. *P. ulmi*, *P. citri*, *P. mori*, *P. osmanthi*, *P. bambusicola*, and *P. thelytokus* at a temaperature of 25^{o}C in Japan. The total developmental durations from egg to adult were found to be 11.4–12.3 days for females and 10.4–12.1 days for males. Sakunwarin *et al*. (2003) made observations on the

biology and life table of the cassava mite, *T. tuncatus*. The authors recorded that the net reproductive rate (Ro) was the highest (37.39) at 24°C, followed by 37.00 at 31°C. Yadav *et al*. (2003) observed the duration of development of *E. orientalis* at ambient temperature and recorded that a period of 5.38 days was required for hatching of eggs on *Ziziphus mauritiana* under ambient temperature of 17°C. Childers *et al*. (2003) reviewed the developmental biology, feeding injury and economic importance of four species of tenuipalpid mites *viz*. *B. californicus, B. obovatus, B. phoenicis* and *B. lewisi* and reported that the longevity of each *Brevipalpus* species was two to three times greater than the corresponding longevity of various tetranychid mites. Biswas *et al*. (2004) observed the impact of temperature on hatching, duration of development and reproduction of the carmine spider mite, *T. cinnabarinus* on eggplant. While studying the developmental cycle of *T. urticae*, Reis *et al*. (2005) observed that the eggs took approximately 10 days to hatch. Groot *et al*. (2005) provided information on the adaptations acquired by an asexual false spider mite, *B. phoenicis* and explained the General Purpose Genotype (GPG) and Frozen Niche Variation (FNV) for present pattern of reproduction. The study was based on mites from three populations infesting three host plants *viz*. citrus, hibiscus and acerola. Ji *et al*. (2005) studied the life cycle of *O. biharensis* at different temperatures and observed a higher fecundity of 71.6 eggs/female and the lowest mean longevity of 19 ± 3.11 days at 35°C ,

whereas at 15°C, longevity was highest (98.9 ± 20.77 days) and fecundity was lowest.

Adango *et al*. (2006) conducted a comparative study on the demography of the spider mite, *T. ludeni* on two vegetable crops *viz*. *Amaranthus cruentus* and *Solanum macrocarpon* by maintaining the mite population in a growth chamber at 27°C and 70 ± 10 per cent relative humidity. The authors found that the duration of immature development was shorter on *A. cruentus* than on *S. macrocarpon* and the total fecundity per female was higher in the case of *A. cruentus* due to longer survival of the adult female. Noronha (2006) studied the biological aspects of *T. marianae* reared on yellow passion fruit leaves and showed that the mite took 10.73 ± 0.18 days to complete its development from egg to adult stage. Ghoshal *et al*. (2006) traced the life cycle of *T. neocaledonicus* on a mangrove plant, *Rhizophora mucronata*, in the laboratory at 30°C and recorded the durations as 3.33 ± 0.23 days, 3.25 ± 0.22 days, 3.8 ± 0.17 days and 3.6 ± 0.15 days for egg, larva, protonymph and deutonymph respectively. The total duration, fecundity, longevity and sex ratio (male:female) were 13.5 ± 0.15 days, 39.8 ± 0.85 eggs, 13.2 ± 0.23 days and 1: 1.65, respectively. Teodoro and Reis (2006) observed the reproductive performance of *B. phoenicis* on citrus and coffee at 25 ± 2°C & 70 ± 10 per cent RH and 14 h of photophase. According to the authors the lengths of embryonic and post-embryonic periods were different due to the variation in host on which the mite was reared. The mite

showed better development and higher survival and fecundity on citrus fruits than on coffee leaves. The intrinsic rate of population increase (r_m) was recorded as 0.128 and 0.090 - females/female/day on citrus fruits and coffee leaves respectively. It was concluded that citrus fruits were more suitable for the development of *B. phoenicis* than coffee leaves. The average duration of a generation (T) was observed as 31.7 and 34.4 days respectively in citrus and coffee leaves. Groot and Breeuwer (2006) reported that false spider mites like *B. obovatus*, *B. phoenicis* and *B. californicus* reproduced mainly by thelytokous parthenogenesis due to the presence of feminizing bacterial symbionts of the genus *Cardinium*.

Haque *et al*. (2007) studied the durations of the developmental stages of the red spider mite, *O. coffeae* infesting rose and recorded the shortest and highest durations as 5.3 ± 0.16 days at 30.28^{o}C & 70 per cent RH and 12.91 ± 0.21 days at 19.8^{o}C & 75.41 per cent RH respectively. Biological observations were made by Vasquez *et al.* (2008) on the avocado brown mite, *O. punicae* on six grapevine cultivars *viz.,* Tucupita, Gillanueva, Red Globe, Sirah, Sauvignon and Chenin Blanc at 27 ± 2^{o}C & 80 ± 5 per cent RH and recorded relatively high fecundity on Tucupita leaves (2.8 eggs/female/day) during an oviposition period of 11.4 days and a low fecundity on Sirah and Gillanueva leaves, with 0.9 and 1.8 eggs/female/day during 7.9 and 6.7 days respectively. Taleb and Sardar (2008) made a demographic evaluation of *T. bioculatus* on the leaves of three host plants *viz*. cosmos (*Cosmos bipinnatus*),

rose (*Rosa* sp.) and marigold (*Tagetes* sp.) in a controlled condition with a temperature of 20.3 ± 0.66°C and a relative humidity of 75.25 ± 3.30 per cent. The authors noted that the fecundity ranged from 70.6 to 109.8 eggs per female and it significantly differed among the mites living on different host plants. The marigold and cosmos favored an increase in mite population by 2.2 and 1.5 times respectively, which was higher than those which fed on rose in the generation times (GT) of 18.22 and 19.18 days. Sangeetha and Ramani (2008a) conducted a study on the embryonic development of *T. neocaledonicus* infesting *M. oleifera* through *in situ* examination of eggs in successive days of incubation and provided data on the sequence of events involved. The same authors (2008b) observed the breeding biology of *T. neocaledonicus* on *M. oleifera* under three constant temperature-humidity conditions *viz*. 34 ±1°C & 50 ± 5 per cent RH, 30 ± 1°C & 40 ± 5 per cent RH and 25 ± 1°C & 80 ± 5 per cent RH. Shortest pre-oviposition period (1.5 ± 0.12 days) was noted at 34 ± 1°C & 50 ± 5 per cent RH and highest at 25 ± 1°C & 80 ± 5 per cent RH (1.9 ± 0.07 days). Razmjou *et al*. (2009) observed the effect of soyabean cultivars on the life history parameters of *T. urticae*. Gotoh *et al*. (2010) reported the reproductive performance of seven strains of the tomato red spider mite, *T. evansi* at five different temperatures.

Roy *et al*. (2011) carried out both laboratory and field studies on the life history features of the mite, *P. harti* on the medicinal plant, *Oxalis corniculata*. The authors observed that the average longevity of the adult

mites ranged between 2 and 11 days and a total period of 8–13 days was required to complete the life cycle from egg to the adult stage. Sangeetha and Ramani (2011b) conducted studies on the life cycle of *T. cinnabarinus* on the lablab bean, *Dolichos lablab* at 30 ± 2°C and 70 ± 5 per cent relative humidity. The total developmental period from egg to adult was recorded as 7.33 ± 0.13 days and the fecundity was averaged to 42.5 ± 1.7 eggs and the longevity was observed to be 9.2 ± 0.13 days. Ullah *et al*. (2011) made a comparative study on the development and demographic parameters of *T. merganser* and *T. kanzawai* at different temperatures. Sangeetha and Ramani (2011c) studied the biology of *T. ludeni* on velvet bean. Biswas *et al*. (2013) conducted a study on the life cycle of *T. macfarlanei* on two medicinal plants *viz*. *J. adhatoda* and *Clitoria ternatea* under laboratory conditions at 32.5°C and 75 per cent RH. The durations of different life stages *viz.* egg, larva, protonymph, deutonymph, adult, total life cycle, preoviposition, oviposition, post oviposition periods, fecundity, longevity of female and male, and sex ratio were recorded. The total developmental time of *T. macfarlanei* from egg to adult was recorded as 6.4 ± 0.37 and 10.6 ± 0.56 days on *C. ternatea* and *J. adhatoda* respectively. The plant, *C. ternatea* was found to be the most suitable host than *J. adhatoda* because life cycle was completed with a shorter time on it. The fecundity and female longevity of *T. macfarlanei* were also found to be longer on the host, *C. ternatea.*

Sangeetha (2013) studied the postembryonic development of *O. bihrensis* on cow pea in the laboratory condition at 30 ± 2°C and 70 ± 5 per cent RH and the duration of development of all life stages of the mite was observed under parthenogenetic and sexual modes of reproduction. The respective durations of preoviposition, oviposition and postoviposition periods were observed as 1.5, 11.5 ± 0.75 and 0.9 ± 0.25 days. The fecundity of this species was observed as 50.9 ± 4.7 and 40.2 ± 1.4 eggs respectively for mated and unmated females. Sangeetha *et al.* (2013) studied the breeding biology of the citrus brown mite, *E. orientalis* on leaves of Neem, *Azadirachta indica,* by adopting leaf disc method at 35 ± 2°C and 60 ± 5 per cent relative humidity. The authors observed that the species required 9.48 ± 0.09 days for completion of its development from egg to the adult stage and the respective durations of pre-oviposition, oviposition and post-oviposition periods were 0.5 ± 0, 7.7 ± 0.15 and 0.4 ±0.07 day. Fecundity and longevity of the species were recorded as 30.1 ± 2.1 eggs and 8.6 ± 0.14 days respectively. Bazgir *et al*. (2015) studied the influence of temperature on the life table parameters of the Iranian false spider mite, *Cenopalpus irani* on apple leaves. The investigation was carried out under laboratory conditions at temperatures 20, 25, 30 and 32°C at 50 ± 5 per cent RH. It was observed that the highest rate of egg hatching was 95 per cent and the survival rate for the immature stages was 89.5 per cent at 30°C. The durations for the development of the life stages were found decreased with the increase in temperature. The

oviposition period was observed as 50.17 ± 1.55 and 26.38 ± 0.81 days respectively at 20 and 30^{o}C. Prasad *et al*. (2015) traced the life cycle of *T. ludeni* on the leaves of cowpea, *Vigna sinensis* at two different mean room temperatures during March and May in 2009. The incubation period averaged to 5.0 ± 0.7 and 4.20 ± 0.40 days respectively during March and May and the development of females took longer time than that of the males in both the months at a mean temperature of 25.95^{o}C.

MATERIALS AND METHODS

Materials for performing biological studies were selected considering the prevalence of mite infestation, nature, extent and severity of damage induced by the species on respective host plant, the local availability and medicinal value of the host plants for their regular collection for making repeated and uninterrupted observation on various biological parameters so as to confirm the results. Accordingly three common, dominant, locally prevalent and most injurious species *viz*. *Tetranychus neocaledonicus*, *Oligonychus biharensis* and *Brevipalpus phoenicis* were selected for detailed studies on their feeding and breeding biology on different host medicinal plants of local importance. Of these, the first two species represented spider mites of the family Tetranychidae and the third species represented a false spider mite of the family Tenuipalpidae.

1. Host plants selected for conducting detailed biological studies of phytophagous pest mites

Seven species of host medicinal plants as detailed below were selected for conducting biological studies of the pest mites. These plants were recognized as natural host plants for the pest mite species selected.

1.1. *Cardiospermum halicacabum* L. (Plate. 4; Fig. A & B)

C. halicacabum (Sapindaceae) is a climbing or trailing herb, distributed throughout Kerala and is known by several common names like the balloon vine, balloon vine heart seed, blister creeper, heart's pea, heart seed etc. Besides, there are several vernacular names like *uzhinja*, *karavi*, *karuthakunni*, *paluruvam*, *ulincha*, *valliuzhinja* etc. The flowering and fruiting occurs during the period of July-February. It is one of the most important medicinal plant and the whole part of the plant has got wide range of medicinal properties. The extracts of *C. halicacabum* are variously used as analgesic, antimicrobial, antifungal, anxiolytic, rubifacient, antipyretic, diuretic, laxative, and stomachic, anti-inflammatory and for treatment of rheumatism, nervous diseases, snake bite and chronic bronchitis. Phytochemical screening of the plant showed the presence of saponins, traces of alkaloids, flavanoids, proanthocyanidin, apigenin and phytosterols. Besides the medicinal properties, the plant also possesses larvicidal and ovicidal activities against some species of mosquitoes. This plant was recognized as a most favoured host plant for the vegetable mite, *T. neocaledonicus*, and which was found to induce severe damage on the leaves of the plant and hence selected for detailed biological study.

1.2. *Leucas lavendulifolia* **Sm.** (Plate. 4; Fig. C)

L. lavendulifolia (Lamiaceae) is a well known herbaceous annual plant used in Indian traditional medicine. The common name of the plant is halkusha or gumo and the local name is *thumba* or *rudraspushpam*. The herb is distributed in all districts of Kerala and the flowering and fruiting occurs during August-December period. The plant contains components such as acacetin, chrysoeriol, linifoliside, linifoliol, glucoside, lupeol and taraxerone. The plant has several types of medicinal properties like hepatoprotective, hypoglycemic, antipyretic, antidiarrhoel, antitussive, psychopharmacological, antihelmintic, antimicrobial, febrifuge, stimulant, stomachic, antiulcer etc. Besides these, *L. lavendulifolia* has got insecticidal activity also. This plant also serves as alternative host plant for *T. neocaledonicus* inducing severe damage on leaves and hence selected for detailed biological studies.

1.3. *Justicia adhatoda* **L.** (Plate. 4; Fig. D)

J. adhatoda (Acanthaceae) is a perennial medicinal shrub found to exist throughout the year. The plant is commonly called as vasa, adulsa, vasaka, malabar nut tree and adhatoda and its local names are *adalodakam*, *pothadalodakam* and *vasica*. Various parts of this plant are used for the treatment of bronchitis, bronchial asthma, peptic ulcer, piles, lowering blood pressure, bronchitis, leprosy, blood disorders, heart troubles, thirst, asthma, fever, vomiting, loss of memory, leucoderma, jaundice, tumors, mouth

troubles, sore-eye, tuberculosis and gonorhhea. Vasaka leaves, bark, root bark, fruits and flowers are useful in the removal of intestinal parasites. A warm decoction of its leaves is useful in treating scabies and other skin diseases. The principal constituents of *vasaka* include several alkaloids, the chief one being vasicine. The leaves contain two major alkaloids *viz*. vasicine and vasicinine. Leaves of *J. adhatoda* contain biochemical components like saponins, oils, fats, phytosterols, phenoilc compounds, tannins, flavanoids and proteins. Besides the medicinal properties, the plant has bioinsecticidal activity against many insect pests. The plant was recognized as host for *O. biharensis* which induced severe damage on leaves and hence selected for detailed biological studies.

1.4. ***Biophytum reinwardtii* (Zucc.) Klotzsch.** (Plate. 4; Fig. E)

B. reinwardtii (Oxalidaceae) is an annual medicinal herb, known by the local name *mukkuti* and *teendanazhi*. The flowering and fruiting season of this herb is from July to December. The aerial parts of this ancient medicinal herb are used to cure a variety of diseases like diabetes, snake bite, cancer, diarrhea, arthritis, asthma, epilepsy, bruises, burns, cough, fever, gonorrhea, cardiac disorders, insomnia, scanty menses, muscle cramp, skin diseases, ulcers and wounds. *B. reinwardtii* contains various biochemical components like biflavanones (vizcupressu flavones and amentoflavone), three flavanoids (luteo lin 7-methyl ether, isoorientin and 3' methyl xyluteolin-7-O-glucoside,

two acids (4-caffeoylquinic acid and 5- caffeoylquinic acid), 3', 8''-biapigenin and proanthocyanidins. The plant could be recognized as a preferred host of *O. biharensis,* which induced heavy infestation, leading to death of the plant and hence selected for conducting biological parameters of the mite.

1.5. ***Bauhinia acuminata* L.** (Plate. 4; Fig. F)

B. acuminata (Fabaceae), is a perennial medicinal shrub commonly called as dwarf white Bauhinia and snowy orchid. The local names of the plant are *velutha mantharam* and *mantharam*. *B. acuminata* is an extremely widespread species, with only the general threats of associated habitat loss and degradation as a result of expanding human populations. It is also cultivated as an ornamental plant. This traditional medicinal plant is used for both prophylactic and therapeutic purposes. The bark, flower and root are used for treatment of various skin diseases, worms, tumours, diabetes, biliousness, cold and cough, asthma, bladder stone, veneral diseases, leprosy, digestive diseases etc. Besides these, the plant has got antioxidant, cytotoxic and membrane stabilizing properties. *B. acuminata* contains various biochemical components like flavanoids, glycosides, tannins, saponins and steroids. This plant was found severely infested by the pest mite, *O. biharensis* and hence selected for conducting biological observations on the species.

1.6. ***Mentha rotundifolia* L.** (Plate. 4; Fig. G)

The plant *M. rotundifolia* (Lamiaceae) is commonly called as mint and its local name is *puthina*. This aromatic medicinal plant is almost exclusively perennial. *M. rotundifolia* is a hybrid between *M. longifoloia* (L.) and *M. suaveolens* Ehrh. The leaves have a warm, fresh, aromatic, sweet flavor and are used for preparation of tea, beverages, jellies, syrups, and candies. Extracts of mint leaves are used to treat the diseases like stomach ache, irritable bowel syndrome, chest pains etc. The leaf or whole plant as such is used as room deodizer. Menthol, a component present in the mint essential oil is used as a major ingredient in cosmetics and perfumes. The herb also possesses some environment friendly acaricidal and insecticidal activity. This medicinal plant was selected for the present study duly considering the diverse economic utility of the plant as well as the severity induced on its leaves by the false spider mite, *B. phoenicis* under natural conditions.

1.7. ***Vitex negundo* Linn.** (Plate. 4; Fig. H)

V. negundo (Verbenaceae) is a medicinal shrub of extreme ayurvedic importance. *V. negundo* is commonly called as chaste tree and negundo. The plant is known under several local names such as *karinochi*, *indrani* and *nochi*. *V. negundo* has got a vital clinical importance in the treatment of colds, flu, snake bite, asthma, pharyngitis, menopausal symptoms, malaria and acute rheumatism. It is also used as anti-convulsant, astringent, antibacterial,

antitumor, anthelmintic, anti-inflammatory, anti-rheumatic, anti-pyretic, antiallergic, febrifuge, hepatoprotective, sedative, bronchial relaxant, anticancer, diuretic, antiarthritic, antiandrogenic, anticoronary and antiacne agent. The various chemical components present in *V. negundo* include flavanoids, volatile oils, flavones, glycosidic iridoids, triterpenes, and tannins. The false spider mite, *B. phoenicis* was observed as severe pest on this medicinal shrub and hence selected during the presenty study for conducting biological observations on the species.

2. Laboratory rearing of mites

In order to conduct detailed studies on the biological parameters of the most injurious selected species of pest mites, continuous availability of the species was ensured by raising stock cultures of the species under laboratory conditions. Stock cultures of the selected species was raised by segregating the various life stages of the mite from field collected mite infested leaves of respective host plants. Within the laboratory, the different life stages of individual species segregated from field collected leaves were transferred on to fresh mite free leaf discs/individual leaves, depending up on the size of the leaves. Individual culture set was maintained for each species of pest mite by transferring the life stages to leaf discs (3 cm x 3 cm) or on to intact leaves, placed on moistened cotton pads contained in Petri dishes of 15 cm diameter. While preparing the culture sets, adequate care was taken to prevent chances

of contamination. Fresh leaves/leaf discs, devoid of mites were used for rearing purpose and the cotton pads were saturated with sterilized distilled water. Culture sets for each selected species of pest mite were maintained on fully expanded or neatly cut leaf discs of their respective host plants contained in Petri dishes (Plate. 5; Fig. A) and rearing was carried out in the laboratory under 30 ± 2^{o}C & 70 ± 5 per cent RH. As and when the leaf discs/leaves showed signs of decay, these were immediately replaced with fresh leaf discs/ leaves so as to ensure continuous supply of healthy food for the pest mites selected for rearing. The cotton pads were made wet/water saturated with the help of a 5 ml syringe to maintain the freshness of the leaf disc.

3. Study on feeding biology of selected species of pest mites

Feeding biology study was performed in order to assess the mode of infestation, damage symptoms produced, level of feeding injury produced by the different species of pest mites on their respective host plants under study. The knowledge of the characteristic features of the feeding biology of most injurious groups of phytophagous mites would help the agricultural industry to manage the pest population below the economic injury level.

3.1 Cultivation of host plants of selected species of pest mites

In order to trace the progressive damage induced by three species of pest mites, *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* on their respective host plants, both experimental (mite infested) and control

(uninfested/mite free) sets were maintained for each species of host plant. A total of seven species of host plants *viz*. *C. halicacabum*, *L. lavendulifolia*, *J. adhatoda*, *B. reinwardtii*, *B. acuminata*, *M. rotundifolia* and *V. negundo* were cultivated during the present study. Seeds/seedlings were purchased from nurseries/ herbal nursery and sawn/planted in the garden pots or directly on the ground, depending up on the habit (herb or shrub) of the host plants. Two isolated plots were selected for cultivation of experimental (mite infested) and control (uninfseted) plants separately. After planting, seedlings were irrigated regularly and protected with insect mesh netting.

3.2 Inoculative release of pest mites onto experimental plants

The selected species of pest mites were inoculated on to respective host plants during the most favoured season/period of infestation as evidenced from the visible damage symptoms and high population density under natural conditions. For artificial infestation, active nymphal and adult stages of each species of pest mite cultured in the laboratory were transferred to fresh leaves/leaf discs and kept in Petri dishes lined with moist cotton pads. For making artificial infestation of experimental plants, the petri dishes containing the leaves/leaf discs with various life stages were brought to the experimental plots. The leaf discs were taken out and stappled on the leaves of experimental host plants. The release of pest mites on the host plants was carried out after 4-6 weeks (herbs) and 8-10 weeks (shrubs) of planting. Pest

release on the host plants *viz*. *C. halicacabum*, *J. adhatoda*, *B. acuminata*, *V. negundo* and *M. rotundifolia* was carried out during the months of February-March. While that on *L. lavendulifolia* and *B. reinwardtii* was done during the month of September-October. Artificial infestation of spider mites was carried out by directly transferring the adult females with the help of fine moist camel hairbrush and under the high power of a hand lens. Both the experimental and control plants were kept isolated and covered by fine netting to prevent further invasion by mite/insect pests. The plants were irrigated regularly. The experimental plants were observed regularly to record the visible symptoms of progressive damage owing to mite infestation on the leaves. Control plants were also observed regularly for making comparative assessment.

3.3 Assessment of feeding damages induced by pest mites

The intensity of damage induced by selected species of pest mites on respective host plants was assessed by adopting both qualitative and quantitative techniques.

i) Qualitative assessment of feeding damages

The extent of leaf damage induced by the selected species of pest mites on their respective host plants was assessed qualitatively by examining the mite infested leaf samples under a Stereo zoom microscope (Model No: MVNSZ – 405, Macro Vis, USA), and recording the nature of infestation, feeding activity, damage symptoms developed etc. Visible symptoms of

damage induced by the different life stages of the pest mites were assessed simultaneously under both laboratory and field conditions.

a). Assessment of feeding damages under laboratory condition

The damage induced by selected species of pest mites on respective host plant was assessed by conducting indoor culturing of mites in Petri dishes under controlled temperature-humidity conditions (30 ± 2^{o}C & 70 ± 5 per cent RH). Fresh cultures of selected species were maintained on leaves/leaf discs of respective host plants kept on moistened cotton pads placed in Petri dishes. From these stock cultures , 6-8 newly moulted adult females of each species of pest mite were segregated with a fine camel hair brush and released on to fresh leaf discs/leaves of their respective host plant kept in the Petri dish containing moist cotton pad. Regular observation was made to record data on the feeding activity, mode of infestation and the sequence of damages produced by the mites on the host leaves etc.

b). Assessment of feeding damages under field condition

Studies on feeding damages induced by selected species of mites under field conditions were carried out by conducting outdoor culturing of mites through artificial infestation of pest mites on respective host plants. Mite infested leaves were collected from the artificially infested host plants. For understanding the progressive symptoms of damage induced by the pest mites, two categories of leaves were considered, based on the number of

females present on the leaves as well as the nature and colour of the infested leaves. The two categories of leaves considered were the leaves showing initial stages of mite attack (leaves carrying 5-10 adult females, but without any colour deformity) and the leaves showing moderate to heavy infestation (leaves bearing > 10 adult females and showing light or yellowish green colouration). Leaves of the first category were collected after 3-4 days of infestation and the leaves of second category were collected after 1-2 weeks of artificial infestation. The damage symptoms developed as a result of feeding activity of the immature stages of the pest mites were also recorded on the above mentioned categories of leaves.

c). Assessment of feeding damages by leaf sectioning

Comparative assessment of feeding damage was made by making leaf sectioning of freshly collected mite infested leaves bearing numerous chlorotic spots or patches (experimental) and uninfested, healthy leaves (control) with no symptoms of mite infestation. In order to study the tissue level damages induced by the feeding activity of the pest mite selected, thin sections (cross sections) of the above two categories of host plant leaves were taken, using a sharp blade. The leaf sections were stained with safranin for two minutes. The stained sections were washed in distilled water and slide mounts were prepared in glycerine for subsequent microscopic observations. Photographs of the stained leaf sections were taken with a Canon digital

camera attached to an Axioscope 2 plus Zeiss Trinocular Research microscope. The photographs of mite infested and uninfested leaf sections were compared to know the tissue level damages induced by the pest mites.

ii) Quantitative assessment of feeding damages

For making quantitative assessment of feeding damage, leaf samples collected from the two groups of cultivated host plants *viz*. artificially infested (experimental) and uninfested (control) host plants were considered. Quantitative assessment of feeding damage was made by conducting studies on the factors affecting the photosynthetic efficiency of the host plants i.e. by estimating the concentration of major photosynthetic pigments of mite infested and uninfested leaves and by measuring the chlorophyll fluorescence emission of mite infested and uninfested leaves. Some other biochemical components such as the proline and phenol contents of mite infested and uninfested leaves were also analysed out during the present study. Freshly collected middle aged leaves representing the mite infested and uninfested category was considered for biochemical estimations. Mite infested and uninfested leaves from the cultivated plants were collected separately and brought to the laboratory. The collected leaves were made mite free by wiping carefully with cotton and examining under a stereo zoom microscope prior to biochemical estimations. Each experiment was repeated ten times to get consistent results and the data on the various estimations were recorded and

statistically analyzed for testing significance following IBM SPSS Statistics (Version 19).

A) Assessment of mite induced alterations in the factors affecting photosynthesis of host plants

a) Estimation of concentration of major photosynthetic pigments

The amounts of major photosynthetic pigments *viz*. chlorophyll (chlorophyll *a*, chlorophyll *b* and total chlorophyll) and carotenoids present in mite infested and uninfested leaf samples were estimated following the method of Arnon, (1949).

Procedure: 1g fresh leaf tissue was taken separately and ground to a fine pulp in a mortar by adding 20 ml of 80 per cent acetone as extraction medium. Precautions were taken to avoid any exposure of the extract to light. The extract was centrifuged at 5000 rpm for 5 minutes in a cooling centrifuge at 4^0C, and the supernatant was collected and kept separately. The process of extraction was repeated until the residue or leaf pulp became colourless. The final volume of the combined supernatant was noted and recorded. The absorbance of the solution was read at 663nm, 645nm, and 470nm, (also at 750 nm to be able to correct for impurities) against the solvent blank as 80 per cent acetone, using a UV visible spectrophotometer. The amount of chlorophyll and carotenoids was calculated based on the formula (Arnon,

1949) given below. The concentrations of chlorophyll and carotenoid pigments were expressed in mg/g fresh weight of the leaf tissue.

Calculations:

μg chlorophyll *a* = $[12.7 (A_{663-} A_{750}) - 2.69(A_{645-} A_{750})] \times V/ W$

μg chlorophyll *b* = $[22.9 (A_{645-} A_{750}) - 4.68(A_{663-} A_{750})] \times V/ W$

μg total chlorophyll = $[20.2 (A_{645-} A_{750}) + 8.02(A_{663-} A_{750})] \times V/ W$

μg carotenoids = $[1000(A_{470}) + 3.27\{(\text{chlorophyll a}) – (\text{chlorophyll b})\}] \times V/ (W \times 229)$

Where **A** is the absorbance, **V** is the final volume of supernatant, and **W** is the fresh weight of tissue extracted (g).

b) Assessment of photosynthetic efficiency of host plants

Chlorophyll fluorescence transient values were measured at room temperature on the freshly collected fully expanded leaves by using portable fluorescence monitoring system (Handy PEA, Hansatech Ltd., Vorfolk, UK) (Plate. 5; Fig. B & C). Prior to fluorescence measurements, a circular area of the upper surface of the leaves was dark adapted for 15-20 minutes using the dark adaptation clips. Data on general parameters like F_0 (minimum/initial fluorescence), Fm (maximum fluorescence), Fv (variable fluorescence) etc. were recorded separately for uninfested and mite infested leaves. The values of Fv/Fm (where $Fv = Fm-F_0$), a parameter commonly known as maximum

quantum yield of primary photochemistry or maximal electron transport rate (ETR) of PS II of both uninfested and infested leaves were recorded separately. For the present study, the leaf samples (n=10) of fresh uninfested and heavily infested middle aged leaves were collected from the cultivated host plants.

B) **Estimation of biochemical compounds**

a) Estimation of proline

The concentration of proline present in uninfested and mite infested leaves of host was determined using the method described by Bates *et al.* (1973).

Reagent preparation: Acid Ninhydrin - Warmed 1.25 g ninhydrin in 30 ml glacial acetic acid and 20 ml 6 M phosphoric acid, with agitation until dissolved. Stored at 4^{o}C and used within 24 hours.

Procedure: 0.5g of fresh leaf tissue was weighed and homogenized using 10 ml of 3 per cent aqueous suphosalicylic acid solution as the extraction medium. The homogenate was filtered through Whatman No. 2 filter paper and the filtrate was used for estimation. 2ml filtrate was taken in a test tube and added 2ml each of glacial acetic acid and acid ninhydrin. The test tube containing filtrate and reagents were kept in boiling water bath for 1 hour. The reaction was terminated by placing the test tube in an ice bath for 5-8

minutes. 4 ml toluene was added to the reaction mixture and stirred well for 20-30 seconds. From the two layers of solution in the test tube the toluene layer was separated using a separating funnel. The red coloured intensity of the remaining solution was measured at a wavelength of 520 nm. The concentration of proline was calculated using a standard curve of pure proline and expressed on a fresh weight basis (µ moles per g tissue).

Calculations:

$$\mu \text{ moles per g tissue} = \frac{\mu\text{g proline/ml} \times \text{ml toluene}}{115.5} \times \frac{5}{\text{g sample}}$$

Where, 115.5 is the molecular weight of proline.

b) Estimation of phenol

The response of host plants to mite attack in terms of the alterations in concentration of total phenol content of mite infested and uninfested leaves was determined using the method of Malik and Singh (1980).

Procedure: 1g of fresh leaf tissue was weighed and homogenized using 10 ml of 80 per cent ethanol as the extraction medium. The homogenate was centrifuged at 10,000 rpm for 20 min. The supernatant was collected and kept separately. Re-extracted the residue with 5 ml of 80 per cent ethanol and centrifuged. The combined supernatants poured into a watch glass and kept for evaporation. Add 5ml of distilled water to the watch glass containing dried

residue and mix well. The mixed solution was transferred into a clean test tube. Pipetted out two aliquots (1ml and 2ml) in separate test tubes and made up to 3 ml with distilled water. 0.5 ml of Folin-Ciocateau reagent was added to each test tube and kept for 3 min. The solution in the test tubes mixed thoroughly after adding 2 ml of 20 per cent Na_2CO_3 solution and placed them in boiling water bath for 1 min. The solution was cooled and measured the absorbance at 650 nm against a reagent blank using a UV spectrometer. A standard curve was prepared using different concentrations of catechol.

Calculations:

From the standard curve found out the concentration of phenols in the test sample and expressed as mg phenols/100 g material.

4. Study on breeding biology of selected species of pest mites

Developmental studies of selected species of mites on their respective host plants were carried out under controlled laboratory conditions (25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH) in an incubator. During the present study, attempts were made to assess the impact of temperature, humidity and host plants on the duration of development of the different species of pest mites selected for biological observations. The species of pest mites selected for detailed developmental studies were *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*. The duration of development of *T. neocaledonicus* was traced on leaves of two medicinal

plants *viz*. *C. halicacabum* and *L. lavendulifolia.* The impact of three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata* on the duration of development of *O. biharensis* was assessed during the present study. The developmental biology of the false spider mite, *B. phoenicis* was studied on the leaves/ leaf discs of two host plants *viz*. *M. rotundifolia* and *V. negundo* by adopting leaf disc method.

4.1. Experimental set up for conducting studies on breeding biology of pest mites:

Studies on the post-embryonic development of the three species of pest mites mentioned above were carried out in an incubator in the laboratory at three different temperature–humidity. combinations *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. The relative humidities were maintained at constant levels by keeping saturated solutions of different salts at specific temperature in the incubator, as described below:

a) Preparation of saturated salt solutions to maintain constant RH

The three combinations of temperature and relative humidities were maintained in an incubator by using saturated solutions of different salts (Winston and Bates, 1960). To prepare the saturated solutions, a specific amount of the required salt was added into a beaker containing a specific amount of distilled water and mixed thoroughly with the help of a glass rod.

Saturated solution of NaCl (38g/100ml) was kept at 25 ± 2°C to maintain the relative humidity 80 ± 5 per cent. Relative humidity of 70 ± 5 per cent kept at 30 ± 2°C was set using the solution mixture containing equal volume of saturated solutions of NaCl (38g/100ml) and KCl (39g/100ml). The solution mixture containing equal volumes of saturated solution of LiCl (92g/100ml) and Mg $(NO_3)_2$ (81g/100ml) were used to set the relative humidity of 60 ± 5 per cent at 35 ± 2°C. After setting/maintaining a constant temperature in an incubator, the beaker containing saturated solution was kept in it to attain a specific relative humidity. The temperature and relative humidity in the incubator were checked daily for 4-5 days using a Thermo Hygrometer. The incubator was used for the present study when the Thermo Hygrometer showed a stable reading for the required temperature and relative humidity combination.

b) Studies on breeding biology of pest mites following leaf disc method

Studies on the breeding biology of three selected species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* were carried out using the leaf disc method. For each species, culture sets (n=10) were prepared with Petri dishes (100mm dia. x 15mm H) based with neatly cut and water saturated cotton pads (90 mm dia. x 10 mm H). The fresh leaves or leaflets or pinnules of respective host plants collected for preparing the leaf discs were wiped with moist cotton to remove the associated debris or any life stages of

mites on it. The cotton pads in the Petri dishes were saturated with distilled water with the help of a 5 ml syringe and fresh leaves/ leaf discs (2 cm x 2 cm) of respective host plant of each of the pest mite species were placed on these pads with the adaxial or abaxial surface upwards, depending up on the feeding preference of the species. The Petri dishes were covered with lids and used as the culture dishes for tracing the postembryonic development of the pest mite species selected for the present study.

In accordance to the varied modes of reproduction of pest mites, as evidenced through the results of preliminary observations made during the present study, separate culture dishes were prepared for making observation on the life cycle of each species under the sexual and parthenogenetic mode of reproduction. For tracing the life cycle under the sexual mode of reproduction study, 10-12 female deutonymphs of each species were segregated under Stereo zoom microscope from the stock cultures for the subsequent transfer to the fresh leaves/leaf discs kept on moistened cotton pads placed in the culture dishes. When these deutonymphs entered in to the quiescent phase, 3-4 active adult males were introduced on to the leaves/leaf discs placed in the culture dishes. Inactive or dead males were replaced with fresh active males on the leaves/leaf discs during the period of observation. For tracing the life cycle under the parthenogenetic mode, female deutonymphs (n=10-12) alone were transferred on to the leaves/leaf discs in the culture dishes. Regular observation was made with an interval of 2 hrs in both sets of culture dishes,

to follow moulting and adult emergence, (mating also under sexual mode). Following the adult emergence, and subsequent mating (under sexual mode), two new sets of culture dishes containing 5 Nos. of fresh leaves/ leaf discs each, serially numbered from 1-5, were prepared and labelled as set S' and P' respectively for tracing the sexual and parthenogenetic modes of development (Plate. 5; Fig. D). The mated females were transferred on to the leaves/ leaf discs (1/leaf/leaf disc) kept in the culture set S'. Similarly, the newly moulted females from the parthenogenetic set were also transferred to the leaves/leaf discs (1/leaf/leaf set) in culture set P'. Regular observation was made, with an interval of 3 hrs in each of the culture sets to collect data on pre-oviposition, oviposition, post-oviposition and longevity periods of females under both the sexual and parthenogenetic modes of reproduction. As and when required, the old/decayed leaf discs were replaced with new and fresh ones during the entire period of study. Observations were continued in both sets of culture dishes so as to collect data on fecundity, nature of eggs, incubation period, hatching, percentage of egg viability, developmental durations of the immature stages, durations of quiescent instars, moulting, total immature duration of F1 generation, percentage of immature survivability, sex ratio (percentage of females), longevity of adults etc. In the case of the tenuipalipid species, *B. phoenicis* studies were made to trace duration of development under parthenogenetic mode alone, owing to the unavailability of males during field sampling. The results of developmental studies were confirmed

by making repeated observations in ten replicates for each species and the obtained data were statistically analyzed following IBM SPSS Statistics (Version 19). The data on life cycle of each species were tabulated and presented. Photographs of the various life stages of the different species studied were taken with a Canon digital camera attached to an Axioskop 2 plus Zeiss Trinocular Research microscope and presented.

4.2. Morphological studies of life stages of pest mites

For studying the morphological characters of the different life stages *viz*. the larva, protonymph, deutonymph and adult (both male and female) of the three species of pest mites, the specimens of the life stages were preserved in 70 per cent alcohol and dehydrated subsequently in different gradients of alcohol (80 per cent, 90 per cent and absolute) and cleared in a mixture of lactic acid and ethyl alcohol (1:1 V/V). The cleared specimens were slide mounted in Hoyer's medium and kept in an oven at 45-55^{o}C for 1-3 days. Morphological details of the different life stages were drawn using a Camera Lucida attached to a Meopta Research microscope. Measurements of the life stages were taken under a Meopta Research microscope, calibrated using the stage and ocular micrometers. Photographs of specific characters (aedeagus of male spider mites) of the species of pest mites were taken from the slide mounted specimens and presented.

4. 3. Scanning Electron Microscopic Studies

Scanning electron microscopic images of the specific features of the mite species selected for the present study were taken and presented**.** The SEM images were taken using Hitachi SU6600 Variable Pressure Field Emission Scanning Electron Microscope (FESEM), available at the NIT, Calicut. The images of various parts *viz*. mouth parts, anterior leg segments, ventral and dorsal regions, anterior and posterior regions etc. of the different species of pest mites were taken and presented.

OBSERVATIONS

Results of the study on the feeding biology of the three species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* on their respective host plants revealed the mode of infestation by these mites, visible symptoms of damage developed, comprising the structural aberrations/tissue level damages, alterations in the physiological processes and biochemical compounds on their respective host plants etc. Depending up on the texture of the leaves, the feeding damages produced by these mites also were found varied.

1. FEEDING BIOLOGY OF PEST MITES

1.1 Feeding biology of *T. neocaledonicus* (Plate 6 & 7)

a) Preferred feeding sites on host plants:

Results of studies on the nature of infestation and feeding preference of the most common and injurious species of spider mite, *viz*. *T. neocaledonicus* enabled to disclose the varied levels of damage induced on two species of host plants selected for the present study *viz*. *C. halicacabum* and *L. lavendulifolia*. The life stages of *T. neocaledonicus* were found to colonize mainly on the lower surface of the middle aged leaves of both species of host plants. Majority of the life stages of the mite, especially the most voracious feeders like the adult females and deutonymphs were found to confine their

feeding sites on the laminar area lying along the major and minor veins on the lower surface of the leaf (Plate. 6; Fig. A) of *C. halicacabum.* The immature life stages *viz*. the larvae and protonymphs were found to feed along the major and minor veins and also other soft and smooth area of the leaf. On *L. lavendulifolia*, the mites were found to feed more on the apex and middle region of the leaf compared to the basal region near petiole (Plate. 6; Fig. B & E) whereas on *C. halicacabum* the life stages were found to feed more on the posterior and middle portion of the leaflets (Plate. 6; Fig. A & C) The females of the species laid eggs on the leaves of both species of host plants, especially on the foliar surface adjacent to the midrib and other veins. (Plate. 6; Fig. A).

b) Nature of feeding activity:

The results of laboratory observations on the feeding activity of *T. neocaledonicus* revealed that the adult females and deutonymphs were the more voracious feeders when compared to the larvae and protonymphs, inducing pronounced feeding symptoms. While feeding, the adult females inserted their feeding stylets into the interior of the of leaf tissues and sucked out the cell contents. The process of feeding at each feeding site continued for 1-2 minutes. After 1-2 minutes of continuous feeding, the mites were found to retract stylets from the feeding site and initiated feeding activity by inserting cheliceral stylets into fresh leaf tissue of the adjacent foliar surface. The male individuals of *T. neocaledonicus* were found to feed only for 0.5-1 minutes at

a particular feeding site and thus caused less feeding damages compared to that of the adult females. The males always were found to wander on the leaf surface whereas the females always engaged in feeding. When the population density of *T. neocaledonicus* was high, the life stages of the mites were found distributed on the whole surface of the infested leaf and thus producing aggravated feeding damages (Plate. 7; Fig. C.)

c) Damage symptoms produced:

During initial stages of infestation, the feeding symptoms were well visible as small round or irregular white spots, developed on the lower surface of mite infested leaves. While feeding, the mites sucked out the cellular components/sap from the injured leaf tissue and thus produced white chlorotic spots on the surface of the infested leaves (Plate. 6; Fig. A & B). Due to the continuous feeding activity of the mites on an infested leaf, the chorotic spots were found coalesced to form a large sized white chlorotic patches (Plate. 6; Fig. E). The chlorotic patches further coalesced to impart a pale green or yellowish color to the infested leaf. Small brownish or necrotic spots were found to develop at the patched area on the surface of infested leaf (Plate. 6; Fig. D.) The leaves with chlorotic or necrotic spots then turned to yellowish or brownish in color (Plate. 6; Fig D.). In some cases, mite infested leaves presented a sunken or curled appearance at the feeding sites (Plate. 7; Fig. B.). Later, these leaves showed a crinkled or crumpled appearance. As a result of

these sequential events, premature leaf defoliation was also observed on mite infested host plant (Plate. 7; Fig. A.). On severely infested host plants, almost all the leaves were found inhabited by large numbers (20-30) of different life stages of the pest mite. The immature stages were found protected by a covering of silken web comprised of silken threads woven by the adult females across the leaf surface (Plate. 7; Fig C.) The mite infested leaves were found to carry a large number of molting skins of the various life stages, and fecal pellets which were found entangled with the dust particles (Plate. 7; Fig C.) among the silken threads. The combined symptoms of feeding were found to induce a decline in the vigor of the host plants.

d) Tissue level damages: (Plate. 8)

Microscopic examination of leaf sections of both the uninfested and mite infested leaves of *C. halicacabum* and *L. lavendulifolia* revealed clear evidence for the tissue level damages induced by *T. neocaledonicus.* The uninfested leaves showed closely packed palisade parenchyma with the normal alignment of tissues in both the host plants (Plate. 8; Fig A, B & C). The lower surface of infested leaves showed reduced number of chloroplast cells (Plate. 8; Fig. D, E & D), especially at the feeding sites and adjacent areas. The leaves of *L. lavendulifolia* showed a reduced number of chloroplast cells along the mid rib region, which formed the major feeding site of the life stages of *T. neocaledonicus* (Plate. 8; Fig. F & G). The epidermal cells on the

lower surface of the leaves were found ruptured owing to the piercing activity of the mite with its cheliceral stylet. Tissue level injury induced by the feeding activity of the mite was observed on both the spongy and palisade parenchyma cells of the leaves and the heavily infested leaves showed irregular and distorted epidermal cells and collapsed palisade parenchyma cells. Large intercellular spaces resulted from the loss of cellular components were also observed in leaf sections, at the severely injured feeding sites (Plate. 8; Fig G & H).

e) Factors affecting photosynthesis:

i) Estimation of concentration of major photosynthetic pigments:

Table.8. illustrates the results of quantitative estimation of photosynthetic pigments like the chlorophyll (chl *a*, chl *b* and total chlorophyll) and carotenoids present in the uninfested and mite (*T. neocaledonicus*) infested leaves of the two host plants *viz*. *C. halicacabum* and *L. lavendulifolia.* As presented in Table. 8. a notable reduction was observed in the concentration of all the above photosynthetic pigments in both species of host plants. The amount of chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids in the uninfested leaves of *C. halicacabum* was recorded as 2.37 ± 0.021, 1.87 ± 0.023, 4.24 ± 0.017 and 1.69 ± 0.009 mg/g fresh leaf tissue respectively. The loss in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids recorded during the present study due to

infestation by *T. neocaledonicus* was 1.26 ± 0.065, 1.12 ± 0.051, 2.39 ± 0.028 and 0.83 ± 0.024 mg/g fresh leaf tissue respectively in the host *C. halicacabum.* The percent loss in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids was recorded as 53.16 ± 0.0.085, 59.89 ± 0.099, 56.24 ± 0.104 and 49.11 ± 0.073 respectively for *C. halicacabum* (Fig. 4). Similarly, the photosynthetic pigments in *L. lavendulifolia* also showed a marked reduction due to infestation by *T. neocaledonicus* and the concentrations recorded were 1.50 ± 0.014, 0.87 ± 0. 025, 2.37 ± 0.031 and 1.01 ± 0.023 mg/g fresh leaf tissue respectively for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids. The loss in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids was observed as 0.71 ± 0.072, 0.48 ± 0.038, 1.19 ± 0.049 and 0.50 ± 0.054 mg/g fresh leaf tissue respectively (*L. lavendulifolia*). The per cent loss of photosynthetic pigments was calculated as 47.33 ± 0.096, 55.17 ± 0.087, 50.21 ± 0.112 and 49.50 ± 0.069 respectively for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Fig. 4). Statistical analysis of the data obtained on quantitative loss of photosynthetic pigments following t-test proved its significance at $p < 0.01$ level, in both species of host plants studied.

ii) Assessment of photosynthetic efficiency

Data on the various parameters of chlorophyll fluorescence like F_0 (minimum/initial fluorescence), Fm (maximum fluorescence), etc. were

recorded separately for the uninfested and infested leaves of *C. halicacabum* and *L. lavendulifolia* and presented in Table. 9. Data on Fv/Fm (where Fv = Fm-F_0), a parameter commonly known as the maximum quantum yield of primary photochemistry or maximal electron transport rate (ETR) of the PS-II recorded for both uninfested and infested leaves of the above host plants are presented in Table. 10. The Fv/Fm ratio is a parameter used for analysing the potential PS-II efficiency in the photochemical reactions of a plant. As shown in the Table. 10, the Fv/Fm values for uninfested and infested leaves of *C. halicacabum* were recorded as 0.818 ± 0.021 and 0.407 ± 0.045 respectively and those of *L. lavendulifolia* were 0.823 ± 0.005 and 0.432 ± 0.023 respectively for uninfested and infested leaves (Fig.7). The data obtained on chlorophyll fluorescence up on statistical analysis following t-test were found highly significant ($p < 0.01$) for both species of host plants mentioned above.

f). Estimation of biochemical compounds:

i) Estimation of proline:

Results of quantitative studies on the concentration of proline in uninfested and mite infested leaves of *C. halicacabum* and *L. lavendulifolia* are presented in Table. 11. As shown in the table, the amount of proline was found to increase in mite infested leaves when compared to that of uninfested leaves. The increase in proline content in the leaves of *C. halicacabum* and *L. lavendulifolia* was recorded as 2.457 ± 0.084 and 2.347 ± 0.068 µmol/g fresh

leaf tissues respectively. The per cent increase in proline content in the leaves of *C. halicacabum* and *L. lavendulifolia* was recorded as 128.44 ± 0.057 and 114.26 ± 0.091 respectively (Table. 11; Fig. 10). Statistical analysis of the data on quantitative estimation of proline content following t-test showed that these were highly significant at $p < 0.01$ level.

ii) Estimation of phenol:

The amount of phenol present in the mite infested and uninfested leaves of *C. halicacabum* and *L. lavendulifolia* is illustrated in Table. 11. The amount of phenol showed an increasing trend in leaves infested by *T. neocaledonicus* where as its concentration was comparatively low in uninfested leaves. Leaves of both host plants showed a similar trend. The increase in total phenol content in the infested leaves of *C. halicacabum* and *L. lavendulifolia* was recorded as 0.625 ± 0.073 and 1.524 ± 0.065 mg/100g fresh leaf tissues respectively. An increase of 32.35 ± 0.084 per centwas observed in *C. halicacabum* whereas it was 35.30 ± 0.058 in *L. lavendulifolia* (Table. 11; Fig. 13). Up on statistical analysis, data for both species of plants were found significant at $p < 0.01$.

1.2. Feeding biology of *O. biharensis* (Plate. 9)

a) Mite feeding sites:

Results of field studies on the feeding activity of the sporadic pest mite, *O. biharensis* disclosed the development of direct and visible damages

on its host plants. The actively feeding life stages of *O. biharensis* were found to colonize mainly on the upper surface of the middle aged leaves of host plants *viz*. *J. adhatoda* and *B. acuminata.* On *B. reinwardtii*, the species showed a preference to occupy the upper surface of the pinnules. The adults and nymphs *O. biharensis* were found to suck leaf sap from the upper foliar surface, particularly along the veins of the host plant leaf (Plate 9; Fig. A, B & C). The various life stages of the mite were found aggregated on or around the midrib and apex region of the leaf in the case of *J. adhatoda.* On the leaves of *B. acuminata*, the mites were found to colonize mostly the middle portion of the upper laminar surface, whereas on *B. reinwardtii*, the presence of various life stages could be noted on the entire surface of the pinnules. The adult females of *O. biharensis* mostly laid their eggs on the leaf surface, adjacent to the veins. Large number of egg cases were observed around the major and small netted veins (Plate 9; Fig. C).

b) Nature of feeding activity:

Laboratory observation on the mode of feeding activity of the various life stages of *O. biharensis* revealed their sap sucking habit from the leaf tissues by piercing the latter and inserting the cheliceral stylets into the leaf tissues to suck out the contents. Subsequent to the piercing activity of the active stages of the mite, damage symptoms were also found initiated and progressed in the form of speckles on the surface of the leaf. Through the

regular piercing and retrieving activities of the cheliceral stylets into leaf tissues, the mites sucked out the cell contents from the leaf tissues and as a result, severe marked feeding injuries/damages were produced on the leaf surface, at the feeding sites and adjacent areas (Plate. 9; Fig A, B, C, J & I). The process of feeding continued for 2-3 minutes at each feeding/injured spot and after this the mites retracted its feeding stylets and moved to adjacent areas in search of fresh leaf sap. The males of *O. biharensis* also were found to exhibit voracious feeding activity on the leaves. When the population density of the mite was high, the life stages of mite were found to occupy both surfaces of the leaves of their host plants.

c) Damage symptoms produced:

The feeding activity of the various life stages of *O. biharensis* was found culminated in the development of white coloured chlorotic spots or patches at the feeding sites and adjacent areas of mite infested leaves (Plate. 9; Fig A, B, C & H). Due to the prolonged feeding activity of the pest mite and during heavy mite infestation, the chorotic spots were found merged together to form white coloured chorotic patches (Plate. 9; Fig D, E & H). 5). The chlorotic patches produced through the feeding activity of *O. biharensis* were relatively larger in size (3-4 mm in diameter) than those produced by *T. neocaledonicus* on the leaves of its host plants. As the population density of the mite got increased, feeding damages also got worsened, leading to the

formation of large, bleached areas on the surface of infested leaf. Small brownish or necrotic patches also were found formed on the surface of leaves bearing the chlorotic patches. *O. biharensis* infestation also imparted a crinkled, curled, crumpled appearance to the infested leaves or pinnules (Plate. 9; Fig F, H & I). The severely infested leaves turned to yellowish or brownish in colour (Plate. 9; Fig G, H & I). Premature defoliation was also observed in the case of severely infested host plants. In the case of *B. reinwardtii*, the whole plant was found destroyed as a result of mite infestation. During heavy infestation, the mites were found to colonize on young or newly sprouted leaves on the twigs of the host plants and inducing feeding damages. When the population of the mite was high, almost all life stages were found aggregated on the entire surface of the infested leaf. The host plant leaves were found contaminated with molting skins, faecal pellets and webs entangled with the dust particles of the pest mite (Plate. 9; Fig. I & J). As a cumulative effect of mite infestation, the vigor of the host plants was found greatly reduced.

d) Tissue level damages (Plate. 10)

The cross sections of the leaves of *J. adhatoda*, infested by *O. biharensis* up on microscopic examination presented clear evidences for cellular damages. At the onset of mite infestation, the feeding injuries were found confined to the cell layers of the upper surface of the leaf. The

uninfested leaf of *J. adhatoda* showed closely packed palisade parenchyma cell layers and uninjured epidermal cells (Plate. 10; Fig. A). The infested leaf showed the punctured and distorted palisade parenchyma cell layers at the feeding sites (chlorotic spots or patches) on the upper surface of the leaf (Plate. 10; Fig. B, C & D). The epidermal cell layers of mite infested leaf showed a distorted appearance when compared to that of the uninfested one (Plate. 10; Fig. B & C). As a result of acute feeding injury induced by *O. biharensis*, a drastic reduction in the number of palisade parenchyma cells and chloroplast cells was observed at the feeding sites, marked by chlorotic spots, patches and bleached area on the surface of the leaf. Large intercellular spaces were formed as a result of the loss of leaf tissues/cells from the mite feeding sites on the infested leaf (Plate. 10; Fig. C & D). During heavy infestation, the life stages of the mite were found colonizing on both surfaces of the leaves and as a result of their intense feeding activity, tissues were transformed into necrotic and large intercellular spaces were formed on the lower surface of the infested leaf of *J. adhatoda* (Plate. 10; Fig. E & F).

e). Factors affecting photosynthesis:

i) Estimation of concentration of major photosynthetic pigments:

To understand the intensity of the feeding damages induced by *O. biharensis* on the three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata*, the concentrations of the major photosynthetic pigments like

chlorophyll (chl *a*, chl *b* and total chlorophyll) and carotenoids present in both uninfested and infested leaves were estimated and presented (Table.12). The amount of chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids present in the uninfested leaves of *J. adhatoda* was recorded as 1.82 ± 0.006, 1.14 ± 0.015, 2.90 ± 0. 025 and 1.31 ± 0.033 mg/g fresh leaf tissue respectively. As shown in the table, the loss in major photosynthetic pigments *viz*. chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids were observed as 0.98 ± 0.032, 0.69 ± 0.041, 1.61 ± 0.081 and 0.69 ± 0.032 mg/g fresh leaf tissue respectively for *J. adhatoda*. The percentage loss of photosynthetic pigments was observed as 53.85 ± 0.076, 60.53 ± 0.102, 55.52 ± 0.097 and 52.67 ± 0.085 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Table. 12. Fig. 5). The data on quantitative loss in photosynthetic pigments were proved to be significant ($p < 0.01$) when analysed statistically.

Similar to the host plant, *J. adhatoda*, photosynthetic pigments in *B. reinwardtii* also recorded a marked reduction. The loss in concentrations of chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids were recorded as 0.77 ± 0.047, 0.58 ± 0.074, 1.34 ± 0.029 and 0.59 ± 0.073 mg/g fresh leaf tissue respectively (Table. 12). The percentage loss in the photosynthetic pigments was observed as 49.04 ± 0.075, 53.21 ± 0.096, 50.57 ± 0.048 and 46.46 ± 0.085 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Fig. 5). The data were proved significant ($p < 0.01$) when

analysed statistically. *O. biharensis* was found to induce considerable loss in the photosynthetic pigments in the leaves of the host plant, *B. acuminata* also and the corresponding losses were 1.51 ± 0.025, 0.54 ± 0.034, 2.04 ± 0.053 and 0.81 ± 0.056 mg/g fresh leaf tissue respectively (Table. 12). The percentage loss in photosynthetic pigments was recorded as 47.04 ±0.079, 52.94 ± 0.068, 48.34 ± 0.074 and 41.97 ± 0.067 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Table. 12. Fig. 5). Statistical analysis showed that the data on quantitative loss in photosynthetic pigments following t-test were significant ($p < 0.01$ level).

b) Assessment of photosynthetic efficiency:

Data on the various parameters associated with chlorophyll fluorescence such as F_0 (minimum/initial fluorescence), Fm (maximum fluorescence) etc. were recorded and presented for the uninfested and infested leaves of the host plants of *O. biharensis viz. J. adhatoda*, *B. reinwardtii* and *B. acuminata* (Table. 9). As indicated in the tables, the Fv/Fm values of mite infested leaves were found reduced in all the three species of host plants. The values of Fv/Fm for uninfested and infested leaves of *J. adhatoda*, were recorded as 0.825 ± 0.019 and 0.325 ± 0.067 respectively. The values of Fv/Fm for uninfested and infested leaves of *B. reinwardtii* were recorded as 0.812 ± 0.008 and 0.464 ± 0. 053 respectively. Fv/Fm values for the uninfested and infested leaves of *B. acuminata* could be recorded as 0.807 ±

0.025 and 0.523 ± 0.062 respectively (Table. 10; Fig. 8). Up on statistical analysis, the data on loss in chlorophyll fluorescence efficiency following t-test were proved highly significant at $p < 0.01$ level.

f). Estimation of biochemical compounds:

i) Estimation of proline:

To assess the extent of damage caused by the pest mite, *O. biharensis* on the three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata*, the amount of proline present in mite infested and uninfested leaves were estimated separately. An increase in proline content was observed in mite infested leaves of all the three species of host plants and which could be recorded as 3.617 ± 0.062, 1.294 ± 0.025 and 0.667 ± 0.085 µmol/g fresh leaf tissues respectively for *J. adhatoda*, *B. reinwardtii* and *B. acuminata*. The percentage increase of proline content observed in *J. adhatoda*, *B. reinwardtii* and *B. acuminata* could be recorded as 187.62 ± 0.051, 147.89 ± 0.043 and 98.23 ± 0.061 respectively (Table.13; .Fig. 11). The data were proved significant at $p < 0.01$ when analysed statistically following t-test.

ii) Estimation of phenol:

For rating the intensity of feeding damage induced by the pest mite, *O. biharensis* on the three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata*, the amounts of phenol present in both infested and uninfested

leaves were estimated. The phenol content was found increased in the leaves of all the three species of plants due to infestation by the mite. The increase in phenol content recorded during the study were 3.967 ± 0.025, 1.191 ± 0.087 and 0.875 ± 0.061 mg/100g fresh leaf tissues for *J. adhatoda*, *B. reinwardtii* and *B. acuminata* respectively. The percentage increase in the phenol content observed in *J. adhatoda*, *B. reinwardtii* and *B. acuminata* were 47.02 ± 0.046, 38.20 ± 0.058 and 25.61 ± 0.073 respectively (Table.13. .Fig. 14). Statistical analysis of the data on quantitative increase in phenol content following t-test showed that these were proved highly significant at $p < 0.01$ level in *J. adhatoda* and *B. reinwardtii*, whereas in *B. acuminata* significance was found at $p < 0.02$ level.

1.3. Feeding biology of *B. phoenicis* (Plate. 11)

a) Mite feeding sites:

The different life stages of the false spider mite, *B. phoenicis* were found to coloniz more on the lower surface of the middle aged leaves of the both species of host plants *viz*. *M. rotundifolia* and *V. negundo*. The areas along the midrib and the other veins and veinlets were found preferred by the mite where they aggregated and initiated feeding activity (Plate. 11; Fig A). The life stages of the mite were also found feeding on the outer margins as well as the basal portions adjacent to the petiole of the leaf. During heavy infestation, when the mite population got increased, the mites were found to

move towards the young and newly sprout leaves and they were found to colonize the upper surface of the leaves also. The adult females of *B. phoenicis* laid eggs near the veins on the leaf surface or in cracks or crevices on the surface of the leaves. Almost all the life stages of the species showed a preference to the area adjacent to the veins on the leaf surface during the period of their quiescence. Molting skins in large numbers were observed along the midrib region on the lower surface of the leaves of the host plants of *B. phoenicis* (Plate.11; Fig. C & D).

b) Nature of feeding activity:

The life stages of the species while feeding pierced the leaf tissue by inserting their chelicerae. All active life stages of the mite *viz*. the larva, protonymph, deutonymph and the adults were recognized as voracious feeders by sucking the sap from the leaf tissues. By inserting their chelicerae deep into the leaf tissue, the various life stages sucked out the sap/cellular contents from the injured sites. When compared to the spider mites studied, the feeding time of *B. phoenicis* was more and it sucked cell sap for 3-5 minutes from each feeding spot. Due to their slow and sluggish nature, these mites often occupied the nearby areas of the feeding sites on the leaf as their feeding sites and which resulted in the formation of a cumulative effect of feeding damage within a short period of time (Plate. 11; Fig. C).

c) Damage symptoms produced:

The feeding activity of *B. phoenicis* did not produce immediate severe damage symptoms on their host leaves as observed in the case of spider mite species studied. But once the damage symptoms initiated, the damaged leaf became deformed within a short period of time. The infested leaf first showed a flecked appearance at the region where the mite inserted its chelicerae for feeding. The feeding damages induced by *B. phoenicis* were observed as light green or yellowish colored irregular spots or patches produced at the mite feeding sites (Plate. 11; Fig. E, F, G & H). A large number of life stages, moulting skins and faecal pellets was present on the leaf surface, entangled with the dust particles (Plate. 11; Fig. C & D). The yellow spots or lesions formed on the infested leaves were later turned in to brown coloured necrotic spots or patches (Plate. 11; Fig. E & F). The large sized brown necrotic patches (3-4 mm in diameter) were visible as brownish, shaded areas on the infested leaves. The damaged areas were characterized by brown colour and these regions and quite often the entire leaves were found deformed (Plate. 11; Fig. F, G & H). The brown patches on the surface of the leaves were often found coalesced to give a brownish appearance and such leaves were found abscised prematurely.

e). Factors affecting photosynthesis:

i) Estimation of concentration of major photosynthetic pigments:

For rating the extent of leaf damage induced by *B. phoenicis* on the two host plants *viz*. *M. rotundifolia* and *V. negundo*, the concentrations of the major photosynthetic pigments like chlorophyll (chl *a*, chl *b* and total chlorophyll) and carotenoids present in both uninfested and infested leaves were estimated and presented (Table.14). The amount of chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids in the uninfested leaves of *M. rotundifolia* was recorded as 2.34 ± 0.007, 1.78 ± 0.023, 4.11 ± 0.014 and 1.83 ± 0.009 mg/g fresh leaf tissue respectively. As shown in the table, the loss in the chlorophyll *a,* chlorophyll *b,* total chlorophyll and carotenoids could be recorded as 1.08 ± 0.022, 0.99 ± 0.034, 2.06 ± 0.053 and 0.82 ± 0.062 mg/g fresh leaf tissue respectively in the host, *M. rotundifolia* (Table. 14). The percentage loss in photosynthetic pigments observed during the study was 46.15 ± 0.082, 55.62 ± 0.065, 50.12 ± 0.091 and 44.81 ± 0.047 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Table. 14. Fig. 6). Similar to the host plant, *M. rotundifolia*, the photosynthetic pigments in *V. negundo* also showed a notable reduction and the quantitative losses in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids recorded during the study were 1.29 ± 0.054, 0.95 ± 0.071, 2.23 ± 0.055 and 0.71 ± 0.072 mg/g fresh leaf tissue respectively (Table. 14). The percentage loss in photosynthetic pigments observed during the study were

40.06 ± 0.038, 45.02 ± 0.052, 41.92 ± 0.073 and 38.80 ± 0.066 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids (Table. 14. Fig. 6). Data on the quantitative loss in photosynthetic pigments using t-test showed significance at $p < 0.01$ level for both the host plants studied.

b) Assessment of photosynthetic efficiency:

General parameters like F_0 (minimum/initial fluorescence), Fm (maximum fluorescence), etc. were measured for the uninfested and mite infested leaves of the host plants, *M. rotundifolia* and *V. negundo* (Table. 8). The chlorophyll fluorescence emission was found reduced in mite infested leaves of both species of host plants. The value of Fv/Fm for the uninfested and infested leaves of *M. rotundifolia* recorded during the study were 0.818 ± 0.017 and 0.491 ± 0.074 respectively and those for uninfested and infested leaves of *V. negundo* were 0.833 ± 0.016 and 0.520 ± 0.025 respectively (Table. 9; Fig.9). Statistical analysis of the data on quantitative loss in chlorophyll fluorescence following t-test were proved highly significant at $p < 0.01$ level, in both species of plants.

f). Estimation of biochemical compounds:

i) Estimation of proline:

The biochemical damage induced by *B. phoenicis* on the two host plants, *M. rotundifolia* and *V. negundo* was assessed by quantifying the proline content of mite infested and uninfested leaves. In both species of host

plants, mite infested leaves disclosed increased quantities of proline when compared to the uninfested leaves. The increase in proline content observed during the study were 1.485 ± 0.091and 1.407 ± 0.025 µmol/g fresh leaf tissues in *M. rotundifolia* and *V. negundo* respectively. The percentage increase in proline content was recorded as 116.65 ± 0.058 and 87.28 ± 0.064 respectively for *M. rotundifolia* and *V. negundo* (Table.15; Fig. 12). The data on quantitative increase in proline content following t-test were proved highly significant at $p < 0.01$ level, for both species of host plants studied.

ii) Estimation of phenol:

For rating the intensity of feeding damages induced by *B. phoenicis* on the two host plants *viz*. *M. rotundifolia* and *V. negundo,* the amounts of phenol present in both mite infested and uninfested leaves were estimated. An increase in phenol content was observed in both species of host plants owing to mite infestation. The increase in phenol content was observed to be 0.909 ± 0.075 and 1.604 ± 0.038 mg/100g fresh leaf tissues in *M. rotundifolia* and *V. negundo* respectively. The percentage increase in phenol content was recorded as 31.18 ± 0.087 and 23.54 ± 0.049 for *M. rotundifolia* and *V. negundo* respectively (Table. 15; Fig. 15). Statistical analysis of the data on quantitative increase in the amount of phenol following t-test were proved highly significant at $p < 0.01$ level in the host plant *M. rotundifolia*, whereas in *V. negundo* it was observed to be significant at $p < 0.02$.

2. BREEDING BIOLOGY OF PEST MITES

In the present study three species of pest mites were considered for detailed observations on their breeding biology. The species selected were *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*, of which the former two species represented the spider mite and the third species was a representative of the false spider mite. Both species of spider mites were found to reproduce through dual modes of reproduction, comprising the parthenogentic and sexual cycles whereas the false spider mite species reproduced only through parthenogentic mode, as evidenced during the study. All the progenies produced through parthenogenetic reproduction in *T. neocaledonicus* and *O. biharensis* were developed into males while progenies developed through sexual reproduction included both males and females. In *B. phoenicis*, the entire population was found to comprise females in field condition also and the species reproduced only through parthenogenesis. Depending upon the host plants, temperature-humidity conditions and mode of reproduction/development the life history durations of pest mites showed slight or significant differences. Data on pre-oviposition, oviposition, post-oviposition and adult longevity of both mated (fertilized) and unmated (unfertilized) females of pest mites at three temperatures-humidity conditions *viz*. 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH, on each host plants were recorded during the present study. The breeding biology parameters *viz*. fecundity, egg viability,

immature survivorship, durations of the various life stages and adults, moulting, mating etc. were studied.

2.1. Breeding biology of *Tetranychus neocaledonicus* (Plate. 12 & 13)

Data on the breeding biology parameters of both mated and unmated females of *T. neocaledonicus* infesting on two major host plants *viz*. *C. halicacabum* and *L. lavendulifolia* are detailed here.

Oviposition and adult longevity

The durations (in days) of pre-oviposition, oviposition, post-oviposition periods and adult longevity were recorded separately for both mated and unmated females of *T. neocaledonicus* on *C. halicacabum* and *L. lavendulifolia.*

The female during its pre-oviposition stage appeared to be larger in size and bright red in colour. The female during its oviposition and post-oviposition period assumed dark red color. The ovipositing females were found to spin silken threads which progressively got trasnsformed into webs leaf surface of host plants, ensuring protection to the eggs and the subsequent life stages of the species. The female was found to lay eggs more frequently on the lower surface of the leaves of the host plants, adjacent to the midrib, and along the major and minor veins of the leaves. But on *C. halicacabum*, a few eggs were found deposited on the upper surface of the leaf also. Mostly,

the eggs were found laid in close proximity on the foliar surface, as if they were laid in colonies.

The durations of pre-oviposition, oviposition and post-oviposition periods of the species under the parthenogenetic and sexual cycles were found subjected to variation depending upon the differences in host plants as well as temperature-humidity conditions tested. Accordingly, the mean durations of pre-oviposition period of mated female of *T. neocaledonicus* on *C. halicacabum* was recognized as 2.14 ± 0.08, 1.71 ± 0.06 and 1.14 ± 0.03 days respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH and that of unmated female on the same host was observed to be 2.01 ± 0.07, 1.62 ± 0.02 and 1.09 ± 0.05 days respectively for the same temperature humidity conditions (Table. 16). On *L. lavendulifolia*, the mean durations of the pre-oviposition period of mated and unmated females of *T. neocaledonicus* were 2.23 ± 0.07, 2.01 ± 0.06 & 1.68 ± 0.05 days and 2.11 ± 0.08, 1.73 ± 0. 05 & 1.24 ± 0.06 days respectively (Table. 20). A slight decrease was observed in the duration of pre - oviposition period at 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. In mated females, the mean duration of pre-oviposition period was observed to be slightly higher than that of the unmated females on both host plants. The mean pre-oviposition period of both mated and unmated females was of lowest duration on *C. halicacabum* than that of *L. lavendulifolia*, at all the three temperature-humidity parameters tested.

The mean durations of oviposition period of the species on *C. halicacabum* for mated and unmated females were recorded as 9.02 ± 0.15, 7.41 ± 0.09 & 7.19 ± 0.14 days and 9.63 ± 0.08, 8.07 ± 0.10 & 7.92 ± 0.13 days respectively for the temperature-humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH (Table. 16). On *L. lavendulifolia*, the oviposition periods for mated and unmated females were found averaged to 8.67 ± 0.12, 7.35 ± 0.10 & 6.87 ± 0.17 days and 9.01 ± 0.08, 7.85 ± 0.09 & 7.28 ± 0.11 days respectively (Table. 20). A notable decrease was observed in the mean durations of oviposition period at 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH, on both the host plants studied. A slightly higher duration of oviposition period was recorded for unmated females. No significant difference was observed in the mean durations of oviposition periods on both the host plants.

The mean post-oviposition period of the mated females of the species on *C. halicacabum* at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH respectively was 2.69 ± 0.12, 2.03 ± 0.06 & 1.68 ± 0.09 days and 2.81 ± 0.10, 2.11 ± 0.07 & 1.72 ± 0.06 days (Table. 16). On *L. lavendulifolia*, the mean post-oviposition period of the mated females could be recorded as 2.52 ± 0.05, 2.05 ± 0.11 & 1.83 ± 0.06 days while that of unmated female was 2.57 ± 0.15, 2.14 ± 0.08 & 1.91 ± 0.04 days under the same temperature-humidity conditions (Table. 20). There was

no significant difference in the mean durations of post-oviposition periods of females on both the host plants and the shortest duration could be recorded at 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH.

The longevity of the mated females of *T. neocaledonicus* on *C. halicacabum* at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH was on an average 13.85 ± 0.23, 11.15 ± 0.15 & 10.01 ± 0.18 days respectively whereas that of unmated females showed a very slight increase as 14.45 ± 0.25, 11.80 ± 0.20 & 10.73 ± 0.17 days respectively (Table. 16). On *L. lavendulifolia*, the adult longevity at the three temperatures-humidity conditions was 13.42 ± 0.17, 11.41 ± 0.22 & 10.38 ± 0.15 days respectively for mated females and 13.69 ± 0.20, 11.72 ± 0.13 & 10.43 ± 0.18 days respectively for unmated females (Table. 20). No significant difference was observed in the adult longevity of the females on both the host plants and minimum adult longevity was recorded at 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH.

Fecundity

The number of eggs laid by a single female was found minimum on the 1st day of oviposition and from the 2nd and 3rd days onwards, a gradual increase egg production was observed in both mated and unmated females, at all the three temperature-humidity conditions on both host plants studied. The maximum number of eggs was laid by the females on the 5th or 6th days of

oviposition period and thereafter a gradual decline in the number of eggs was observed.

Under the temperature-humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH, the fecundity recorded on *C. halicacabum* was 33.76 ± 1.23, 42.63 ± 1.08 & 49.71 ± 0.93 respectively for mated females and 28.42 ± 1.30, 36.67 ± 1.25 & 41.83 ± 1.19 respectively, for unmated females (Table. 17). Under the same temperature-humidity conditions, and on a different host plant *L. lavendulifolia*, the fecundity was noted to be 26.76 ± 1.23, 35.63 ± 1.08 & 39.71 ± 0.93 and 22.42 ± 1.30, 32.67 ± 1.25 & 37.83 ± 1.19 respectively for the mated and unmated females (Table. 21). The daily production of eggs by mated females on *C. halicacabum* was 3.74 ± 0.12, 5.75 ± 0.09 and 6.91 ± 0.04 respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH whereas that of unmated females was 2.95 ± 0.11, 4.54 ± 0.10 and 5.28 ± 0.06 respectively (Table. 17).

The rate of egg production per day on *L. lavendulifolia* by the mated females was 3.16 ± 0.09, 4.85 ± 0.13 & 5.78 ± 0.07 whereas that of unmated females was 2.49 ± 0.21, 4.16 ± 0.05 & 5.05 ± 0.08 respectively (Table. 21). On both the host plants, the daily production of eggs was comparatively higher in the mated females and no significant differences ($p \leq 0.05$) could be observed between the two host plants. The rate of oviposition was high on *C.*

halicacabum and 35 ± 2°C & 60 ± 5 per cent RH was found to favour the maximum fecundity in both mated as well as unmated females.

Hatching

The eggs of *T. neocaledonicus* were smooth, round and white coloured when freshly laid. On progressive days of incubation, the eggs attained yellow colouration (Plate. 12; Fig. A). and during the final days of incubation, the eggs turned into orange red and the eye spots of the developing larva were clearly visible as prominent red spots (Plate. 13; Fig. B). At the time of hatching or at the end of incubation period, the size of eggs showed a slight increase and a change in shape was also observed from the globular to oval. A transverse slit was found developed at the apical pole, which continued to extend in either direction as a result of the thrusting movement of the emerging larva. The continued thrusting movements of the anterior portion and legs of the larva led to a widening of the slit further culminating in the easy and complete splitting of the egg shell. The process of hatching was found completed within 16-18 minutes, on both the host plants.

The hatching success (the per cent of egg viability) recorded for the mated and unmated females of the species on *C. halicacabum* at temperature-humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH was 80.12 ± 2.04, 89.54 ± 1.19 & 92.41 ± 1.22 and 76.37 ± 2.13, 83.56 ± 1.87 & 85.71 ± 0.11

respectively (Table. 17). Under the same temperature-humidity conditions, the per cent of egg viability recorded on *L. lavendulifolia* was 77.32 ± 2.15, 85.34 ± 2.11 & 88.56 ± 1.35 and 73.87 ± 2.31, 80.76 ± 1.32 & 82.81 ± 1.57 respectively, for the mated and unmated females (Table. 21).

Duration of the development of different life stages

The duration of the immature stages *viz*. egg, larva, protonymph, deutonymph and quiescent stages showed slight variation depending upon the differences in the temperature-humidity conditions and the host plants selected. The duration of developmental stages of both the sexual and parthenogenetic progenies of *T. neocaledonicus* on *C. halicacabum* and *L. lavendulifolia* were also found to show variation. The duration of the various developmental stages under the parthenogenetic mode of development were observed to be comparatively low than that of the sexual cycle at all the temperature-humidity conditions studied. Further, higher temperature conditions were found to induce a decrease in the durations of the various developmental stages of the species.

Egg incubation period

Depending upon the differences in the temperature-humidity conditions and host plants, the incubation period (embryonic developmental period) showed notable variations. The incubation period on *L. lavendulifolia* was found slightly higher than that on *C. halicacabum* at all the three

temperature-humidity conditions studied. The shortest period of incubation was observed at 35 ± 2°C & 60 ± 5 per cent RH. The incubation periods on *C. halicacabum* at various temperature-humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH were 3.76 ± 0.08, 3.11 ± 0.07 & 3.09 ± 0.04 days respectively for sexual cycle and 3.52 ± 0.02, 3.01 ± 0.04 & 2.98 ± 0.03 days respectively for parthenogenetic cycle (Table. 18 & 19). Under the same temperature-humidity conditions, the incubation period on *L. lavendulifolia* was 4.50 ± 0.06, 3.55 ± 0.07 & 3.30 ± 0.09 days and 4.1 ± 0.04, 3.3 ± 0.05 & 3.00 ± 0.07 days for sexual and parthenogenetic cycles respectively (Table. 22 & 23).

Larval period

The newly hatched larva was small, delicate, hexapod and pale yellow coloured (Plate. 12; Fig. C). As the hatching process was over, the larva remained motionless on the leaf surface for some time and then initiated movement and slowly started to feed. While feeding, the larva inserted its cheliceral stylets into leaf tissue and sucked out the cell contents or tissue fluids. A few hours after the initiation of feeding activity, the body colour of the larva got transformed to pale yellow and then to light green. The eyes of the larva were well visible at this stage.

The duration of larval period under the sexual cycle was observed to be 2.38 ± 0.06, 1.83 ± 0.06 & 1.73 ± 0.05 days respectively at 25 ± 2°C & 80 ± 5

per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH on the host plant, *C. halicacabum* (Table. 18). The larval period under parthenogenetic mode could be recorded as 2.31 ± 0.06, 1.62 ± 0.07 & 1.59 ± 0.08 days at the same temperature-humidity conditions (Table. 19). On *L. lavendulifolia*, the larval stage lasted for 3.20 ± 0.05, 2.40 ± 0.05 & 2.25 ± 0.08 days and 2.9 ± 0.05, 1.9 ± 0.04 & 1.87 ± 0.05 days respectively under the sexual and parthenogenetic cycles on (Table. 22 & 23).

Protonymphal period

The newly moulted protonymph was easily distinguishable from the larval stage based on its larger body size and possession of 4 pairs of legs. Soon after moulting, the color of the protonymph was pale yellowish green and as it proceeded with feeding activity, the color turned to bright green (Plate. 12; Fig. E). The protonymph was more fastidious in producing feeding damages on the host leaf than the larva and its feeding activity was found to induce immediate negative impact on the leaf surface.

The mean duration of the active protonymphal period under the sexual cycle was recorded as 2.42 ± 0.05, 1.45 ± 0.04 & 1.39 ± 0.06 days respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH on the host, *C. halicacabum* (Table. 18 & 19). Under the parthenogenetic mode, the mean duration of the active protonymphal period lasted for 2.21 ± 0.05, 1.13 ± 0.06 & 1.12 ± 0.04. On the

host, *L. lavendulifolia* the protonymphal period had an average duration of 2.45 ± 0.09, 1.70 ± 0.04 & 1.61 ± 0.03 days and 2.32 ± 0.05, 1.46 ± 0.06 & 1.32 ± 0.07 days respectively under the sexual and parthenogenetic modes respectively at same temperature-humidity conditions (Table. 22 & 23).

Deutonymphal period

The deutonymph formed the largest among the immature stages of the species and it was dark greenish red in colour (Plate. 12; Fig. F). The deutonymph resembled the adult in many features and during this period, the male and female individuals could be easily distinguished by the shape of their hysterosoma. The female hysterosoma was comparatively oval and broader (Plate. 12; Fig. H) while that of the males was comparatively narrow and wedge shaped.

The mean duration of active deutonymphal period of *T. neocaledonicus* on *C. halicacabum* was recorded as 2.81 ± 0.08, 2.04 ± 0.05 & 1.94 ± 0.05 days respectively, under the sexual mode at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH whereas it was 2.64 ± 0.07, 1.92 ± 0.04 & 1.84 ± 0.02 days respectively under the parthenogenetic mode and at the same temperature-humidity conditions (Table. 18 & 19). The duration of deutonymphal stage under the sexual mode of reproduction on *L. lavendulifolia* was recorded as 2.83 ± 0.05, 2.76 ± 0.05 and 2.62 ± 0.04 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent

RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. Under the parthenogentic mode of reproduction and at the same temperature-humidity conditions, the duration of the deutonymphal stage was recorded as 2.75 ± 0.02, 2.37 ± 0.04 and 2.16 ± 0.02 days (Table. 22 & 23).

Quiescent period

A period of physically inactive phase known as the quiescent phase/stage was found to intervene between two consecutive active instars, prior to moulting, from the larval stage onwards till the final moult. The phase was found initiated by becoming sluggish in habit, and retarding the feeding activity. Further, the instar assumed an oval shape and its body appeared shiny. It selected a suitable sheltering site on the leaf tissue where it assumed a sedentary posture and its mobility was found arrested. During quiescence, the posterior pairs of legs of the instar were found retracted and brought together under the body and its feeding stylets were found inserted into the leaf tissue. This sedentary and non-feeding stage was recognized as the quiescent stage/phase and at the end of which the body of the instar became turgid and cloudy as it was found preparing for the subsequent moulting to release the succeeding instar. In the life history of *T. neocaledonicus,* three such quiescent phases were observed *viz*. the first quiescence (protochrysalis) in between the larva and protonymphal stage, the second quiescence

(deutochrysalis) in between the protonymph and deutonymphal stage and the third quiescence (teliochrysalis) in between the deutonymph and adult stage.

Depending upon the temperature-humidity conditions provided, the durations of the quiescent stages also exhibited slight variations. The durations of the quiescent periods were low at the high temperature conditions. On *C. halicacabum*, the durations of the protochrysalis stage at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH were 1.17 ± 0.07, 0.76 ± 0.08 & 0.75 ± 0.07 days respectively for the sexual progenies and 1.08 ± 0.05, 0.64 ± 0.03 & 0.61 ± 0.05 days respectively for the parthenogenetic progenies (Table. 18). At the same temperature-humidity conditions, the durations of deutochrysalis stage were 1.11 ± 0.09, 0.68 ± 0.08 & 0.65 ± 0.08 days respectively (sexual progenies) and 1.01 ± 0.03, 0.62 ± 0.02 & 0.60 ± 0.06 days respectively (parthenogenetic progenies) (Table. 19). The durations of the teliochrysalis stage were 1.28 ± 0.04, 0.65 ± 0.07 & 0.62 ± 0.08 days and 1.01 ± 0.04, 0.60 ± 0.05 & 0.57 ± 0.08 days respectively for the sexual and parthenogenetic progenies (Table. 18).

At 25 ± 2°C & 80 ± 5 % RH, 30 ± 2°C & 70 ± 5 % RH and 35 ± 2°C & 60 ± 5 % RH, the durations of the protochrysalis stage of the species on *L. lavendulifolia* were 1.30 ± 0.07, 1.06 ± 0.10 & 1.05 ± 0.05 days respectively (sexual cycle) and 1.21 ± 0.03, 0.96 ± 0.05 & 0.93 ± 0.03 days respectively

(parthenogenetic cycle) (Table. 22 & 23). The mean durations of the deutochrysalis stage were 1.11 ± 0.08, 0.82 ± 0.03 & 0.77 ± 0.06 days respectively (sexual progenies) and 1.04 ± 0.04, 0.83 ± 0.07 & 0.81 ± 0.04 days respectively (parthenogenetic progenies) (Table. 22 & 23). The durations for the teliochrysalis stage were recorded as 1.48 ± 0.07, 1.35 ± 0.06 & 1.19 ± 0.10 days respectively (sexual progenies) and 1.29 ± 0.07, 0.98 ± 0.03 & 0.83 ± 0.06 days respectively (parthenogenetic progenies) (Table. 22 & 23).

Moulting

At the end of each of the three quiescent phases, the process of moulting, leading to the emergence of the succeeding active instar from the cuticle of the preceding instar was observed. The moulting of the instar was found facilitated by the splitting of the old cuticle along a definite line or lines. Expansion of the body of the instar was a marked change observed at the onset of moulting. As a result of this, a horizontal split was formed at the mid dorsal region between the second and third pairs of legs (Plate. 12; Fig. G). The split further extended to either side and finally met ventrally. Due to the continuous backward thrusting action of the emerging life stage, the old cuticle was found broken/widened at the split region and the posterior part of the body got exposed from the cuticle. The remaining body parts, especially the delicate gnathosoma and legs were withdrawn carefully from the moulting skin by the backward crawling movement of the life stage. The process of

moulting took 12-14 minutes to complete. After the moulting process, the white coloured old cuticle/ exuviae were left behind on the leaf surface (Plate. 12; Fig. E & H).

Total duration of developmental stages

The total duration of development or the sum of the durations of development of all the immatures (egg, larva, nymphs and quiescent stages) *of T. neocaledonicus* on *C. halicacabum* were 14.94 ± 0.29, 10.82 ± 0.24 and 10.18 ± 0.27 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH under the sexual cycle while in the parthenogenetic mode, the durations were 13.78 ± 0.23, 9.54 ± 0.24 and 9.31 ± 0.18 days respectively for the same temperature-humidity conditions (Table. 18 & 19). The total duration of development of immature stages under the sexual and parthenogenetic modes of reproduction on the host, *L. lavendulifolia* could be recorded as 16.85 ± 0.24, 13.64 ± 0.35 & 12.78 ± 0.38 days and 15.61 ± 0.29, 11.80 ± 0.25 & 10.92 ± 0.24 days respectively fat the three temperature-humidity conditions selected (Table. 22 & 23). Significant variation could be accounted in the duration of development of the species in accordance with the differences in the host plants (at $p \leq 0.05$ level of significance).

The percentage of immature survivability recorded on *C. halicacabum* at temperature-humidity conditions *viz*. 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ±

2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH were 84.53 ± 1.32 per cent, 93.67 ± 2.15 per cent and 96.72 ± 1.09 per cent respectively when the biology was studied under the sexual mode of reproduction. The percentage of immature survival recorded under the parthenogenetic mode were 81.26 ± 2.19 per cent, 87.55 ± 1.43 per cent & 90.34 ± 1.10 per cent respectively (Table. 17). The survival rates recorded on *L. lavendulifolia* for the same temperature-humidity conditions were 80.53 ± 1.25 per cent, 88.61 ± 2.03 per cent & 91.75 ± 2.11 per cent and 78.72 ± 2.87 per cent, 84.31 ± 1.09 per cent & 86.92 ± 2.26 per cent respectively for the sexual and parthenogenetic cycles (Table. 21).

Adult stages

The adult female was bright red in colour and the male was creamy yellow. The male was characterized by the possession of elongate legs, prominent red eye spots and narrow tapering hysterosoma (Plate. 13; Fig. A & B). The size of the male was smaller than that of the female and it was very active also. The very active adult males were often found moving in search of quiescent female deutonymphs. The average duration of adult stages on *C. halicacabum* under the sexual mode of development was recorded as 11.92 ± 0.35 days (female -13.54 ± 0.15 & male - 10.29 ± 0.22 days), 10.10 ± 0.29 days (female -11.32 ± 0.23 & male - 8.87 ± 0.17 days) and 9.08 ± 0.30 days (female -10.19 ± 0.21 & male - 7.96 ± 0.15 days), respectively at 25 ± 2°C &

80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH (Table. 18). The longevity of the adult stage was 10.04 ± 0.30, 7.98 ± 0.26 and 7.64 ± 0.21 days respectively for the parthenogenetic progenies (Table. 19). On *L. lavendulifolia*, the mean longevity of the adult stage in sexual progenies lasted for 11.62 ± 0.43 days (female -13.17 ± 0.24 & male - 10.06 ± 0.25 days) at 25 ± 2°C & 80 ± 5 per cent RH, 9.83 ± 0.40 days (female -11.05 ± 0.27 & male - 8.61 ± 0.20 days) at 30 ± 2°C & 70 ± 5 per cent RH and 8.71 ± 0.41 days (female -9.98 ± 0.25 & male - 7.43 ± 0.19 days) at 35 ± 2°C & 60 ± 5 per cent RH (Table. 21). While under the parthenogenetic mode, the duration of the adult was 9.47 ± 0.36, 8.22 ± 0.29 and 7.01 ± 0.33 days respectively for the three temperature-humidity conditions (Table. 22). The sex ratio (male : female) of the mite under sexual mode of development was 2 : 10 and 1 : 10 on *C. halicacabum* and *L. lavendulifolia* respectively. The progenies produced via parthenogenetic development were all found to be males.

Mating

The mating process usually accomplished immediately after the last moult (teliochrysalis) of the female. The adult male was found actively moving on the leaf surface in search of the female teliochrysalis (3rd quiescent stage). As soon as the male succeeded in detecting the teliochrysalis by contact, it remained adjacent /around that till the last moulting was over

leading to the adult emergence (Plate. 13; Fig. A). The males while guarding the female quiescent deutonymph, were also found helping in the moulting of the female teliochrysalis by pulling out and thereby removing the exuviae of the latter. The sperm transfer was found achieved through copulation. Immediately after the complete removal of the exuvium (moulting skin) or even before that the adult male was found to mate with the newly moulted adult female. While mating, the males crawled under the posterior end of the female body and arched the posterior part of its hysterosoma in an upward fashion, to accomplish coupling. During mating, the body of the female mite was strongly held by the male with its fore legs (Plate. 13; Fig. B). The process of mating was found to last for 2-3 minutes. Immediately after copulation, the male moved away from the mated female in search of virgin females to mate. In laboratory cultures, a male was found to mate with 3-4 females per day, whereas the female was found to copulate only once in its life time.

Morphological description of the life stages of *T. neocaledonicus* Andre, 1933.

In the genus *Tetranychus*, empodium of the female is distally split into 3 pairs of proximoventral hairs. Duplex setae on tarsus I widely separated. Dorsal body setae are long and slender with pointed ends. Only one pair of para-anal setae present.

Egg (Plate. 12; Fig. A).

Measurements:

114 – 119 μm

The eggs were spherical, smooth, transluscent and creamy white in colour when freshly laid (Plate 12; Fig. B). The colour of the eggs then turned to pale yellow and then to orange, and just prior to hatching the red eye spots became clearly visible. A portion of gnathosoma and legs of the larvae could be easily visible through the slit developed on the egg case, a few hours prior to hatching.

Larva (Plate. 12; Fig. C).

Colour: Pale yellow

Measurements:

Length: 209 – 226 μm

Width:127–159μm

Dorsal region (Figure 16 A)

Dorsal region is rounded in shape; body with fine striations that show variation in different regions; rostrum broadly conical with an anterior protruding part; stylets short and extending beyond the rostral region; peritremes distally curved and joined basally beneath the stylets; 12 pairs of dorsal setae; P_2 comparatively longer and thicker; setae L_4 shortest, all dorsal setae smooth and pointed; pedipalp 4 segmented.

Ventral region (Figure 16 B)

Striations present; setae MV_1 and MV_2 present; 2 pairs of anal and 2 pairs of para-anal setae present; para-anal setae comparatively thicker and longer than anal setae; genital area indistinct; 3 pairs of legs, each terminates with an empodium, legs 6 segmented, setae on tarsus 1-3: 12, 12 and 10.

Protonymph (Plate 12; Fig. E)

Colour: Yellowish green

Measurements:

Length: 247 – 278 µm

Width: 184 – 229 µm

Dorsal region (Figure 16 C)

Striations present; rostrum narrow and extended; stylets long, protruded forward in parallel to each other; protruded far beyond the anterior margin of the rostrum; peritreme structute similar to that in the larva; propodosoma broader posteriorly; pedipalp 4 segmented and terminates in a sensillus; dorsal setae 12 pairs, long, thin and smooth.

Ventral region (Figure 16 D)

Setae MV_1 and MV_2 present; 1 pair of long, smooth and tapering post-genital setae (*POG*) present; anal area well distinguished with 2 pairs of anal

and 2 pairs of para-anal setae; 4 pairs of legs, number of setae on tarsus of legs 1-4: 12, 12, 14 and 14.

Deutonymph (Plate 12; Fig. F)

Colour: Greenish red

Measurements:

Length: 334 – 367 µm

Width: 201 – 238 µm

Dorsal region (Figure 17 A)

Presence of striations on entire body surface including legs; rostrum stout and broad; peritreme curved downward with a hook like end; propodosoma with straightened anterior region; 13 pairs of dorsal setae, 1 pair added anew, all dorsal setae smooth and pointed, seta P_2 longest and D_2 shortest; dorsal setae longer than ventral setae.

Ventral region (Figure 17 B)

Anal area highly developed, 2 pairs of anal and 2 pairs of para-anal setae; genital area well striated, 1 pair of pre-genital setae (*PRG*) added anew, *PRG* narrow and pointed; 1 pair of post-genital setae (*POG*); setae MV_3 added anew; setae on tarsal segment of legs 1-4: 18, 18, 17 and 16.

Adult Female (Plate 12; Fig. H)

Colour: Bright red

Measurements:

Length: 383 – 412 µm

Width: 204 – 257 µm

Dorsal region (Figure 17 C)

Striations well visible; propodosoma rounded anteriorly; pedipalp thick and four segmented; pedipalp terminating in small and strong sensillum; peritreme distally curved; 13 pairs of long, smooth and pointed setae on dorsal region.

Ventral region (Figure 17 D)

Presence of 3 pairs of setae (MV_1, MV_2 and MV_3); 2 pairs of anal and 2 pairs of para-anal setae present, anal setae smallest, para-anals long and narrow and located above the anal setae laterally; genital area with 1 pair of *PRG*, 1 pair of *POG* and 1 pair of genital setae.

Leg

Legs 6 segmented – coxa, trochanter, femur, genu, tibia and tarsus, tibia I with 1 sensory and 7 tactile setae, tarsus 1 with 2 sensory and 3 tactile

setae proximal to duplex setae, tibia II with 1 sensory and 6 tactile setae, tarsus II with 1 sensory and 3 tactile setae proximal to duplex setae.

Adult Male (Plate 13; Fig. A)

Colour: Creamy yellow

Measurements:

Length: 357 – 383 µm

Width: 189 – 212 µm

Dorsal region (Figure 18 A)

Ventral region (Figure 18 B)

Body elongated and tapering posteriorly; knob of the aedeagus berry like and very distinctive, the rounded anterior projection more strongly developed than the posterior convexity (Figure 18 C; Plate 13; Fig. D).

Leg

Tibia I with 3 sensory and 8 tactile setae, tarsus I with 2 sensory and 4 tactile setae proximal to duplex setae; tibia II with 7 tactile setae and tarsus II with 1 sensory and 3 tactile setae proximal to duplex setae.

2.2. Breeding biology of *Oligonychus biharensis* (Hirst) (Plate. 14 & 15)

In the present study, *O. biharensis* was recognized as a species capable of undergoing dual modes of reproduction *viz*. the partheogenetic as well as sexual, under both laboratory and field conditions. Hence, the species was subjected for detailed studies on development under both modes of reproduction under laboratory conditions at three selected sets of temperature-humidity conditions and on three species of medicinal plants *viz*. *J. adhatoda, B. reinwardtii* and *B. acuminata.*

Oviposition and adult longevity

The adult females of *O. biharensis* were dark red in color (Plate. 15; Fig. B & C). and were found to show preference to lay eggs mostly on the upper surface of the leaves of the host plants, *J. adhatoda* and *B. acuminata*, but on *B. reinwardtii*, both surfaces of the leaves were found equally preferred by the females for oviposition. The pattern of oviposition was observed to be similar to that of *T. neocaledonicus*. During the present study, the durations (in days) of pre-oviposition, oviposition and post-oviposition periods as well as the longevity were recorded separately for both mated and unmated females of *O. biharensis* on the above three species of host plants.

As shown in Table. 24,.the duration of pre-oviposition period in mated females of *O. biharensis* on the host, *J. adhatoda* showed variation as 1.92 ± 0.04, 1.30 ± 0.03 and 0.95 ± 0.07 days respectively depending up on the

varied temperature-humidity conditions like 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. The durations of pre-oviposition period in unmated female under the same temperature-humidity conditions were recorded as 1.88 ± 0.06, 1.17 ± 0.02 and 0.89 ± 0.03 days respectively. On the other two species of host plants also, slight variations could be observed in the pre-oviposition periods of the species under the same temperature-humidity conditions mentioned above. The pre-oviposition periods of mated and unmated females on *B. reinwardtii* were recorded as 2.02 ± 0.06, 1.48 ± 0.03 & 1.06 ± 0.05 and 1.83 ± 0.08, 1.25 ± 0.07 & 0.98 ± 0.04 days respectively (Table. 28).While on the host *B. acuminata*, the pre-oviposition period recorded for mated and unmated females were 1.94 ± 0.08, 1.33 ± 0.05 & 0.96 ± 0.07 and 1.91 ± 0.6, 1.18 ± 0.04 & 0.87 ± 0.02 respectively (Table. 32). Upon statistical analysis, no significant difference could be recorded in the durations of the pre-oviposition period of the species on the three species of host plants tested.

The mean duration of oviposition period of mated females were found to last for 9.17 ± 0.19, 8.03 ± 0.24 and 7.42 ± 0.15 days respectively on the host, *J. adhatoda* under the selected temperature-humidity conditions of 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. A very slight extension was noted in the mean duration of the oviposition period of unmated females on the same host plant and which could be recorded as 9.61 ± 0.07, 8.64 ± 0.10 and 7.95 ± 0.08 days

respectively under the same laboratory conditions provided (Table. 24). On *B. reinwardtii*, the mean duration of oviposition period in mated and unmated females lasted for 9.26 ± 0.13, 8.35 ± 0.09 & 7.07 ± 0.10 and 9.94 ± 0.15, 8.69 ± 0.07 & 8.26 ± 0.12 days respectively for the same temperature-humidity conditions mentioned above (Table. 28). On the host plant, *B. acuminata* a slight reduction in the oviposition period was noted for the mated and unmated females and which could be recorded as 8.03 ± 0.17, 7.12 ± 0.08 & 6.22 ± 0.14 and 8.36 ± 0.20, 7.43 ± 0.15 & 6.32 ± 0.12 days respectively (Table. 32). The shortest duration in the oviposition period was recorded on the host, *B. acuminata*.

For the temperature-humidity conditions of 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH, the mean duration of post-oviposition period also showed variation as 1.21 ± 0.06, 1.01 ± 0.03 & 0.90 ± 0.07 days respectively for the mated females and 1.52 ± 0.04, 1.11 ± 0.05 & 0.98 ± 0.08 days respectively for the unmated females on the host, *J. adhatoda* (Table. 24). The mean duration of post-oviposition period on *B. reinwardtii* was recorded as 1.34 ± 0.05, 1.02 ± 0.07 & 0.84 ± 0.05 days and 1.42 ± 0.07, 1.14 ± 0.09 & 0.95 ± 0.08 days respectively for the mated and unmated females (Table. 28). The mean duration of the post-oviposition period were 1.31 ± 0.09, 1.06 ± 0.05 & 0.91 ± 0.03 days and 1.52 ± 0.07, 1.05 ± 0.08 & 0.98 ± 0.05 days respectively in mated and unmated females on the host, *B. acuminata* (Table. 32). There were

no significant variations in the mean duration of the post-oviposition period among the three host plants tested.

The longevity of the mated and unmated females of *O. biharensis* on *J. adhatoda* recorded during the study were 12.30 ± 0.17, 10.34 ± 0.12 & 9.27 ± 0.10 days and 13.01 ± 0.15, 10.92 ± 0.19 & 9.82 ± 0.11 days respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH (Table. 24). On the host, *B. reinwardtii*, the longevity of the mated and unmated females could be recorded as 12.62 ± 0.18, 10.85 ± 0.25 & 9.97 ± 0.20 days and 13.19 ± 0.17, 11.08 ± 0.23 & 10.19 ± 0.14 days respectively under the three temperature-humidity conditions (Table. 28). While on *B. acuminata*, the adult longevity was noted as 11.28 ± 0.23, 9.51 ± 0.19 & 8.09 ± 0.17 days and 11.79 ± 0.21, 9.66 ± 0.16 & 8.17 ± 0.18 days respectively for the mated and unmated females (Table. 32). The adult longevity of the species on *J. adhatoda* and *B. reinwardtii* did not show much variation and it was recognized as the lowest on the host, *B. acuminata*.

Fecundity

The females of *O. biharensis* were found to lay the minimum number of eggs during the initial stages of oviposition, irrespective of variations in temperature-humidity conditions and host plants, as evidenced during the present study. The maximum number of eggs was laid during the middle days of oviposition period. The fecundity of the mated female on the host plant, *J.*

adhatoda under the three sets of temperature–humidity conditions mentioned above was observed to be 43.62 ± 2.21, 47.31 ± 3.15 and 56.19 ± 2.16 at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH respectively (Table. 25). Under the same temperature-humidity conditions, the fecundity of the unmated female showed a slight decrease and could be recorded as 38.92 ± 1.53, 44.87 ± 2.34 and 49.36 ± 1.72 (Table. 25). The mean number of eggs laid by the mated and unmated females of the species on the host, *B. reinwardtii* were found to be 38.51 ± 2.40, 44.62 ± 2.27 & 51.23 ± 1.65 and 35.75 ± 1.23, 41.91 ± 2.16 & 47.53 ± 2.32 respectively (Table. 29). On *B. acuminata*, the fecundity was slightly reduced and the mean number of eggs laid by mated and unmated females was 31.43 ± 1.21, 37.86 ± 2.14 & 42.58 ± 1.09 and 27.26 ± 1.35, 32.55 ± 2.16 & 35.64 ± 2.11 respectively (Table. 33).

The daily output of eggs by the mated female of *O. biharensis* on *J. adhatoda* at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH was found averaged to 4.76 ± 0.08, 5.89 ± 0.15 and 7.57 ± 0.06 respectively whereas that of the unmated female was on an average 4.05 ± 0.13, 5.19 ± 0.09 and 6.21 ± 0.07 respectively (Table. 25). On *B. reinwardtii*, the mean number of eggs laid/day/ mated female was observed to be 16 ± 0.11, 5.34 ± 0.09 & 7.25 ± 0.10 respectively whereas it was 3.60 ± 0.08, 4.82 ± 0.16 & 5.75 ± 0.07 respectively by the unmated female (Table. 29). For the three temperature-humidity conditions, the mean

rate of egg production by the mated females on the host, *B. acuminata* was observed as 3.91 ± 0.17, 5.32 ± 0.09 & 6.85 ± 0.11 respectively and 3.26 ± 0.20, 4.38 ± 0.07 & 5.64 ± 0.08 respectively by the unmated females (Table. 33). The fecundity and the daily output of eggs laid by a single mated and unmated female was found to be high on *J. adhatoda* and low on *B. acuminata* at all temperature-humidity conditions.

Hatching

The newly laid eggs were yellowish orange coloured and spherical (Plate. 14; Fig. A). On progressive days of incubation, the colour of egg was found to change to orange- brown. The red coloured prominent eye spots were well visible at the end of incubation (Plate. 14; Fig. B). An increase in size and loss of the original shape of the eggs were the major signs of the onset of hatching. The process of hatching was found similar to that of *T. neocaledonicus* and the vigorous movement of the emerging larva aided in the fast rupturing of the slit. While hatching, the mouth parts and first pair of legs were found protruded out of the egg shell, followed by the emergence of the last two pairs of legs (Plate. 14; Fig. C). The process of hatching was found completed within 8-10 minutes and the variations in temperature-humidity conditions did not exert any significant impact on hatching. The exuviae left behind by the hatched larvae were found accumulated on the leaf surface of host plants.

In the mated females of *O. biharensis*, the per cent of egg viability at the three temperature-humidity conditions like 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH, could be recorded as 78.41 ± 2.04, 85.03 ± 1.87 and 89.26 ± 2.35 respectively on *J. adhatoda* whereas it was 74.98 ± 2.67, 81.47 ± 3.14 and 85.21 ± 1.28 respectively for unmated females (Table. 25). For the same temperature-humidity conditions, the percentage of egg viability was recorded on *B. reinwardtii* as 75.32 ± 3.15, 82.16 ± 1.61 & 85.24 ± 2.67 respectively for mated females and 71.65 ± 1.37, 78.39 ± 2.15 & 81.93 ± 2.20 for unmated females (Table. 29). On *B. acuminata*, the percent of hatching success of eggs laid by mated females was 73.25 ± 2.18, 79.47 ± 1.35 & 83.24 ± 2.16 respectively whereas that of unmated females was 69.08 ± 3.05, 76.43 ± 1.76 & 79.06 ± 1.31 respectively (Table. 33). The percentage of egg viability was observed to be high on the host plant, *J. adhatoda* and low on *B. acuminata*.

Duration of the developmental stages

Data on the durations of the developmental stages/immature life stages of both the sexual and parthenogenetic progenies of *O. biharensis* on the three preferred host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata* were recorded during the current study. The results of the study revealed that the duration of development of the parthenogenetic progenies was comparatively lower than that of the sexual progenies on all the host plants. The duration of

development of the various life stages of the species was found decreased at the higher temperature conditions selected.

Egg incubation period

The incubation period or the embryonic developmental period in *O. biharensis* showed marked variations depending up on the differences in the temperature-humidity conditions and host plants. The shortest period of incubation was observed at the higher temperature conditions provided on all the three host plants. The incubation period of the sexual progeny of *O. biharensis* on *J. adhatoda* was averaged to 3.11 ± 0.09, 2.60 ± 0.07 and 2.46 ± 0.06 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH (Table. 26) and 35 ± 2^{o}C and 60 ± 5 per cent RH. While in the parthenogenetic progeny, the mean incubation period was observed to be 3.06 ± 0.07, 2.49 ± 0.06 and 2.44 ± 0.07 days respectively (Table. 27). On *B. reinwardtii*, the average duration of incubation period under the three sets of temperature-humidity conditions could be recorded as 3.4 ± 0.06, 2.88 ± 0.06 & 2.72 ± 0.09 days for sexual progeny and 3.25 ± 0.05, 2.71 ± 0.06 & 2.56 ± 0.04 days for parthenogenetic progeny (Table. 30 & 31). The mean incubation period of the species under the sexual and parthenogenetic modes of reproduction on the host plant, *B. acuminata* was recorded as 3.78 ± 0.06, 2.89 ± 0.03 & 2.67 ± 0.03 days and 3.49 ± 0.05, 2.76 ± 0.04 & 2.55 ± 0.04 days respectively (Table. 34 & 35).

Larval period

The newly hatched larva of *O. biharensis* appeared more active than that of the *T. neocaledonicus* and it was small, spherical and reddish orange in color (Plate. 14; Fig. D). The larva was characteristically a hexapod with 3 pairs of yellowish-orange coloured legs. Upon progressive feeding, the body color of the larva got changed into dark red. The feeding period of the larval stage was found to last for 1.11 ± 0.08, 0.96 ± 0.08 and 0.83 ± 0.09 days at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C and 60 ± 5 per cent RH respectively in the sexual progeny on the host plant, *J. adhatoda* (Table. 26 &). The duration of larval period recorded under the parthenogenetic mode of reproduction was found averaged to 1.12 ± 0.05, 0.93 ± 0.03 and 0.76 ± 0.06 days respectively for the same temperature-humidity conditions studied (Table. 27). On the host plant, *B. reinwardtii* the respective durations of the larval stage in sexual and parthenogenetic progenies were observed to be 1.2 ± 0.07, 0.99 ± 0.05 & 0.89 ± 0.06 days and 1.17 ± 0.06, 1.03 ± 0.04 & 0.86 ± 0.06 days under the three temperature-humidity conditions mentioned above (Table. 30 & 31). As shown in the table, the mean duration of larval period on *B. acuminata* was traced as 1.71 ± 0.05, 1.21 ± 0.04 & 1.02 ± 0.07 days and 1.39 ± 0.03, 1.05 ± 0.03 & 0.95 ± 0.02 days respectively for the sexual and parthenogenetic progenies (Table. 34 & 35) under the three sets of temperature-humidity conditions mentioned above.

Protonymphal period

The protonymph was comparatively larger than the preceding stage, and possessed four pairs of yellowish orange legs and reddish-orange coloured body (Plate. 14; Fig. F). Concomitant with the feeding activity, a dark colour appeared on the dorso-lateral surface of the body. The feeding activity of protonymph was comparatively more intensive as it could result in the development of immediate and visible damage symptoms within a short period of time. The active feeding period of the protonymph on *J. adhatoda* under the three sets of temperature-humidity conditions selected *viz*. 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C and 60 ± 5 per cent RH was found averaged to 1.31 ± 0.06, 0.83 ± 0.05 & 0.81 ± 0.04 days respectively, for the sexual progeny and 1.13 ± 0.04, 0.90 ± 0.07 & 0.79 ± 0.06 days respectively for the parthenogenetic progeny (Table. 26 & 27). On *B. reinwardtii*, the protonymph developed through the sexual mode was found to feed for an average of 1.53 ± 0.09, 1.11 ± 0.05 & 0.94 ± 0.04 days respectively, whereas the feeding period of the protonymph showed a slight decrease when developed under parthenogenetic mode and which could be recorded as 1.23 ± 0.04, 0.99 ± 0.05 & 0.89 ± 0.03 days respectively (Table. 30 & 31). The active feeding period of the protonymph developed under the sexual and parthenogenetic modes on the host plant, *B. acuminata* lasted for 1.86 ± 0.05, 1.23 ± 0.08 & 1.04 ± 0.04 days and 1.49 ± 0.04, 1.08 ± 0.05 & 0.93 ± 0.03 days respectively (Table. 34 & 35).

Deutonymphal period

The deutonymph was larger than the protonymph and appeared reddish in colour (Plate. 14; Fig. H). initially and later became more darkened upon feeding and developed dark blotches on the dorsum. The colour of the deutonymph turned more darker as it approached the teliochrysalis stage. The shape of the hysterosoma of the deutonymph showed marked variation depending up on the sex of the individual and in the male deutonymph the hysterosoma was pointed or tapering at its posterior part, whereas the female deutonymph was distinguishable based on its round-oval hysterosoma. On *J. adhatoda*, the deutonymph developed through the sexual mode was found to feed for an average of 1.53 ± 0.05, 0.97 ± 0.05 and 0.89 ± 0.10 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C and 60 ± 5 per cent RH while that under the parthenogenetic mode showed a slight reduction in the duration recording 1.32 ± 0.03, 0.91 ± 0.04 & 0.82 ± 0.07 days respectively on the same host and temperature-humidity conditions (Table. 26 & 27). The deutonymphal period lasted for 1.57 ± 0.05, 1.07 ± 0.09 & 0.96 ± 0.09 days and 1.49 ± 0.03, 0.96 ± 0.06 & 0.88 ± 0.02 days respectively under the sexual and parthenogenetic modes of reproduction on the host plant, *B. reinwardtii* (Table. 30 & 31). On *B. acuminata*, the feeding period of the deutonymph lased for 1.73 ± 0.03, 1.21 ± 0.06 & 1.05 ± 0.08 days and 1.67 ± 0.03, 1.09 ± 0.03 & 0.98 ± 0.05

days respectively for the sexual and parthenogenetic progenies (Table. 34 & 35).

Quiescent periods

Resembling the other tetranychid species studied earlier *viz*. *T. neocaledonicus*, *O. biharensis* also was found to possess three inactive (quiescent) phases in its life cycle, one each at the end of the active stages like the larva, protonymph and the deutonymph. Prior to the initiation of quiescence, each of the active instar ceased feeding activity and wandered on the leaf surface in search of a secluded area adjacent to the midrib or other veins on the leaves of the host plants to initiate the period of quiescence. As soon as the instar succeeded in locating the secluded site on the leaf, it stopped movement and it pierced the leaf tissue to insert its feeding stylets and the posterior pair of legs was found retracted and brought together under the body (Plate. 14; Fig. E). During the period of quiescence, the body of the inactive life stage was found covered by a transparent covering and the latter assumed a cloudy appearance prior to moulting.

The durations of the protochrysalis, deutochrysalis and teliochrysalis showed slight variations depending upon the temperature-humidity conditions and host plants selected for the study. At 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C and 60 ± 5 per cent RH, the durations of the protochrysalis recorded during the study on the host plant, *J.*

adhatoda were 0.93 ± 0.05, 0.69 ± 0.06 & 0.67 ± 0.08 days respectively under the sexual mode of development whereas under the parthenogenetic mode, the durations were 0.90 ± 0.03, 0.61 ± 0.08 & 0.56 ± 0.05 days respectively (Table. 26 & 27). The deutochrysalis stage was found to last for an average of 0.85 ± 0.09, 0.62 ± 0.11 & 0.52 ± 0.09 days respectively under the sexual mode and 0.82 ± 0.06, 0.61 ± 0.05 & 0.51 ± 0.03 days respectively under the parthenogenetic mode. The teliochrysalis was found to last for 0.95 ± 0.08, 0.79± 0.10 & 0.73 ± 0.09 days under the sexual mode while that under the parthenogenetic mode was 0.89 ± 0.05, 0.70 ± 0.09 & 0.61 ± 0.05 days respectively (Table. 26 & 27).

At 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C and 60 ± 5 per cent RH, the durations of protochrysalis on the host, *B. reinwardtii* could be recorded as 1.14 ± 0.05, 0.80 ± 0.07 & 0.71 ± 0.08 days respectively under the sexual mode and 0.97 ± 0.04, 0.71 ± 0.07 & 0.67 ± 0.05 days respectively under the parthenogenetic mode (Table. 30 & 31). The duration of deutochrysalis period averaged to 0.87 ± 0.04, 0.64 ± 0.06 & 0.53 ± 0.05 days respectively under the sexual mode and 0.84 ± 0.05, 0.62 ± 0.05 & 0.53 ± 0.07 days respectively under the parthenogenetic mode. The teliochrysalis was found to require an average of 0.98 ± 0.08, 0.82 ± 0.04 & 0.73 ± 0.10 days respectively under sexual and 0.91 ± 0.02, 0.73 ± 0.06 & 0.65 ± 0.05 days respectively under parthenogenetic modes of development (Table. 30 & 31).

Under the three temperature-humidity conditions but on another host plant, *B. acuminata* the duration of protochrysalis was recorded as 1.23 ± 0.03, 0.91 ± 0.05 & 0.82 ± 0.06 days and 1.04 ± 0.04, 0.93 ± 0.07 & 0.74 ± 0.06 days respectively for the sexual and parthenogenetic progenies (Table. 34 & 35). The duration of the deutochrysalis stage observed during the study was 1.05 ± 0.04, 0.74 ± 0.03 & 0.63 ± 0.05 days and 0.97 ± 0.05, 0.76 ± 0.08 & 0.67 ± 0.07 days respectively under sexual and parthenogenetic modes of development. The period of teliochrysalis under the sexual mode of development was recorded as 1.08 ± 0.07, 0.95 ± 0.05 & 0.84 ± 0.05 days whereas that under the parthenogenetic mode could be recorded as 1.03 ± 0.06, 0.94 ± 0.05 & 0.81 ± 0.03 days respectively (Table 34 & 35).

Moulting

The process of moulting in *O. biharensis* very closely resembled that of *T. neocaledonicus* and the emergence of the succeeding instar from the preceding stage was facilitated by the splitting of the old cuticle along a definite line or lines. The formation of the slit and their further widening process resembled those of *T. neocaledonicus*. A backward thrust exerted by the moulting instar culminated in the widening of the slit and separation of the moulting skin/old cuticle from the body of the moulted instar (Plate 14; Fig. E, G & H). The process of moulting was found to complete within 11-13 minutes. The exuviae of the anterior two pairs of legs appeared intact whereas

those of the posterior part were found broken into pieces and rarely remained intact after emergence of succeeding instars (Fig. 3, 7, 8 & 10).

Total duration of developmental stages

The total duration of development from egg to adult in *O. biharensis* on *J. adhatoda* was recorded as 9.79 ± 0.34, 7.58 ± 0.23 and 6.89 ± 0.37 days under the sexual mode of reproduction at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. On the same host plant and at the same temperature- humidity conditions, the parthenogenetic development was completed with an average of 9.24 ± 0.22, 7.15 ± 0.18 and 6.49 ± 0.31 days respectively (Table. 26 & 27). On *B. reinwardtii*, the mean duration of development was recorded as 10.67 ± 0.36, 8.30 ± 0.31 & 7.47 ± 0.30 days and 9.86 ± 0.27, 7.75 ± 0.29 & 7.04 ± 0.31 days respectively under the sexual and parthenogenetic mode of development (Table. 30 & 31). On the host plant *B. acuminata*, the mean duration of sexual development of the species was 12.42 ± 0.31, 9.13 ± 0.37 & 8.06 ± 0.35 days respectively and 11.08 ± 0.29, 8.61 ± 0.36 & 7.62 ± 0.28 days respectively for the parthenogenetic development (Table. 34 & 35).

The percentage of immature survivorship for the sexual development recorded on *J. adhatoda* at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH was 86.35 ± 2.12, 95.73 ± 3.10 and 97.51 ± 2.09 respectively. While in the parthenogenetic

development, the percentage of immature survivorship recorded was 85.67 ± 2.11, 93.94 ± 1.43 and 94.36 ± 1.08 respectively (Table. 25). The percentage of immature survivorship on *B. reinwardtii* was 82.65 ± 1.12, 89.27 ± 2.09 & 92.94 ± 2.16 and 79.84 ± 1.53, 85.47 ± 3.15 & 89.53 ± 1.28 for the sexual and parthenogenetic progenies respectively (Table. 29). The percentage of immature survivorship for sexual and parthenogenetic progenies on *B. acuminata* were 79.53 ± 1.87, 84.37 ± 2.15 & 87.42 ± 1.49 and 74.15 ± 2.34, 81.62 ± 2.07& 83.17 ± 1.12 respectively (Table. 33).

Adult stages

The adult males and females of *O. biharensis* were red in colour, with the females being more dark coloured than the males (Plate. 15; Fig. A). The size and shape of the male and female individuals showed variation. The males were smaller with elongate yellowish-orange coloured legs while the females were larger than the males and with short legs. The female hysterosoma was oval in shape, whereas in males, it was tapered posteriorly. The active males were found moving in search of quiescent deutonymphs (teliochrysalis) or newly emerged females for mating.

At 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH, the adult longevity under sexual mode of development on the host, *J. adhatoda* was 11.42 ± 0.42 days (female - 12.46 ± 0.25 & male- 10.38 ± 0.22), 9.63 ± 0.29 days (female - 10.53 ± 0.17 & male

- 8.72 ± 0.15) and 8.44 ± 0.25 days (female - 9.05 ± 0.12 & male - 7.83 ± 0.16) respectively (Table. 26) For the same temperature-humidity conditions, the adult longevity in parthenogenetic progenies was recorded as 9.13 ± 0.31, 7.94 ± 0.28 and 7.25 ± 0.36 days respectively (Table. 27). On the host, *B. reinwardtii* the adult stages lived for 11.47 ± 0.39 days (female - 12.63 ± 0.28 & male - 10.31 ± 0.20), 9.71 ± 0.34 days (female - 10.79 ± 0.25 & male - 8.62 ± 0.23) and 8.77 ± 0.31 days (female - 9.84 ± 0.22 & male - 7.69 ± 0.16) days respectively in the sexual mode of development while the parthenogenetically developed adult stages lived for 10.08 ± 0.31, 8.27 ± 0.35 & 7.43 ± 0.28 days respectively (Table. 30 & 31). The durations of the adults on the plant, *B. acuminata* were 10.30 ± 0.46 days (female - 11.03 ± 0.29 & male - 9.56 ± 0.21), 8.41 ± 0.33 days (female - 9.43 ± 0.24 & male - 7.39 ± 0.19) and 7.28 ± 0.32 days (female - 8.01 ± 0.15 & male - 6.54 ± 0.23) respectively in the case of sexual development (Table. 34). The parthenogenetically developed adults lived for 8.29 ± 0.35, 6.53 ± 0.41 and 5.73 ± 0.37 days respectively (Table. 35). The sex ratio recorded under sexual mode of development in *O. biharensis* was 3 : 10 on the host plants *viz*. *J. adhatoda* and *B. reinwardtii*, whereas the sex ratio was found to be 2 : 10 on the host *B. acuminata*. Under parthenogenetic development all the progenies were found to be males.

Mating

The newly emerged male was found wandering on the surface of the leaf in search of the adult females for mating. The males preferred to mate with the newly emerged or unmated females. The adult male individuals were found wandering around the teliochrysalis stage of the females. The mating process was usually accomplished immediately after the last moult (teliochrysalis) of the female. The process of mating was found similar to that of *T. neocaledonicus*. The process of mating took 2-3 minutes. A single male was found to copulate with 3-4 females per day whereas the female was found copulated only once.

Morphological description of the life stages of *O. biharensis* (Hirst, 1925)

Genus *Oligonychus* is characterized by the presence of pad like claws with tenent hairs; empodium is claw like and has proximoventral hairs set at right angles to the empodium. Two pairs of anal setae and a single pair of para-anal setae present.

Egg (Plate 14; Figs. A & B)

Measurements:

Diameter 127 – 133 μm

Eggs spherical, yellowish orange in colour when freshly laid. The colour of the egg changed to orangish red before hatching. Red eye spots clearly visible through the translucent egg case, few hours before hatching.

Larva (Plate 14; Figs. C & D)

Colour: Reddish-orange

Measurements:

Length: 170 – 205 µm,

Width: 121 – 147 µm

Dorsal region (Figure 19 A)

Rounded in shape, with a transparent texture; rostrum extended anteriorly; distally curved peritremes; 10 pairs of dorsal setae, all smooth and pointed.

Ventral region (Figure 19 B)

Setae MV_1 and MV_2 present; indistinct genital area; anal region with 2 pairs of anal and 1 pair of para-anal setae; 3 pairs of legs.

Protonymph (Plate 14; Figs F & G)

Colour: Reddish-orange

Measurements

Length: 251 – 287 µm

Width: 144 – 179 µm

Dorsal region (Figure 19 C)

Striations present; rostrum protruding; stylets protruded forward, parallel to each other; peritremes distally curved; propodosoma more or less narrow; 12 pairs of dorsal setae, all long and thin.

Ventral region (Figure 19 D)

Medioventral setae MV_1 and MV_2 present; genital area as in larva; 2 pairs of anal and 1 pair of para-anal setae present, anal setae short and para-anal setae long; 4 pairs of legs.

Deutonymph (Plate 14; Fig. H)

Colour: Reddish

Measurements:

Length: 310 – 347 µm

Width: 207 – 246 µm.

Dorsal region (Figure 20 A)

Body with transverse striations; rostrum stout and long; peritremes directed backwards and curved into hook like at its distal end; seta P_1

comparatively shorter than P_2 and P_3; hysterosomal setae D_5 added a new, all setae except D_5 long and pointed.

Ventral region (Figure 20 B)

Setae MV_3 added a new; anal area well developed and distinct; 2 pairs of anal setae and 1 pair of para-anal setae present; genital setae located slightly anterior to genital opening.

Adult female (Plate 15; Figs. B & C)

Colour: Brick red

Measurements:

Length: 362 – 391 μm

Width: 251 – 274 μm.

Dorsal region (Figure 20 C)

Gnathosoma well projected anteriorly; peritremes directed backwards, curved into a pair of hook like structures distally; anterior margin of propodosoma arched, seta P_1 shorter than P_2 and P_3; presence of transverse striations; all the hysterosomal setae except D_5 elongated and pointed, seta D_5 short and thin.

Ventral region (Figure 20 D)

Medio-ventral setae MV_1, MV_2 and MV_3 present; genital seta situated anterior to genital opening, genital opening bordered by diverging striations; 2 pairs of anal and 1 pair of para-anal setae present.

Leg

Tibia I with 1 sensory and 5 tactile setae, tarsus I with 1 sensory and 4 tactile setae proximal to duplex setae; tibia II with 7 tactile setae; tarsus II with 2 tactile setae, proximal to duplex setae.

Adult Male (Plate 15; Fig. B)

Colour: Red

Measurements:

Length: 341 – 379 µm

Width: 162 – 174 µm

Dorsal region (Figure 21 A)

Ventral region (Figure 21 B)

Males with slender elongated body and with long yellowish orange legs; Aedeagus long and slender with axis of the distal enlargement parallel to the shaft (Figure 21 C; Plate 15; Fig. E).

Leg

Tibia I with 3 sensory and 8 tactile setae, tibia II with 7 tactile setae, tarsus I with 2 sensory and 4 tactile setae, tarsus II with 1 tactile setae, proximal to duplex setae.

2.3. Study on breeding biology of *Brevipalpus phoenicis* (Plate. 16 & 17)

In the present study, the developmental parameters of an injurious species of false spider mite *viz*. *B. phoenicis* were studied by culturing them on two species of host medicinal plants *viz*. *M. rotundifolia* and *V. negundo*. Results of field studies showed that the populations of *B. phoenicis* comprised entirely of female individuals and hence data were collected on the developmental aspects of the species under parthenogenetic mode of reproduction alone.

Oviposition and adult longevity

The females of *B. phoenicis* showed a general preference to the lower surface of leaves for depositing eggs. However, when the population density of the mite reached peak levels, the female extended ovipositional preference to the upper surface of the leaves of the host plants also. The female extruded single eggs through the slightly lowered posterior part of its hysterosoma (Plate. 16; Fig. C). and these eggs were generally found laid along the major/minor veins or in the cracks and crevices present on the leaf surface.

Due to their sticky nature, these eggs were found firmly adhered to the leaf surface until they were hatched. On the surface of severely infested leaves, the eggs were found laid side by side, imparting an aggregated nature.

The duration of pre-oviposition, oviposition and post-oviposition periods as well as the adult longevity of the adults of *B. phoenicis* were found to vary depending up on the variations in the temperature-humidity conditions and the host plants. In the present study, the duration of pre-oviposition period of *B. phoenicis* was found to be 4.37 ± 0.31, 3.42 ± 0.25 and 3.26 ± 0.18 days respectively at 25 ± 2^{o}C & 80 ± 5 % RH, 30 ± 2^{o}C & 70 ± 5 % RH and 35 ± 2^{o}C & 60 ± 5 % RH on the host plant, *M. rotundifolia* (Table. 36). However, the duration of pre-oviposition period was found slightly extended on the host plant, *V. negundo* at all the three temperature-humidity conditions, which recorded 6.02 ± 0.27, 5.16 ± 0.32 and 4.73 ± 0.20 days respectively (Table. 39). Under the same temperature-humidity conditions and on the host plant, *M. rotundifolia,* the oviposition periods of the species were observed to be 18.23 ± 0.42, 17.32 ± 0.30 and 16.49 ± 0.23 days respectively (Table. 36). The respective durations of oviposition period under the same temperature-humidity parameters on *V. negundo* were found to be slightly decreased as 15.36 ± 0.35, 14.39 ± 0.29 and 13.87 ± 0.37 (Table. 39). The durations of post-oviposition period on the host plants, *M. rotundifolia* and *V. negundo* under the above three temperature-humidity conditions were 4.03 ± 0.27, 3.18 ± 0.21 & 3.11 ± 0.15 days and 3.61 ± 0.31, 3.24 ± 0.19 & 2.90 ± 0.24 days

respectively (Table. 36 & 39). The adult longevity of the species on *M. rotundifolia* and *V. negundo* under temperature-humidity conditions of 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH, also showed variation as 26.63 ± 0.52, 23.92 ± 0.61 & 22.86 ± 0.43 days and 24.99 ± 0.70, 22.79 ± 0.41 & 21.50 ± 0.39 days respectively (Table. 36 & 39).

Fecundity

The number of eggs laid by the females of the species was observed to be minimum during the initial days i.e. from the first to fourth days of oviposition. A slight increase in the rate of oviposition was observed during the middle days of oviposition period i.e. from the fifth to eleventh days of oviposition. The rate of oviposition was found decreased from the 12th day onwards. Some females were found to lay eggs in alternate days alone during the final days of oviposition.

The mean number of eggs laid by the species when reared on the host, *M. rotundifolia* showed variation depending up on variations in temperature-humidity conditions and it was recorded as 29.82 ± 1.23 at 25 ± 2°C & 80 ± 5 per cent RH, 35.61 ± 1.15 at 30 ± 2°C & 70 ± 5 per cent RH and 31.74 ± 0.89 at 35 ± 2°C & 60 ± 5 per cent RH (Table. 37). When the species was reared on the leaves of *V. negundo*, the fecundity was found slightly decreased and it could be recorded as 23.41 ± 0.35, 28.62 ± 0.27 and 25.14 ± 0.42 respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ±

2°C & 60 ± 5 per cent RH (Table. 40). Under the same temperature-humidity conditions, the daily production of eggs could be recorded as 1.64 ± 0.07, 2.06 ± 0.05 and 1.93 ± 0.04 respectively on *M. rotundifolia* (Table. 37). On the host plant, *V. negundo* the rate of egg production showed a very slight reduction as 1.52 ± 0.08, 1.99 ± 0.06 and 1.81 ± 0.05 respectively (Table. 40).

Hatching

Newly laid eggs were red coloured, elliptical and slightly broadened at one end (Plate. 16; Fig. A). On the previous day of hatching, the eggs were turned to opaque-white in colour. The hatching process was found initiated by the formation of a semicircular slit at the broader end of the egg. The slit got extended further in either directions to form a complete circular cut on the egg case. The wriggling movement of the emerging larva enhanced the widening of the egg case further and it protruded its first two pairs of legs through the slit. This was followed by the thrashing action of the larval propodosoma and movement of the basal segment of the legs. Due to the continuous rhythmic leg movements, the larva escaped out, leaving behind the egg case on the leaf surface. The entire process of hatching was found completed within 22-26 minutes.

The percentage of egg viability recorded on *M. rotundifolia* were 82.74 ± 1.86, 87.11 ± 2.03 and 88.82 ± 1.37 at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH (Table. 37).

While on *V. negundo* the percentage of egg viability were 76.37 ± 2.31, 81.15 ± 1.47 and 79.21 ± 1.64 respectively for the three temperature-humidity conditions (Table. 40).

Durations of the developmental stages

During the present study, data were recorded separately on the duration of development of the various instars of *B. phoenicis viz*. the egg, larva, protonymph, deutonymph and the respective quiescent stages on the host plants, *M. rotundifolia* and *V. negundo*. Data on the process of moulting, total durations of development and the percentage of the immature survivorship were also noted. The durations of the various instars were found decreased when the species was cultured at higher temperature conditions and the development of the species was found completed comparatively faster on the host, *M. rotundifolia*.

Egg incubation period

The incubation period was found to vary with respect to the temperature-humidity conditions and the host plants. The duration of incubation period on the host plant, *M. rotundifolia* was observed to be 6.09 ± 0.31, 5.17 ± 0.15 and 5.24 ± 0.21 respectively (Table. 38) under the selected temperature-humidity conditions of 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH. On *V.*

negundo, the incubation period was found slightly extended to 7.27 ± 0.23, 6.38 ± 0.19 and 6.43 ± 0.31 respectively (Table. 41).

Larval period

The newly hatched larva was small, flat, bright orange-red in colour and provided with three pairs of legs (Plate. 16; Fig. B). The larva was found to feed on the leaf surface. As the feeding process progressed, the colour of the larva turned to dark red with black and orange patches on the body. The active larval period on the host plant, *M. rotundifolia* lasted for 4.15 ± 0.25, 3.21 ± 0.23 and 3.30 ± 0.19 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH (Table.) whereas it was more extended on *V. negundo*, reaching 4.76 ± 0.18, 4.13 ± 0.27 and 4.11 ± 0.15 days respectively under the above temperature-humidity conditions (Table. 38 & 41).

Protonymphal period

The protonymph was comparatively larger in size, more darker in color and characterized by the possession of 4 pairs of legs. The orange and black patches on the body were well visible during this stage (Plate. 16; Fig. D). The duration of active protonymphal period on the host plant, *M. rotundifolia* at 25 ± 2^{o}C & 80 ± 5 per cent RH was recorded as 3.27 ± 0.28 days, at 30 ± 2^{o}C & 70 ± 5 per cent RH, 3.06 ± 0.15 days and at 35 ± 2^{o}C & 60 ± 5 per cent RH, 3.11 ± 0.21 days (Table. 38). The protonymphal period on *V.*

negundo lasted for 3.52 ± 0.24 days at 25 ± 2°C & 80 ± 5 per cent RH, 3.21 ± 0.16 days at 30 ± 2°C & 70 ± 5 per cent RH and 3.29 ± 0.27 days at 35 ± 2°C & 60 ± 5 per cent RH (Table. 41).

Deutonymphal period

The deutonymphs were larger in size than the protonymphs and were more voracious feeders (Plate. 16; Fig. F). They were more active and moved faster on the leaf surface. The mean duration of active feeding period of the deutonymph on *M. rotundifolia* was 4.16 ± 0.22, 3.86 ± 0.13 and 3.89 ± 0.20 days at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH respectively (Table. 38). While on *V. negundo*, the deutonymphal period was slightly extended to 4.52 ± 0.35, 3.94 ± 0.26 and 4.23 ± 0.17 days respectively, under the same three temperature-humidity conditions (Table. 41).

Quiescent periods

At the end of each of the active immature stage, a physically inactive or immobile quiescent stage was observed (Plate. 16; Fig. C & H) in *B. phoenicis* also. Before entering into the quiescent stage the, active instars were found to cease feeding activity and became lethargic. Upon quiescence, the instar assumed a characteristic posture, by inserting its feeding stylets into the leaf tissue and with the legs stretched straight/outward. Three quiescent

stages *viz*. the protchrysalis, deutochrysalis and teliochrysalis were observed in between the active immature stages.

On *M. rotundifolia*, the mean durations of the proto, deuto and teliochrysalis stages of the species recorded during the study were 2.26 ± 0.12, 2.93 ± 0.19 and 2.53 ± 0.32 days respectively at 25 ± 2°C & 80 ± 5 per cent RH; 2.14 ± 0.16, 2.24 ± 0.20 and 2.19 ± 0.24 days respectively at 30 ± 2°C & 70 ± 5 per cent RH; 2.27 ± 0.23, 2.32 ± 0.17 and 2.32 ± 0.16 days respectively 35 ± 2°C & 60 ± 5 per cent RH (Table. 38). On *V. negundo* , the mean durations of proto, deuto and teliochrysalis stages were 2.43 ± 0.31, 3.11 ± 0.30 and 2.61 ± 0.27 respectively at 25 ± 2°C & 80 ± 5 per cent RH; 2.24 ± 0.22, 2.43 ± 0.18 and 2.26 ± 0.19 days respectively at 30 ± 2°C & 70 ± 5 per cent RH; 2.37 ± 0.34, 2.47 ± 0.21 and 2.45 ± 0.13 days respectively 35 ± 2°C & 60 ± 5 per cent RH (Table. 41).

Moulting

The process of shedding out of the outer cuticle of the preceding instar, called moulting could be noted at the end of each of the quiescent phase of *B. phoenicis*. Prior to moulting, the outer cuticle of the quiescent stage developed a silvery white colouration which was followed by the appearance of a horizontal slit at the mid dorsal region of the body, between the second and third pairs of the legs. The horizontal slit, subsequently got extended along either side of the body and finally met ventrally. The moulting

individual was found to exert a backward thrusting movement which accelerated the widening of the slit further, culminating in the emergence of the succeeding instar from the old exuviae, leaving behind the latter on the leaf surface.

Total duration of developmental stages

The number of days required for the development of the various instars of the species also showed variation depending up on the host plants and the temperature-humidity variations. The total durations of development from egg to adult stage on *M. rotundifolia* was observed as 25.39 ± 0.54, 21.87 ± 0.49 and 22.45 ± 0.34 days at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH respectively (Table. 38). Whereas on *V. negundo*, the durations of development was found completed in 28.22 ± 0.62, 24.59 ± 0.46 and 25.36 ± 0.50 days respectively (Table. 41). The percentage of immature survivorship on *M. rotundifolia* were 84.26 ± 1.53, 90.11 ± 1.47 and 89.61 ± 1.25 respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C & 60 ± 5 per cent RH (Table. 37). On *V. negundo*, the percentage of immature survivorship could be noted as 79.54 ± 1.73, 84.72 ± 1.62 and 83.14 ± 1.35 respectively (Table. 40).

Adult stage

The body of adult female of *B. phoenicis* was characteristically

elliptical, flat and light red coloured (Plate. 16; Fig. G & H) and it was active and mobile as the previous instar. On progressive days, when the female reached the post-oviposition stage, the colour of the body got transformed to blackish red. The adult mite population was found to comprise only female individuals.

Morphological description of life stages of *B. phoenicis*

Egg (Plate 16; Fig. A)

Measurements:

Length: 96- 102 µm

Width: 71- 74 µm

Freshly laid eggs appeared as elliptical, shiny, soft, sticky and bright orange-red in colour. A day before hatching, the eggs became pale red in colour and the red eyes of the larvae were visible within.

Larva (Plate 16; Fig. B)

Colour : Bright orange

Measurements:

Length: 142 - 147 µm

Width: 87 - 93 µm

Dorsal region (Figure 22 A)

Almost rounded in shape, transparent; body with fine striations; rostrum rounded and protruding anteriorly; stylets short and protruding beyond the rostral apex; 3 pairs of prodorsal setae, v_2, $sc_1$and sc_2; v_2 small and lanceolate; 9 pairs of dorsal opisthosomal setae, c_1, c_3, d_1, d_3, e_1, e_3, f_3, h_1 and h_2; h_2 smooth and small; f_3, h_1 large and lanceolate; c_1, d_1, e_1 smooth and dorsocentral.

Ventral region (Figure 22 B)

Striations present; 3 pairs of ventral setae present, *1a,3a* and *4a, 1a* larger than *3a* and *4a*; Genital area indistinct, 2 pairs of pseudoanal setae present; 3 pairs of legs, each terminates with an empodium, legs 6 segmented.

Protonymph (Plate 16; Fig. D)

Colour : Pale red with yellow/green patches

Measurements:

Length: 183 - 190 µm

Width: 113 -121 µm

Dorsal region (Figure 22 C)

Presence of dorsal striations; rostrum narrow and protruding; stylets long, parallel, running forward, extending far beyond the anterior margin of

the rostrum; Pedipalp 4 segmented; Propodosoma broader posteriorly; 3 pairs of prodorsal setae, v_2,sc_1,sc_2; 9 pairs of dorsal opisthosomal setae as similar as in the larval stage, h_2 large, lanceolate;

Ventral region (Figure 22 D)

3 pairs of ventral setae; 1 pair of aggenital setae; Two pairs of smooth pseudo anal setae ps_1 and ps_2; anal region with well developed anal plates; 4 pairs of legs, all terminating in to empodia.

Deutonymph (Plate 16; Fig F)

Colour: Pale red with dark green patches

Measurements:

Length: 260- 273µm

Width: 142-156 µm

Dorsal region (Figure 23 A)

Surface of body including the legs reticulated; Rostrum stout and broad; well developed rostral shield; anterior region of propodosoma more straightened; dorsal setae larger than the setae of ventral side; presence of 9 pairs of dorsal opisthosomal setae.

Ventral region (Figure 23 B)

Only 1 pair of aggenital setae (ag_1); genital plate (GP) developed with one pair of genital setae (g_1); anal plate (AP) highly developed; 2 pairs of smooth pseudo anal setae ps_1 and ps_2.

Adult Female (Plate 16; Figs. H & I)

Colour: Pale red with dark green patches

Measurements:

Length: 279 -286 µm

Width: 161 – 169 µm

Dorsal region (Figure 23 C)

Well developed rostral shield; pedipalp stout and four segmented; a pair of prominent eyes present; well marked striations; ornamentation ranges from smooth to reticulate; verrucose, aerolate and colliculate; cuticular feature often present on the body surface; 9 pairs of dorsal opisthosomal setae, *f3* , h_2, and h_1 small and smooth.

Ventral region (Figure 23 D)

Ventral setae smooth; well developed ventral plate (V.P), anal plate (A.P.) and genital plate (G.P.); a pair of genital setae (g_2) added anew; 2 pairs of pseudo anal setae (ps_1 and ps_2); genital setae thicker than *ag* and *ps*; legs 6 segmented; tarsus 1 with single solenidion (ω), tarsus II with two solenidia (ω_1 and ω_2).

PART – III

BIOLOGICAL CONTROL OF PEST MITES

INTRODUCTION

Of the various pest control strategies developed globally, chemical control involves only immediate and temporary decimation of the pest population and moreover, it leads to various health cum environmental problems resulting from the resurgence and resistance of pests, destruction of natural enemies, secondary pest out breaks, environmental pollution, residual problems in agricultural crops and fields and so on. As a safer and best alternative tool, biological control through the intentional usage of beneficial living organisms has gained much momentum in the present scenario, for suppression of pest population, below the economic injury levels, without disrupting the natural environment. Strategies of natural suppression of pests utilizing the biological enemies and application of plant based products are considered to be less harmful and moreover constitutes an ecofriendly approach to reduce yield loss and to attain better crop production.

Natural enemies, being the key component among the various biological control measures need special mention and their collection, rearing and appropriate and timely release in to the field determines the success of any biological control programme. Natural enemies like the predators, parasitoids, pathogens etc. exert effective control over pest population so as to maintain it always below the economic injury level. Among the various groups of natural enemies, arthropods, especially the insects and mites

constitute an important group comprising the predators and parasitoids. The populations of phytophagous mites are known to be suppressed by various groups of insect and mite predators. Of these, predatory mites constitute an excellent beneficial group of natural enemies which have the potential to suppress the pest mite populations. Varied families of predatory mites like Phytoseiidae, Cunaxidae, Bdellidae, Laelapidae, Stigmaeidae, Tydeidae, Cheyletidae etc. are known to have the potential to keep down the populations of phytophagous mites to desirable levels. Of these, members of Phytoseiidae owing to their extremely superior searching capacity, high consumption rate and very short life cycle have qualified as a superior group among the predatory mites. Based on their feeding habits, phytoseiids are classified into four categories (McMurtry and Croft, 1997) *viz*. Type I as specialized predators, Type II as selective predators, Type III as generalist predators and Type IV as specialized pollen feeders/generalist predators. More than 50 per cent of the members of Phytoseiidae come under the category Type II predators. Based on their ability for selective predation and high consumption rate, various countries have successfully implemented integrated pest control programmes by importing phytoseiid predators. Various species of phytoseiid predators like *Phytoseiulus persimilis*, *Amblyseius longispinosus*, *A. channabasavannai*, *A. largoensis*, *Eusieus ovalis*, *Cunaxa myabunderensis* etc. are recognized as very common predators associated with the pest mites on their respective host plants. The life stages of these predatory mites do not

induce any damage to the host plants as they feed on pollen and nectar in the absence of prey population. For exploiting the predatory potential of the phytoseiid mites, in the present study attempts were made by rearing three species *viz*. *Amblyseius* (*Amblyseius*) *largoensis* (Muma), *A.* (*Euseius*) *ovalis* and *Cunaxa myabunderensis* (Gupta) under laboratory conditions to evaluate their feeding potential against the selected species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*.

Apart from predatory mites, varied groups of insects belonging to the families Coccinellidae, Staphylinidae, Thripidae, Cecidomyidae etc. also have been recognized as potential predators on the pest mites. The larval and nymphal stages of predatory insects *viz*. *Stethorus punctillum S. punctum*, *S. pauperculus*, *Oligota flaviceps*, *O. oviformes*, *Scolothrips asura*, *S. longicornis*, *S. sexumaculatus* etc. have been observed to live in association with the pest mites on their respective host plants. The prey handling time of insect predators is comparatively shorter and their rate of predation is comparatively greater than those of the predatory mites. In the present study, attempts were also made to evaluate the predatory potential of insect predators like *Feltiella acarisuga* (Vallot) and *Scolothrips asura* Ramakrishna and Margabhandu against the selected species of pest mites.

Another ecofriendly and safe approach to pest control in the natural way is the application of biopesticides. Biopesticides have gained much

importance nowadays as a better alternative to synthetic pesticides, based on the possession of an array of beneficial properties which could be categorized as repellent, antifeedant, growth regulator, toxic etc. against the pest organisms. Among the various kinds of biopesticides, the secondary metabolites derived from plants dominate the usage since they have limited impact on the beneficial organisms. Plants are rich sources of many volatile compounds or oils which help the pest population to keep a distance away from the economically important crops. The application of the essential oils of many plant extracts is found to be more effective than their crude extracts. Research on the active ingredients, preparation and application and environmental impact of botanical pesticides are prerequisites for sustainable agriculture. The plant derived compounds cause both direct and indirect effects on pest populations and they induce mortality on the life stages of the mites, reduce fecundity, affect general fitness, reduce feeding activity etc. The plant derived volatile compounds are found to degrade quickly when applied in the greenhouses or agricultural fields and hence have reduced residual effect on nontarget organisms. Some commonly used plants for botanical preparations against the pest populations are *Azadirahcta indica*, *Glyricidia sepium*, *Chromolaena odorata*, *Lantana camara*, *Ocimum americanum* etc. Considering the environmental safety of botanical pesticides and the minimized residual problems on natural enemy complex, in the present study, attempts were made to formulate different concentrations of plant extracts

from selected species of plants like *Glyricidia sepium* (Jacq.) and *Chromolaena odorata* (L.) the efficacy of these extracts were evaluated against the different life stages of selected species of pest mites like *T. neocaledonicus* and *O. biharensis*.

REVIEW OF LITERATURE

The present review includes citations of earlier research works carried out on aspects of natural suppression of pest mites through the release of biological enemies like predatory mites and insects. Earlier findings on the suppression effect of plant derived biopesticides on insect and mite pests also have been incorporated in the present review.

1. Natural enemies

The possibilities of biological control of the spider mite pest, *T. telarius* infesting the greenhouse plants by releasing the predatory mite, *Phytoseiulus persimilis* were explored by Chant (1961) and he reported that the predator was highly efficient in controlling the pest population and thereby reducing the crop damage. Lewis (1973) observed the predatory habit of thrips on pest mites and recorded that all species of the genus *Scolothrips* possessed specialized predation on spider mite pests. Zaher *et al*. (1975) conducted studies on the feeding habits of the cunaxid predator *viz*. *Cunaxa capreolus* on the citrus brown mite, *Eutetranychus orientalis*. The consumption rate of the predator showed an increase with slight increase in temperature. Mallik and Channabasavanna (1976) identified *A. longispinosus* as a highly potential predator of spider mites and they suggested the possibility of utilising the species for controlling the spider mite pest, *T.*

ludeni. Takafuji and Chant (1976) observed that the predator, *Iphiseius degenerans* did not consume the captured prey completely and this feeding habit was observed frequently as the prey density got increased. Gilstrap and Oatman (1976) reported *Scolothrips sexmaculatus* as a potential predator of spider mites and recorded a decrease in prey consumption when the temperature increased to more than 30^{o}C. They found that immatures of *S. sexmaculatus* consumed an average of 11.7 eggs of *T. pacificus* per day at 26^{o}C whereas the adult females of the species had a consumption rate of 39 to 47 eggs/ day as the temperature increased from 18 to 30^{o}C.

Tanigoshi and McMurtry (1977) reported the coccinellid predator, *Stethorus picipes* as an effective biocontrol agent against the pest mite, *O. punicae* and the larvae and adults of the predator preferrably fed on the eggs of spider mites. Ball (1980) evaluated the potential of *P. macropilis*, *Proprioseiopsis temperellus*, *Neoseiulus fallacis*, and *Galendromus longipilus* as predators of the two spotted spider mite, *T. urticae*. Harris (1982) reported that the Cecidomyid predator, *Lestodiplosis oomeni* could effectively feed on the carinate tea mite, *Calacarus carinatus* as well as on other mites infesting tea plants in Indonesia. Boyne and Hain (1983b) based on laboratory experiments showed that the phytoseiid predator, *N. fallacis* could be used as an effective control agent of the spruce spider mite infesting the fraser fir seedlings.

Havelka and Kindlemann (1984) showed that the predatory mite, *P. persimilis* could be used for the control of the spider mite pest, *T. urticae* infesting glasshouse cucumbers. Gerson (1985) reported that *P. persimilis* was well-adapted to live and move through the silken web spun by spider mites on their host plants and could consume large number of prey mites within a short period of time. Gupta (1985) enlisted the potential predatory mite species feeding on the pest mites inhabiting on various species of economically important plants in India. Helle and Sabelis (1985) reported the predatory habit of insect groups such as Coleoptera, Dermaptera, Diptera, Hemiptera, Neuroptera, and Thysanoptera on spider mites. Oatman *et al*. (1985) successfully detected *Feltiella occidentalis* as an effective predator of almost all life stages of spider mites infesting strawberry in California. Chazeau (1985) observed that the adults and larvae of *Stethorus* and *Parastethorus* spp. of Coccinellidae were able to feed very actively on the spider mites as well as false spider mites. The authors found that when spider mite density was high, insect predators suppressed their populations owing to their voracity and reproductive capacity.

While conducting surveys on predatory mites inhabiting 11 species of major crops in Willamette Valley, Hadam *et al*. (1986) collected a total of 1, 209 phytoseiid mites and the authors also studied the pesticide resistance in the phytoseiid predatory mite, *T. pyri*. van Lenteren and Woets (1988) suggested that varied parameters possessed by phytoseiid mites like

phytoseiid mites fast movement, rapid developmental cycle, dependence on alternative food source, high climatic adaptation, lack of harmful effects on beneficial and easy culturing favoured the effective utility of these predatory mites in biological control programs. Gerson and Smiley (1990) prepared the relevant taxonomic keys and other important details of the members of major predatory mite families. Clements and Harmsen (1990) reported the prey capturing behavior and prey-stage preferences of the Stigmaeid and Phytoseiid mites and their potential compatibility in biological control of most severe mite pests. Aydemir and Toros (1990) found that some species of the genus *Scolothrips* were predators on the spider mite pest, *T. urticae* infesting bean plant in Erzincan. Gough (1991) studied the predatory potential of *P. persimilis* in controlling the population of *T. urticae* on rose hedges in southern Queensland. Selhorst *et al*. (1991) prepared a model to describe the predator- prey interaction between *S. longicornis* and *T. cinnabarinus*.

A rapid decline in the two spotted spider mite population was observed by Spicciarelli *et al.* (1992) when the phytoseiid mites were released on to the mite infested leaves. Smiley (1992) reported that the cunaxid predatory mites were fast moving, adapted to live in a variety of habitats like plants, soil, moss, bark and food stores and could successfully thrive on prey items comprised of small arthropods like mites and nematodes. He also found that the members of the family Bdellidae shared some features of cunaxid mites. Shimoda *et al*. (1993) reported that a single larva of the staphylinid beetle,

Oligota kashimirica benefica could consume 300–400 eggs of *T. urticae* during its development period. Grout (1994) showed that *Euseius* spp. formed the most common species among the phytoseiid predators in citrus-growing regions in citrus plantations in Southern Africa. Daneshvar and Abaii (1994) provided information on the successful usage of the phytoseiid predator, *P. persimilis* against the spider mite population in soybean fields at a release rate of five predators per plant. Waite and Gerson (1994) made observations on the predatory habit of the larva of the cecidomyid predator, *Arthrocnodax* sp. on a serious eriophyid mite pest, *A. litchi* in Australia and China.

Castagnoli *et al.* (1995) reported *N. californicus* as one of the most effective phytoseiid predator which could be used successfully for the management of spider mite population on many agricultural crops and fruit orchards. Gilstrap (1995) stated that members of the thrips genus, *Scolothrips* were well known as efficient predators of plant mite pests. Gagné *et al*. (1995) provided information on the potential role of some species of the gall midge genus, *Feltiella* especially, *F. acarisuga* as effective predators on spider mites. Van Driesche and Bellows (1996) suggested that factors such as selection of control agents, quality control, mass-rearing techniques, release methods, and efficacy of target pest suppression were important for manipulating successful biological control strategies against the pest population. Wilson *et al*. (1996) observed that 'phytophagous' thrips were

facultative predators on the two spotted spider mites infesting cotton in Australia. McMurty and Croft (1997) made a review on the feeding habits of the members of Phytoseiidae and their application in biological control. The authors divided the family based on their feeding habits in to four different groups *viz*. Type I) specialized predators of *Tetranychus* like *Phytoseiulus*; Type II) selective predators like *Galendromus, Neoseiulus* and some *Typhlodromus* species; Type III) generalist predators including *Typhlodromus* and *Amblyseius* species and others; and Type IV) specialized pollen feeders/generalist predators like *Euseius.* Kirk (1997) noted that *S. longicornis* had the potential to suppress the spider mite population below the level of damage threshold depending up on the timing of their introduction. He reported that the predatory thrips killed or consumed the pest mites only partially when mite population was high. When the predators were distracted by the passing prey mites, they abandoned the captured preys and attacked the passing preys and this habit of the predators was found to enhance the mortality rate of prey mites.

Lacasa and Llorens (1998) pointed out the possibilities of controlling spider mite population using insect predators. Raworth (1998) recorded excellent control of the two spotted spider mite by releasing the lady bird beetle, *S. punctillum* on tomato, pepper and cucumber grown under greenhouse conditions in Canada. He noted that the per day consumption by the adult beetle ranged from 75-100 two spotted spider mites. Obrycki and

Kring (1998) observed that release of predaceous coccinellid beetles offered adequate control over mite population. Gillespie *et al*. (1998) detected *F. acarisuga* as one of the important biological control agent which could be used successfully for implementing integrated pest management programmes against the two spotted spider mite pest, *T. urticae* on greenhouse vegetable crops. The larval stage of *F. acarisuga* was recognized as a most efficient predator on *T. urticae*. It was found that weekly release of 1000 individuals per ha was extremely effective in controlling spider mites on tomato, pepper and cucumber. Ho and Chen (1998) conducted studies on the life history, food consumption and seasonal occurrence of *F. minuta* on the prey comprised of spider mites infesting eggplant. It was observed that the population of the predator got increased when the number of *T. kanzawai* was more on the host plant. The authors further performed a comparative study on the rate of food consumption by the two predators, *F. minuta* and *A. womersleyi*. Lester *et al*. (1999) reported the pyrethroid-resistant predatory mite, *Amblyseius fallacis* as a potential biological control agent against the most injurious species of tetranychid mites *viz*. *P. ulmi* and *T. urticae* in an Ontario peach orchard. Hoddle *et al*. (1999) successfully carried out observations on the biological control of *O. perseae* using six species of phytoseiid predatory mites *viz*. *G. annectens*, *G. helveolus*, *G. pilosus*, G. *occidentalis*, *N. californicus* and *T. rickeri* on avocado in California by releasing 2000 predatory mites per tree. Zhang *et al*. (1999) recorded instances of effective predation by *A.*

longispinosus on the prey species *viz*. *S. nanjingensis*, a spider mite injurious to bamboo in Fujian, China. Kerguelen and Hoddle (1999) conducted studies on the biological control of *O. perseae* on avocado in California and evaluated the feeding efficacy of *Galendromus helveolus* and *Neoseiulus californicus*. The authors observed a reduction in the leaf area damage induced by *O. perseae* when treated with *N. californicus* alone or in combination with *G. helveolus*. Shih (1999) observed that the eggs of the two spotted spider mite formed the primary food of the predator, *S. sexmaculatus*. Peterson *et al*. (2000) stated that *S. bifidus* could be effectively used to reduce the population of *T. lintearius* based on its functional response to the prey in laboratory arenas.

The possibilities of controlling the population of the two spotted spider mite, *T. urticae* on edible glasshouse crops were explored by Rott and Ponsonby (2000) using a specialist coccinellid, *S. punctillum*. Gillespie *et al*. (2000) studied the life table parameters of *F. acarisuga* on a prey comprised of the eggs of the carmine spider mite, *T. cinnabarinus* under laboratory conditions of 26.7 ± 2^{o}C, 75 ± 5 per cent R.H. The authors observed that the first, second, and third instar larvae of *F. acarisuga* consumed an average of 35.5, 54.0 and 86.9 eggs respectively. Piatkowski (2000) recommended the use of the predatory fly, *Therodiplosis persicae* for suppression of mites injurious to plants in greenhouse conditions. Reis *et al*. (2000) showed that phytoseiid mites could be very effectively used to control the tenuipalpid mite

population which vectored the coffee ring spot virus. Ho and Chen (2001) evaluated the feeding and oviposition responses of the predator, *S. indicus* by offering a diet comprised of eggs of the Kanzawa spider mite. Nicetic *et al*. (2001) explored the possibilities of integrated pest management of the two-spotted mite on greenhouse roses using petroleum spray oil and also by releasing the predatory mite, *P. persimilis.* The relationship between temperature and rate of development of the predator, *S. punctillum* which fed up on the prey mite, *T. mcdanieli* was established by Roy *et al*. (2002).

Studies made by Osborne *et al*. (2002) showed that the adults of the insect predator, *F. acarisuga* possessed excellent ability in flying and tracking colonies of *T. urticae* on their host crops and their feeding potential was greater than that of the phytoseiid predator. The daily consumption rate of the larvae of *F. acarisuga* on the eggs, nymphs and adults of red spider mites was at least five times greater than that of *P. persimilus.* Reis *et al.* (2003) studied the functional response of the predatory mites, *E. alatus* and *I. zuluagai* on the tenuipalpid mite pest, *B. phoenicis* and recorded type II and type I functional responses respectively in the predators. Calvo *et al*. (2003) found that the gall midge, *F. acarisuga* was a potential natural predator of the two spotted spider mite. Kishimoto (2003) assessed consumption rate of insect predators like *S. japonicus*, *O. kashmirica benefica* and *S. takahashii*, on some spider mite species and reported that the prey consumption rate of *S. japonicus* was 16 times higher than that of *S. takahashii*. Colfer *et al*. (2003,

2004) reported that release of predatory mites would serve as an effective means for managing spider mite problems in many cropping systems. The authors recorded the effectiveness of releasing the western predatory mite, *G. occidentalis* in cotton fields to control spider mites. Opit *et al*. (2004) experimentally proved the predatory potential of the phytoseiid mite, *P. persimilis* on the two spotted spider mite, *T. urticae*. The biocontrol efficacy of *S. longicornis* on tetranychid mites under greenhouse situation was observed by Kiliç and Yoldas (2004). Studies on prey consumption and functional response of three acarophagous species *viz*. *S. japonicus, S. takahashii* and *A. californicus* to the eggs of the spider mite, *T. urticae* infesting lima bean leaf discs in the laboratory were made by Gotoh *et al*. (2004) at three constant temperatures (18–20, 25 and 30^{o}C) and 16L:8D. The authors reported that the average daily consumption rates of adult females during the first 20 days after emergence at 25^{o}C were 13.4 eggs for *A. californicus*, 23.0 eggs for *S. takahashii* and 294.4 eggs for *S. japonicas* and the adult females of the three predators showed a type II functional response to prey density, regardless of the temperatures tested. The daily egg consumption rate of immatures of *S. japonicus* was recorded as 9 to 14 times and 23 to 42 times more than those of *S. takahashii* and *A. californicus* respectively.

Escudero and Ferragut (2005) reported that the predator, *P. macropilis* was well adapted to warm climates and was more effective in controlling the

population of the two spotted spider mites in the Mediterranean area. Lahiri *et al*. (2005) carried out a survey on the predatory mites which feed on pest mites infesting the medicinal plants of Kolkata and recorded that members of the family phytoseiidae formed the maximum number (16 spp.) of which four species were found to be highly efficient in feeding on the pest mites. The species of the family Bdellidae, Cunaxidae and Stigmaeidae were comparatively lesser in number. De Boer and Dicke (2005) reported that the predatory mite, *P. persimilis* could be used as a specialized natural controlling agent on herbivorous spider mites. Thakur and Dinabandhu (2005) observed that *N. longispinosus* could feed on *Tetranychus* species infesting on apple and fig trees. Kongchuensin *et al*. (2005) found that the phytoseiid member, *N. longispinosus* could successfully feed on *T. urticae* on 33 species of economically important plants in Thailand. Naher *et al*. (2005) assessed the predatory potential of three species of acarophagous mites *viz*. *P. persimilis, S. punctillum* and *S. sexmaculatus* against *T. urticae* and recorded that the daily consumption rate of *S. punctillum* was higher when compared to that of the other two predators. The larva of *S. punctillum* consumed an average of 114.33 eggs of *T. urticae* per day whereas the adult consumed119.67 eggs, 73.67 immatures and 54.33 adults per day. Tsoukanas *et al.* (2006) studied the effect of temperature on the development of the immature stages of *I. degenerans* when fed up on the pest mite, *T. urticae*. Rhodes *et al*. (2006) was able to prove the biocontrol efficacy of *P. persimilis* and *N. californicus* on

the two spotted spider mites infesting strawberries. The predatory potential of *Galendromous helveolus* on a major citrus pest, *B. californicus* was assessed by Chen *et al.* (2006) in Texas. The authors recorded that a single immature of *G. helveolus* consumed an average of 30.7 eggs, 53.6 larvae, 22.7 nymphs of *B. californicus* during its period of development to adult while an adult female of the species consumed an average of 164.8 eggs, 369.6 larvae, 80.9 nymphs of the pest.

Galvão *et al*. (2007) recorded a phytoseiid member, *A. largoensis* as a potential predator of the coconut mite pest, *A. guerreronis*. Studies made by van Houten *et al*. (2007b) enabled to establish *T. swirskii*, a polyphagous predator as a potential agent in suppressing different species of spider mites. Studies conducted by Reis *et al.* (2007) established a type II functional response in a predatory phytoseiid species, *A. herbicolus* while feeding on the tenuipalpid pest mite, *B. phoenicis*. Fiaboe *et al*. (2007) suggested the ladybird beetle, *S. tridens* as a potential biocontrol agent against *T. evansi* based on various factors like high prey consumption, longevity and high reproductive capacity of the beetle. The predatory habit of *F. acarisuga* on the eggs of the two spotted spider mite was observed by Mo and Liu (2007). Darbemamieh (2008) conducted studies on the spatial distribution and population dynamics of some species of tetranychoid mites and their acarid predators on apples in Kermanshah Orchards. Mineiro *et al*. (2008) studied the population dynamics of the tenuipalpid mite, *B. phoenicis* and its

associated predatory mite families *viz*. Phytoseiidae and Stigmaeidae on coffee in Brazil. Oliveira *et al*. (2009) evaluated the feeding potential of the predatory mite, *P. macropilis* on the two-spotted spider mite on strawberry plants under greenhouse conditions. *P. macropilis* required about 20 days to reduce the pest mite population on strawberry plants which were initially infested with the two spotted spider mites @100 females /plant. Pakyari *et al*. (2009) reported that species of the thysanopteran genus *Scolothrips* were well known as predators of spider mite species like *T. urticae* and the authors analysed the most suitable conditions which favoured the predatory efficacy of *S. longicornis* on populations of the pest mite*, T. urticae.* Biddinger *et al*. (2009) reviewed the research works carried out on the role of members of the genus *Stethorius* as predators of most injurious pest mites. Perumalsamy *et al*. (2009) conducted studies on the predatory efficiency of *S. gilvifrons*, an important predator of the red spider mite, *O. coffeae*, infesting tea in Tamil Nadu, India. The predatory efficiency of *S. gilvifrons* was found increased during the growth of larval instars. An adult female consumed 205.0 eggs, 92.2 larvae, 81.8 nymphs and 52.4 adult mites per day.

Park *et al*. (2010) conducted studies on the predatory potential of *A. swirskii* against the tomato russet mite, *Aculops lycopersici*, a serious pest of greenhouse tomatoes. Haque *et al.* (2010) reported that spider mites problem would increase when natural enemies were destroyed by nonspecific application of insecticides. Negloh *et al*. (2010) studied the impact of season

and fruit age on the population dynamics of the eriophyid mote pest *A. guerreronis* and its associated predatory mite, *N. paspalivorus* on coconut in Benin. Zhu *et al*. (2010) assessed the feeding efficacy of *A. cucumeris* in controlling the population of *B. obovatus*. Mound *et al*. (2010) recorded a new species of predatory thrips *viz*. *Scolothrips ochoa* feeding on species of *Raoiella* on the leaves of *Lophostemon suaveolens* at The Gap, a western suburb of Brisbane in Australia. The authors reported that *S. ochoa* sp. n.was apparently host-specific and it lacked ocellar setae pairs I and II. It differed from other *Scolothrips* species in lacking an elongate pronotal midlateral setae, and by having antennal segments III-IV and V-VI broadly joined.

Darbemamieh *et al*. (2011) carried out observations on the population abundance and seasonal activity of the stigmaeid predator, *Zetzellia pourmirzai* and its prey mites, *C. irani* and *B. rubrioculus* in sprayed apple orchards of Kermanshah, Iran. The smallest optimum sample sizes, calculated with a Taylors' coefficient, were 20.806, 192.912 and 128.117 for *C. irani*, *B. rubrioculus* and *Z. pourmirzai*, respectively. Chauhan *et al*. (2011) managed to suppress the population of the two spotted spider mite on carnation by releasing the predatory mite, *N. longispinosus* and by applying biopesticide. It was found that the predatory mite was highly efficient in controlling the two spotted spider mite on carnation under greenhouse conditions in Himachal Pradesh, India. Reddy *et al* (2011) reported several new pests and predatory mite species associated with economic plants from Guam and the results of

their studies disclosed the presence of *T. marianae* and the predatory mite, *P. horridus* on eggplant, *B. californicus*, *Eupodes* sp. and the predator, *Cunaxa* sp. on guava, *B. californicus*, *Lepidoglyphus destructor* and *A. obtusus* on cycad (*Cycas micronesica*). Sarwar *et al.* (2011) reported four species of predatory mites associated with sucking pests on protected cucumber (*Cucumis sativus*). Pakyari (2011) conducted studies on the rate of development of *S.longicornis* on the prey mite, *T. urticae* at different temperatures *viz*. 15, 20, 25, 30, 35 and 37^{o}C. The total time of development from egg to adult emergence for females was estimated to be 48.1, 22.8, 13.6, 10.6, 8.3 and 9.6 days respectively. The development time showed a decrease with increasing temperature from 15 to 35^{o}C and no development was observed at 40^{o}C. Gonzáles-Zamora *et al*. (2011) recorded *S. longicornis* as a apotential predator of the oriental species of spider mite, *E. orientalis* and found that it exhibited voracious feeding on various life stages of the pest mite, thereby reducing the pest population.

Xiao *et al*. (2011) suggested that the predatory gall midge, *F. acarisuga* could be used successfully for suppressing the populations of the two spotted spider mite, *T. urticae* infesing vegetables cultivated in green houses. The authors further provided experimental evidences based on laboratory cum greenhouse evaluation for the use of corn (*Zea mays*) as a banker plant for the predatory gall midge, *F. acarisuga* to potentially control *T. urticae*. Choice and no choice experiments were carried out to determine

the host plant preference of an alternative prey, *O. pratensis* to corn and green bean, *P. vulgaris*. The rate of predation by *F. acarisuga* on *T. urticae* and *O. pratensis* ranged from 43.7 to 67.9 per cent and 59.2 to 90.3 per cent, respectively, under laboratory conditions where as in a non-cage study, 81.2 per cent of *T. urticae* population was suppressed by *F. acarisuga* in reference to the control (cage treatment). Results of surveys conducted by Gupta and Karmakar (2011) enabled to record 56 species of predatory mites under 24 genera and 10 principal predatory mite families on the medicinal and aromatic plants in India. The predatory mite families recovered were Phytoseiidae, Tydeidae, Stigmaeidae, Cunaxidae, Anystidae, Ascidae, Bdellidae, Cheyletidae, Erythraeidae and Eupodidae and a total of 33 phytoseiid species were identified as potential predators. Chaaban *et al*. (2011) conducted studies on the seasonal distribution pattern of *O. afrasiaticus* and its phytoseiid predators on date palm, *Phoenix dactylfera* (Deglet Noor cultivar) in Tunisian oases for a period of two years and found that the incidence of infestation by *O. afrasiaticus* on the host initiated from the first to the third week of July. Indigenous predators were not observed on the host between mid-July till the end of August. The most common and abundant predator observed was *T.athenas*.

Pakyari and Enkegaard (2012) traced the impact of different temperatures (15 to 37^{o}C, 60 ± 10 % RH, 16:8 L:D) on the rate of consumption of the predatory thrips, *S. longicornis* on the eggs of the two

spotted spider mite, *T. urticae* under laboratory conditions and the results of their studies revealed a significant effect of temperature on prey consumption by the predator. The number of prey eggs consumed daily by the first and second instar larvae showed a linear increase with the increasing temperature from 15 to 37^{o}C and the daily consumption of eggs by ovipositing females followed a nonlinear pattern, with maximum daily predation at 32.8^{o}C. Sarwar *et al*. (2012) proved the effective use of the phytoseiid predator, *N. pseudolongispinosus* for outdoor biological control programmes against spider mites. Carrillo and Pena (2012) reported the association of the predatory mite, *A. largoensis* with the red palm mite, *R. indica* in Florida. The authors evaluated the predator preferences among developmental stages of *R. indica* and estimated the functional and numerical responses of the predator to varying densities of its most preferred prey-stage. The life stages of *A. largoensis* showed more preference to the egg stage of the prey mite and its mean consumption rate was 45 eggs per day. Zheng *et al*. (2012) explored the possibilities of managing populations of *B. obovatus* using predatory mites and through artificial rainfall in South China. The results of the survey made by the authors in the tea gardens of Guangzhou enabled to record 13 species of predatory mites feeding on *B. obovatus*, of which the most abundant predator was *A. hainanensis* and it predatory potential was recorded as 68.6 per cent. Rahman *et al*. (2012) made observations on the predatory efficacy, prey stage preference and optimum predator-prey ratio of the phytoseiid mite,

N. longispinosus on the red spider mite, *O. coffeae* on tea under laboratory and green house conditions. The results their studies disclosed a marked reduction in the number of adult stages of *O. coffeae* and an increase in the number of *N. longispinosus* in both conditions.

Onzo *et al*. (2012) observed the potential of *A. swirskii* to suppress the population of the broad mite, *P. latus* on the gboma eggplant, *S. macrocarpon* in Benin. Elmoghazy *et al*. (2012) practiced integrated approaches for the control of the two spotted spider mite, *T. urticae* on faba bean plant *Vicia faba* by releasing two species of predatory mites *viz*. *N. californicus* and *T. swirskii* in an open field at Behaira Governate, Egypt. The authors observed that *N. californicus* had a higher potential in controlling the pest mite, *T. urticae*. Pappas *et al*. (2013) observed the predatory potential of *P. finitimus* on *T.urticae* along with two other species of insect pests in greenhouse condition. The adult female of *P. finitimus* was found to feed on a large number of eggs and larvae of *T. urticae*. Sajna and Anithalatha (2013) surveyed the fauna of predatory mites associated with 32 species of economically important plants belonging to 27 genera and 21 families in North Kerala. The results of their survey revealed 15 species of predatory mites belonging to 6 genera *viz*. *Amblyseius*, *Typhlodromips*, *Euseius*, *Neoseiulus*, *Phytoseius* and *Paraphytoseius* included under Mesostigmata. The first record on the predaceous thysanopteran species, *S. longicornis* was made by Masarovič *et al*. (2013) from soil and a tree photoeclector samples from Bábsky les wood, a

natural oak-hornbeam forest in Slovakia. Five specimens were captured in soil photoeclectors and two in tree photoeclectors during 2012 vegetation period. Studies on different biological characters and predation capacity of *F. acarisuga* on a diet comprised of eggs of the two spotted spider mite, *T. urticae* at 25 ± 2^{o}C and 60-75 per cent were made by Refaei and Mohamed (2013). The mean duration of developmental stages of *F. acarisuga* was found averaged to 13.5 ± 2.6 and the pre-ovipostion, oviposition and post-oviposition periods were on an average of 2.9 ± 3.9, 6.2 ± 5.2 & 6.9 ± 4.3 respectively. The total number of eggs of *T. urticae* consumed by the larval stages (1st, 2nd, and 3rd) of *F. acarisuga* were 21.9 ± 1.5, 47.1 ± 2.8 and 55.5 ± 2.9 respectively and the female longevity was recorded as 15.2 ± 4.0 days and it increased to 34.9 ± 6.1at the experimental conditions when the daily rate reached 3.7 ± 1.9. A study on the functional responses and prey-stage preferences of the predatory gall midge *F. acarisuga* and two predatory mites *viz*. *N. californicus* and *A. swirskii* on pest mite, *T. urticae* was carried out by Xiao *et al*. (2013). The authors revealed that *F. acarisuga* was highly effective in feeding on the eggs of *T. urticae* when compared to those of the predatory mites. Among the three predators, *F. acarisuga* showed the highest predation on *T. urticae.* The maximum rate of predation by the larva of *F. acarisuga* was recorded as 50 eggs/day*,* followed by the female of *N. californicus* (25.6 eggs/day) and the female of *A. swirskii* (15.1 eggs/day).

Liyaudheen *et al*. (2014) evaluated the feeding efficacy of *E. ovalis* on *T. macfarlanei,* a major spider mite pest with wide host range, inducing considerable damage and yield loss to the vegetable crop, okra, *A. esculentus* in Kerala. The studies on feeding potential of *E. ovalis* were carried out in the laboratory at 30 ± 2^{o}C and 64 ± 2 per cent RH by adopting leaf flotation technique and the results of the study indicated the maximum feeding preference of the predator to the eggs of the pest mite, followed by the larva and protonymph. Prey consumption rates by the adult female, deutonymph, protonymph and the adult male of the predator were 63 per cent, 52 per cent, 50 per cent and 33 per cent respectively. Shimoda *et al*. (2015) mentioned insects as natural enemies for controlling spider mites by testing the efficiency of four insect predator groups (*S. takahashii*; *F. acarisuga; Oligota* spp., and *Stethorus* spp.,) by releasing them on potted komatsuna plants (*Brassica rapa*) infested with the two-spotted spider mite.

2. Biopesticides

Information on the traditional control of insect pests using some medicinal plants was provided by Abubakar and Abdurahman (1998) and they conducted surveys in Kaduna State of Nigeria to identify plant species and understand the methodologies used by the local people to eradicate the insect pests. The plants commonly used for the insect control were *Adansonia digitata*, *Annona senegalense*, *Cyperus rotundus*, *Prakia calppertonia*,

Newbouldia laevis, *Striga senegalense*, *Swartzia madagascariensis* and *Hydropogon contortus* and which possessed insecticidal, antifeedant and repellant properties also. The acaricidal activity of the compounds obtained from the plant, *D. stramonium* against the flat mite, *B. phoenicis* and the eriophyid mite *A. guerreronis* was studied by Guirado *et al*. (2001) and they found that the extracted compounds were toxic to all the life stages of these pest mites. Park *et al.* (2002) evaluated the acaricidal and insecticidal activities of some domestic plant extracts against five major arthtopod pests and reported that the extracts of eight species of plants were more effective, inducing over 80 per cent mortality of the two spotted spider mite, *T. urticae.* Kim *et al*. (2005) screened methanol extracts from 22 species of plants for evaluating their acaricidal and insecticidal activities against *T. urticae*, *P. citri*, *Myzus persicae*, *Trialeurodes vaporariorum*, and *Aphis gossypii*. The extracts from the twig of *Albizzia coreana* and leaf of *Pyracantha angustifolia* exhibited potent acaricidal activity against the two spotted spider mite, *T. urticae.* The extracts prepared from *Camellia japonica* seeds, *Ranunculus japonicus* leaves and roots, *A. coreana* leaves and *Houttuynia cordata* leaves exhibited acaricidal activity against *P. citri* in a field test. Martinez-Villar *et al*. (2005) studied the effect of the 'azadirachtin', one of the key active constituents of neem oil obtained from the plant, *A. indica* against the two spotted spider mite population. The authors observed that the compound 'azadirachtin' had the potential to suppress the mite population by acting as

feeding deterrent and thereby reducing the growth of the mite. Calmasur *et al*. (2006) reported the acaricidal activity of different concentrations of essential oils extracted from three species of plants belonging to Lamiaceae *viz*. *Nepeta racemosa*, *Micromeria fruticosa* and *Origanum vulgare* against the nymphs and adults of the two spotted spider mite, *T.urticae.* The highest mortality was recorded in 2µl/l air doses at 120 hours of exposure. According to Gencsoylu (2007), botanical pesticides would provide mite control at a low cost, and with a low risk to man and environment and thus were recommended for the control of tetranychid mites. The author studied the effect of the pesticide derived from *Asphedolus aestivus* to control the pest, against the mite pest, *T. cinnabarinus*.

Nazli *et al*. (2008) studied the pesticidal activity of different concentrations of ethanolic extracts of the leaves of the plant, *Glyricidia sepium* on insects, nematodes and bacteria, in Pakisthan. The authors found that extract caused 60 per cent mortality of the root knot nematode, *Meloidogyne incognita* and a maximum repellency of 78 per cent was observed against *Aedes aegypti*. The antibacterial activity was more effective against *Escherichia coli* than *S. aureus, S. typhi, Pseudomonas* spp., and *Klebsiella* spp. Sarmah *et al*. (2009) successfully evaluated the effect of aqueous plant extracts of *Acorus calamus*, *Polygonum hydropiper*, *C. infortunatum* and *Xanthium strumarium* on the tea red spider mite, *O. coffeae* under both laboratory and field conditions. Different concentrations of extract

viz. 2.5, 5.0 and 10.0 per cent (w/v) were applied on *O. coffeae* to assess the effect on ovicidal and acaricidal activities. Strong ovicidal activity was observed with *X. strumarium* (87.09 %) and *A. calamus* (70.62 %) whereas lowest activity was reported for *P. hydropiper* (30.86 %) and *C. infortunatum* (20.58 %). Extracts of 5 and 10 per cent concentrations showed more than 50 per cent mortality of mites in the laboratory condition, where as in the field condition 46.9 – 81.8 per cent and 64.7 – 100.0 per cent mite reduction was recorded at 5 per cent and 10 per cent respectively. Sertkaya *et al*. (2010) screened the acaricidal activities of the essential oils obtained from several medicinal plants *viz*. oregano (*Origanum onites*), lavender (*Lavandula stoechas*), thyme (*Thymbra spicata*) and mint (*Mentha spicata*) against the adults of the pest mite, *T. cinnabarinus* under laboratory conditions. The principal compound, carvacrol was present in the essential oils of thyme and oregano (70.93 % and 68.23 %, respectively). Thujone (65.78 %) and carvone (59.35 %) were the two major compounds obtained from the essential oils of lavender and mint respectively. Results of laboratory bioassay showed that all these essential oils were effective in causing mortality in the adult pest mites and the better results were obtained by the oils from thyme and oregano. The mean lethal concentrations (LC_{50}) of the essential oils of thyme, oregano, mint and lavender were 0.53, 0.69, 1.83 and 2.92µg ml^{-1} air, respectively.

Araujo *et al*. (2010) studied the acaricidal effect of the plant-derived molecules extracted from three species of citrus cultivated in north east Brazil

against the pest mite, *T. urticae*. Attia *et al*. (2011) evaluated the biopesticide efficacy of different concentrations of garlic distillate (*Allium sativum*) to suppress the population of the serious mite pest, *T. urticae* and the results of their study showed that the garlic extracts in concentrations of 7.49 and 13.5 mg/l showed LD_{50} and LD_{90} values respectively. Sivira *et al*. (2011) conducted studies on the toxicity of the ethanol extract of the plants of wild oregano, *Lippia origanoides* and *G. sepium* on the population of the spider mite pest, *T. cinnabarinus* in Yaracuy State, Venezuela. Different concentrations of the ethanol extract *viz*. 5, 10, 15, and 20 per cent were applied following the leaf disk immersion technique and the authors recorded a reduction of 43.7 to 57 per cent in the rate of oviposition in *T. cinnabarinus* when treated with 5 per cent oregano or *Glyricidia* extracts respectively. When 10 per cent concentration of the extracts of *L. origanoides* and *G. sepium* were applied, the rate of mortality could be recorded as 42.2 or 72.5 per cent respectively in *T. cinnabarinus*. Jie *et al*. (2011) evaluated the acaricidal activity of acetone, water, ethanol and ethyl acetate extracts of the leaves of *Aloe vera* against the adult females of *T. cinnabarinus* by slide-dip bioassay. Of the four different extracts tested, acetone extract showed the strongest acaricidal activity, with LC_{50} value of 90 ppm at 72 hours whereas LC_{50} values of ethanol, water and ethyl acetate extracts were recorded as 391, 340 and 113 ppm respectively.

Patnaik *et al*. (2011) observed that essential oils and herbal extracts of different formulations extracted from different aromatic and medicinal plants were able to suppress the population build up of the eriophyid mite pest of coconut, *A. guerreronis,* in both laboratory and field conditions. Krishnappa *et al*. (2012) studied the mosquitocidal (larvicidal, ovicidal and pupicidal) activity of the extract of *G. sepium* against the malarial vector, *Anopheles stephensi*. The maximum larval mortality of *A. stephensi* (96.0 ± 2.4 %) was induced by the ethanol extract of *G. sepium* at a concentration of 250 ppm. The LC_{50} and LC_{90} values were recorded as 121.79 and 231.98 ppm respectively and higher concentrations of the solvent extract showed 100 per cent ovicidal activity. The pupae when exposed to different concentrations of ethanol extract were found dead with 58.10 per cent adult emergence when it was treated with 25 ppm concentration. Nong *et al*. (2012) analysed the acaricidal activity of the extract of *Eupatorium adenophorum* prepared by water decocting, ethanol thermal circumfluence, and steam distillation. The acaricidal effect of each extract was tested against *Psoroptes cuniculi* and *Sarcoptes scabiei* in vitro. Ethanol thermal circumfluence extract showed strong acaricidal activity and it killed all *S. scabiei* at 0.5 and 1.0 g/ml (w/v) concentration. A concentration of 1 g/ml extract was found to kill all *P. cuniculi* within 4-hours period. Zaman *et al*. (2012) studied the acaricidal activity of aqueous herbal extracts of *A. indica* leaves, *Calotropis procera* flowers, *Nicotiana tabacum* leaves and *Trachyspermum ammi* seeds following

adult immersion test, larval packet test and ear bag method both in vitro and in vivo conditions. The extract exhibited lethal effects on egg laying (index of egg laying = 0.371404 ± 0.00435), hatching (22.35 %) and total larval mortality at 50 mg ml^{-1} and reduced tick intensity on the infested calves (18 detached out of 35 at 45 per cent (w/w) suspension, topically applied). Felicien *et al*. (2012) conducted studies on the chemical composition and biological activities of the essential oil extracted from the fresh leaves of *Chromolaena odorata* growing in Benin. Twenty three compounds were identified *viz*. α-pinene (20.7 %), pregeijerene (14.6 %), geijerene (12.0 %), β-pinene (10.3 per cent), germacrene-D (9.7 %). The antibacterial activity of the oil was found to be high when compared to the antifungal and antiradical activities.

The various major biological approaches adopted to control the worldwide pest, *T. urticae* with special reference to natural pesticides were reviewed by Attia *et al*. (2013). Kumral *et al*. (2013) evaluated the sub-lethal and lethal effects of the ethanol extracts of the thorn apple leaves, *D. stramonium* against the European red mite, *P. ulmi* and its lady bird predator, *S. gilvifrons* in the laboratory by adopting petri leaf disc-spray tower method. The authors observed that treatments with increasing concentration of leaf extract increased the mortality rate of the adults of both *P. ulmi* and *S. gilvifrons* leading to respective LC_{50} values of 7097.5 and 1853.9 mg/l at 24 hours residual activity and the mortality of both the pest and its predator

increased further at 48 hours. However, the LC_{90} values of the extract were lower for the predator than the pest mite at both 24 and 48 hours. Roh *et al*. (2013) studied the acaricidal and repellent effects of essential oils extracted from nineteen plants of the family Myrtaceae against *T. urticae* in Australia. The assay was carried out in the laboratory following dipping method and choice- and no-choice tests and the results of which showed that the essential oils obtained from *Eucalyptus sideroxylm*, *Callistemon viminalis*, *E. bicostata*, *E. approximans* and *E. maidenii* significantly increased the mortality rate of adult female mites and decreased the fecundity. Results of gas chromatograph/mass spectroscopy analyses revealed that the major components *viz*. 1, 8-cineole, limonene, and α-pinene were present in *E. sideroxylon* and *E. bicostata*. The 1, 8-cineole and limonene showed significant repellent effects on the mites and reduced fecundity in the choice test.

Reddy *et al*. (2014) studied the repellent activity of the methanolic leaf and bark extracts of three species of *Cinnamomum viz., C. camphora, C. tamala* and *C. zeylanicum* on the pest mite, *T. urticae* infesting tomato. The leaf extracts were evaluated at 4 per cent and 8 per cent concentration and the bark extracts were tested at 3 per cent and 6 per cent and high repellency of the pest mites was noted with the leaf extracts of all the three species of *Cinnamomum* at 8 per cent concentration up to 24 hours. Highest repellency of 59 per cent and more mortality were noted with *C. camphora*. Radhakrishnan and Prabhakaran (2014) studied the biocidal activity of

extracts of *Allamanda cathartica*, *Ageratum houstonianum*, *Casuarina equisetifolia*, *L. camara*, *Tithonia diversifoila, Bidens pilosa*, *Conyza bonariensis*, *Crassocephalum crepidioides*, *G. sepium* and *O. basilicum* against the red spider mite, *O. coffe*ae infesting tea. The extracts were evaluated for adulticidal and ovicidal activity at two different concentrations *viz*. 2.5 and 5.0 per cent. Aqueous extracts of *A.catharstica* and *C. bonariensis* showed 100.0 and 80.0 per cent adult mortality respectively at 5 per cent concentration after 96 hours. Neethu *et al*. (2014) reported that a new *Bacillus thuringiensis* strain isolated from the gut of Malabari goat was effective against *T. macfarlanei*. A novel strain (designated as BPU5) of *B. thuringiensis* (Bt) isolated from the rumen of Malabari goat, capable of producing polymorphic d-endotoxin crystals concomitantly with sporulation in Luria– Bertani medium (LB), and the d-endotoxin was efficient to combat *T. macfarlanei*, a severe pest on some agricultural crops. Lawal *et al*. (2015) conducted a study on the phytochemical and insecticidal activity of the leaf extracts of *C. odorata* prepared in different solvents like hexane, chloroform, ethyl acetate and methanol against the stored product pest, *Sitophilus zeamis*. Udebuani *et al*. (2015) studied the insecticidal properties of *C. odorata* against *Periplanata americana* at room temperature and recorded the maximum mortality after exposure of the test species to the highest concentration of the leaf extract. The survival and mortality rates were highly significant at 0.001 per cent level of confidence.

MATERIALS AND METHODS

During the present study, attempts were made to formulate measures for the biological suppression of the selected species of pest mites which were recognized as most injurious to the medicinal plants of local importance. Possibilities for the biological control of pest mites were explored during the present study by adopting two kinds of regulatory measures i.e. (1) by locating and releasing natural enemies like the predatory mites and insects which exhibited potential to suppress pest population and (2) by formulating and applying different concentrations of plant extracts which possessed insecticidal/acaricidal properties.

1. Detection, collection and identification of natural enemies of selected species of pest mites

During the present study, natural enemies representing the predatory mites and insects were identified as potential agents, in suppressing the population of selected species of pest mites. During field surveys carried out for collection of mite fauna infesting medicinal plants, association of life stages of several groups of predatory insects and mites also could be identified on various species of medicinal plants. The various life stages of the natural enemies *viz*. larvae, nymphs and adults present on the mite infested leaves were collected and preserved in 70-75 per cent alcohol for subsequent identification. Live specimens of predatory insects and mites were also

collected along with phytophagous mites from medicinal plants cultivated in various localities of Kerala. Identification of the natural enemies was carried out following relevant taxonomic keys and also seeking help from the expert taxonomists.

2. Studies on feeding potential of natural enemies on selected species of pest mites

A total of five species of natural enemies representing the predatory mites, *Amblyseius largoensis* (Muma), *Euseius ovalis* and *Cunaxa myabunderensis* (Gupta), and insects such as the predatory gall midge, {*Feltiella acarisuga* (Vallot)} and predatory thrips (*Scolothrips asura* Ramakrishna and Margabhandu) were selected for studying the feeding potential on selected species of pest mites (*T. neocaledonicus*, *O. biharensis* and *B. phoenicis*). The various life stages *viz*. larva, nymph and adult of the natural enemies, which were recognized as potential predators of pest mites on their respective host medicinal plants under natural condition were selected for assessing the predatory potential. For conducting studies on the predatory potential of the selected species of natural enemies, laboratory stock cultures were raised and maintained through rearing under constant temperature-humidity conditions in petri dishes following the leaf disc method. Rearing/maintenance of the predatory mites and insects was carried out in an incubator, in which the temperature and relative humidity were maintained at

25 ± 2°C and 60 ± 5 per cent by keeping saturated solution of $NaBr.2H_2O$. Culture of prey/predatory mites /insects was done following leaf disc method. Five each leaf discs (2 cm x 2 cm) were made from the fresh leaves collected from the respective host plants for the rearing purpose.

2.1 Rearing/ Laboratory maintenance of natural enemies

a) Rearing of predatory mites

Known numbers (n = 10) of active adult females of the selected species of the predatory mites *viz*. *A. largoensis*, *Euseius ovalis* and *Cunaxa myabunderensis* were collected from the leaves of respective host plants like *C. halicacabum*, *J. adhatoda* and *V. negundo* from the Calicut university campus.

Adult females (2 nos. each) were released onto each leaf disc kept in the Petri dish. The Petri dish along with the mites was kept in the incubator. After 24 hours the adult females were removed from the leaf discs and the eggs were retained on the leaf disc for subsequent observation. Regular observations were made on the eggs laid on each leaf disc at 6 hours intervals under a Stereo zoom microscope to record hatching and emergence of larva. The culture sets were maintained in Petri dishes, on host leaves kept on moistened cotton pads in the incubator until the development was completed. Various life stages of the prey/mites were offered as food for the developing stages of the predatory mite.

b) Rearing/ Laboratory maintenance of predatory thrips

Ten adult female thrips were collected from the mite infested leaves of respective host plant for subsequent rearing and raising of stock cultures. Two adult females each was released on each leaf disc and kept undisturbed for 24 hours in an incubator. The adult females were found to insert eggs into the surface of the leaf disc. After 24 hours, the females were removed from the leaf discs and the eggs were kept in the incubator for subsequent development. Regular observation was made to detect hatching and emergence of the predatory larva. When the larva of the thrips got emerged, life stages of the prey mites were offered as food and the culture sets were maintained in the incubator until the completion of development.

c) Laboratory maintenance of predatory gall midge larva

The larval stages of the predatory gall midge, were directly collected from mite infested leaves under natural field conditions. The collected larvae were maintained/reared in the laboratory by offering life stages of the prey mite. Studies on the predatory potential of the gall midge larva on the prey mite were made by offering the different life stages of the prey mite and recording the rate of consumption. The adult stages of the gall midge were not considered for studies on predatory habit owing to difficulties in their maintenance under laboratory conditions.

2.2. Experimental set up for studies on predatory potential of the natural enemies

Studies on feeding potential of both the insect and mite predators of different pest mites were carried out at 25 ± 2^{o}C and 60 ± 5 per cent relative humidity following the leaf disc method. Rate of prey consumption by the natural enemies was tested on three species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* on the leaves/leaf discs (3 cm x 3 cm) of their respective host plants. The various life stages of pest mites like the eggs and the most injurious life stages like nymphs and adults were offered as food during the study. The life stages of the pest mite were transferred from the stock cultures to the fresh leaf/leaf discs in a Petri dish with the help of a fine moistened hair brush. In order to get the sufficient number of egg of the pest mites, 12-15 reproductively active females of each species of pest mites were released on fresh leaf/leaf disc in separate Petri dishes and allowed to lay a sufficient number of eggs. The adult females and excess eggs were removed from the leaf disc before releasing the natural enemy onto the leaf disc.

Observation was made on feeding activity, nature of predation and the consumption rate of the natural enemies on the life stages of the pest mites offered. After 24 hours, the number of live and dead life stages of the pest mites was recorded. The experiment was repeated ten times in order to

confirm the results obtained. Data obtained on feeding potential were subjected to statistical analysis for testing significance with IBM SPSS Statistics (Version 19).

a) Predatory potential of the natural enemies on *T. neocaledonicus*

Predatory potential of two natural enemies *viz*. the predatory mite, *A. largoensis* and the predatory gall midge, *F. acarisuga* was assessed on various life stages *viz*. eggs, nymphs and adults (female) of the pest mite, *T. neocaledonicus* was studied on the leaf disc of the host plant, *C. halicacabum*. The adult female of *A. largoensis* and the larval stage (second instar) of the *F. acarisuga* were selected for studying the predatory habit on the pest mite. For conducting feeding experiments, 50 Nos. each of the life stages of *T. neocaledonicus viz*. egg, nymph and adult were introduced on to the leaf discs of the host plant, *C. halicacabum* and to each leaf disc one female of *A. largoensis*/one second instar larva of *F. acarisuga* was introduced in separate petridishes. The predator-prey ratio considered during the study was 1:50. The feeding response of the individual predator towards the different stages of the prey mite was studied through frequent observation under a stereozoom microscope. Data on the rate of consumption by the individual predator on the individual life stage of the prey mite were recorded for an interval of 24 hours and presented.

b) Predatory potential of the natural enemies on *O. biharensis*

The predatory potential of two natural enemies *viz*., the predatory mite, *E. ovalis*, and the predatory thrips, *S. asura* on the life stages *viz*. egg, nymph and adult (female) of the pest mite, *O. biharensis* was assessed on the leaf disc of the host plant, *J. adhatoda*. The adult females of *E. ovalis* and the larval stage (second instar) of *S. asura* were used for the present study. The various life stages *viz*. egg, nymph and adult of *O. biharensis* (50 Nos. each) were provided separately as prey for the adult female of *E. ovalis* and the larval stage of *S. asura* in separate Petri dishes. Data on rate of predation were recorded at an interval of 24 hours on each of the life stages of the natural enemies.

c) Predatory potential of the natural enemies on *B. phoenicis*

The rate of predation by the adult female and nymph of the predatory mite, *C. myabunderensis* and adult female of *A. largoensis* was assessed on the different life stages *viz*. egg, nymph and adult of the pest mite, *B. phoenicis* on the host, *M. rotundifolia*. Each life stages of *B. phoenicis* (30 Nos. each) were provided separately for both the nymph and adult female of the predatory mite in separate Petri dishes. After an interval of 24 hours, the number of life stages of the pest mite consumed by the adult and nymph of *C. myabunderensis* and adult of *A. largoensis* was recorded.

3. Evaluation of the acaricidal activity/bio control efficacy of plant extracts on selected species of pest mites.

In the present study attempts were made to evaluate the efficacy of different concentrations of extracts prepared from two species of plants, as given below:

3.1. Plant species selected:

Two species of plants were selected during the present study for testing the acaricidal activity. The selection of plants was made duly considering their wide distribution pattern and ease of availability from local habitats.

a) *Glyricidia sepium* (Jacq.) (Plate: 18; Fig. A & B)

G. sepium (Fabaceae) is a fast growing exotic and medium sized leguminous tree. The plant has the common name as quick stick, madrecacao (mother of cocoa), spotted *Glyricidia* etc. and local name as *seema konna*. It is widely used as a poison for rodents and in fact the Latin name *Glyricidia* means “rat poison”.

The plant has one of the multipurpose activity as a hedge plant, flowers as food in certain parts of the World, as fuel wood, animal feed, green manure, shade, as supportive plants for many agricultural crops etc. The different solvent extracts of the various parts of the tree have antibacterial, antifungal, nematicidal and insecticidal properties. The plant has medicinal

properties also like antidiarrheal, antidysenteric, antimutagenic, antioxidant, hepatoprotective etc.

b) *Chromolaena odorata* (L.) (Plate: 18; Fig. C & D)

The shrub, *C. odorata* (Asteraceae) is one of the world's tropical weed having the common names like siam weed, chritsmas bush, bitter bush and local name as *communist-pacha*. The shrub has many medicinal properties *viz*. antibacterial, antifungal, antihypertensive, anti-inflammatory, astringent, diuretic and hepatoprotective. The essential oil of the plant possesses insecticidal, insect repellent and nematicidal properties. Phytochemical screening of leaf extracts of *C. odorata* has shown the presence of tannins, steroids, flavanoids, alkaloids and cardiac glycosides. *C. odorata* is distributed throughout Kerala and the flowering and fruiting season of the plant is in the period of November to May.

3. 2. Preparation of crude plant extract:

Fresh and healthy leaves of *C. odorata* and *G. sepium* were collected from the plants growing in Calicut University campus and the adjacent locality. The collected leaves were put in polythene bags and brought to the laboratory for preparation of leaf extracts. In the laboratory, the leaves were washed thoroughly with clean tap water and shade dried for two weeks. The dried leaves were crushed or ground with an electric grinder to get a fine powder and stored in an airtight plastic container. Known weight (100 g) of

the powdered dry plant material was taken into a 1 liter capacity conical flask and 500 ml of distilled water was added to it and shaken for 8 hours in a mechanical shaker and then kept for 24 hours. The extract was separated using the muslin cloth and then filtered. The filtrate was collected in a 1 liter conical flask and the volume was made up to 1liter and the prepared solution was stored as the stock. Different concentrations *viz*. 2.5, 5.0 and 10 per cent were prepared as the test concentrations, from the stock solution.

3.3. Acaricidal / miticidal test on pest mites

The acaricidal test was carried out at 25 ± 2^{o}C and 60 ± 5 per cent relative humidity by following leaf disc method (Ebeling and Pence, 1953; Siegler, 1947). The acaricidal assay was performed with three different concentrations of the plant extract *viz*. 2.5, 5.0 and 10 per cent on the newly emerged active adult females of two most injurious species of spider mites *viz*. *T. neocaledonicus* and *O. biharensis*. Observation was made at three different exposure period *viz*. 24, 48 and 72 hour.

For testing the acaricidal activity 40 adult females of each species of pest mites were transferred from the stock cultures onto new leaf discs in separate Petri dishes 2-3 h before the application of the plant extract. 500µl each from the various concentrations (2.5, 5.0 and 10 per cent) of the extract was sprayed on the leaf disc containing the mites with the help of a glass atomizer. The control set of mites was sprayed with 500µl of sterilized

distilled water. The rate of mortality of pest mites for each concentration of the plant extracts were assessed through observation under a stereo zoom microscope at 24 h, 48 h and 72 h after the treatment. The experiment was repeated for ten times in order to get consistent results. The percentage of mortality was calculated/corrected following Abbott's formula (Abbott, 1925) given below.

Corrected percentage (per cent) of Mortality = (1 – n in T after treatment/n in Co after treatment) x 100

Where as

n = Mite population

T = Treated

Co = Control

Data obtained on the rate of mortality of each species of mite for each concentration of plant extract were subjected to statistical analysis for testing significance.

OBSERVATIONS

During the period of work, the collection and identification of some predatory mites and insects feeding on the pest mites infesting the medicinal plants was also made.

1. Identification of the natural enemies of the pest mites attacking the common medicinal plants of Kerala

A total of 20 species of predatory mites and 5 species of insect predators were identified (Table. 41 & 42). The major families of the predatory mites recovered during the survey were Phytoseiidae, Cunaxidae, Bdellidae, Stigmaeidae and Cheyletidae and the major families of insect predators recovered during the study were Cecidomyiidae, Thripidae and Coccinellidae. The important genera of the predatory mites recorded during study were *Amblyseius*, *Euseius*, *Cunaxa*, *Bdellodes*, *Agistemus* and *Cheyletus*. The important genera of the insect predators were *Feltiella*, *Scolothrips* and *Stethorus*.

The most common potential species of predatory mites recovered from various host medicinal plants during the study period were *Amblyseius largoensis* (Muma, 1955) (Plate. 19; Fig A & E; Plate. 20; Fig H),), *A. channabasavannai* Gupta and Daniel, 1978 (Plate. 20; Fig A & B), *A. indirae* Gupta, 1985, *A. herbicolus* (Chant) (Plate. 19; Fig B), *Neoseiulus*

longispinosus (Evans, 1952), *A. coccineae* Gupta, 1975, *A. paraaearialis* Muma, 1967, *Paraphytoseius multidentatus* (Swirski and Shechter, 1961), *P. orientalis* (Narayanan, Kaur & Ghai) (Plate. 20; Fig E & F), *A. aerialis* (Muma, 1955), *A. adhatodae* Muma, 1967, *Euseius sacchari* Ghai and Menon, 1967, *E. coccineae* Gupta, 1975, *E. ovalis* (Evans) (Plate. 19; Fig C), *E. alstoniae* Gupta, 1975, *E. rhododendronis* Gupta, 1970 (Plate. 20; Fig C & D), *E. finlandicus* (Oudemans, 1915) (Plate. 21; Fig A-D), *Cunaxa myabunderensis* (Gupta & Ghosh, 1980 (Plate. 20; Fig G), *Cheyletus malaccensis* Oudemans, 1903 (Plate. 19; Fig H), *Agistemus* sp., (Plate. 19; Fig D), and *Bdellodes* sp. (Plate. 19; Fig F & G), The most efficient species of insect predators recorded during the study were *Feltiella acarisuga* (Vallot, 1872), *Scolothrips asura* Ramakrishna & Margabandhu, 1931, *S. longicornis* Priesner, 1926, *Stethorus punctillum* Wiese, 1981 and *S. gilvifrons* (Mulsant, 1850) (Table. 41).

The results of the study also enabled to add new distribution records for 15 species of predatory mites and 5 species of insect predators. Accordingly, new record of distribution was attributed to *A. largoensis* (*L. lavendulifolia*, *A. indica*, *M. frondosa* & *I. racemosa*); *A. channabasavannai* (*B. reinwardtii* & *E. sonchifolia*), *A. indirae* (*A. paniculata*, *E. viride* & *B. reinwardtii*); *N. longispinosus* (*G. sepium*, C. *halicacabum* & *L. lavendulifolia*); *A. paraaearialis* (*Eucalyptus globules*); *P. multidentatus* (*I. tinctoria*, *H. aculeatus*, & *L. camara*); *A. adhatodae* (*L. lavendulifolia* & *T.*

chebula); *E. sacchari* (*P. emblica* & *C. infortunatum*); *E. coccineae* (*E. recurvatus* & *G. sylvestre*); *E. ovalis* (*P. amboinicus*, *S. dulcis*, *C. halicacabum*, *I. mauritiana*, *A. indica* & *L. lavendulifolia*); *E. alstoniae* (*E. viride* & *P. corymbosa*); *E. rhododendronis* (*I. balsamina*); *C. myabunderensis* (*V. negundo*, *O. sanctum* & *L. inermis*); *Agistemus* sp. (*A. zeylanicus*); *C. malaccensis* (*A. marmelos*).

The new distribution record for the insect predators were *F. acarisuga* (*C. halicacabum*, *S. dulcis*, *C. ternatea*, *A. indica*, *L. aspera* & *L. lavendulifolia*); *S. asura* (*B. accuminata*, *M. sylvestris*, *B. reinwardtii* & *J. adhatoda*); *S. longicornis* (*C. halicacabum*, *R. communis*, *E. sonchifolia* & *Thottea siliquosa*); *S. punctillum* (*E. sonchifolia*, *C. ternatea*, *A. indica*, *S. rhombifolia*, & *D. motorium*); *S. gilvifrons* (*H. rosa-sinensis*). The species of predatory mites with the respective range of host plants (Table. 42) could be recorded as: *A. largoensis* (20 species of plants), *A. channabasavannai* (11 species of plants), *N. longispinosus* (14 species of plants) and *E. ovalis* (19 species of plants). Among the the insect predators recovered, wide distribution/host range could be evidenced in two species *viz*. *F. acarisuga* (12 plants) and *S. punctillum* (14 plants) when compared to other three species of insect predators.

2. Feeding potential of natural enemies on selected species of pest mites

The natural enemies of the pest mites selected during the present study were found to suppress the pest population through their predatory activity on various life stages of the pest mites. Table. 43, illustrates the results of the predatory potential of the various natural enemies selected during the present study on the three species of pest mites tested *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*. Among the natural enemies selected for detailed studies, the insect predators were proved more effective in suppressing the mite population, when compared to the mite predators tested.

a) Nature of predation and predatory potential of the natural enemies on *T. neocaledonicus*

The natural enemies selected during the present study to suppress the population of the pest mite, *T. neocaledonicus* were the predatory gall midge, *F. acarisuga* and the phytoseiid predatory mite, *A. largoensis*.

The size of the yellowish orange coloured larvae of the gall midge, *F. acarisuga* ranged from 0.5-2mm (Plate. 22; Fig. A & B), and the adult midge appeared pink-brown. The pupae of the midge were found inside the yellowish white cocoons along the veins of the leaves (Plate. 22; Fig. C). The midge exhibited slow movement on the leaf surface and preferred to confine in areas where the pest mites were aggregated and were found to initiate their

feeding activity. While feeding, the gall midge larva penetrated the posterior part of the hysterosoma of the pest mite with its oral hook, to suck out its body contents. As a result of feeding on the pest mite, the body color of larva of *F. acarisuga* got transformed into more bright orange or red (Plate. 22; Fig. A & B). Quite often, the midge larva slowed down or arrested the movement of the pest mite, by bending its body and pressing the body of the pest mite with its posterior end. It took 1-2 minutes to consume an egg and 2-3 minutes to kill the nymph/adult stages of the pest. It was found that when the midge larva got disturbed or came in contact with a nearby moving prey while it was already engaged in predation, the predator give up the partially fed prey and captured the new prey which came in contact with it. After sucking out the body fluid of the prey completely, the midge larva was found to actively wander in search of another prey. The nymphal and adult stages of *T. neocaledonicus* which were attacked/killed by the larva of *F. acarisuga* were found shrivelled and often assumed a brown or black color (Plate. 22; Fig. H). The larva of *F. acarisuga* showed more preference to the eggs of the pest mite and adult stages were the least preferred (Table. 44).

The adult female of the predatory mite, *A. largoensis* was also proved to be an efficient agent in suppressing the population density of the pest mite, *T. neocaledonicus* (Plate. 19; Fig. A). The predatory mite seized the prey mites more rapidly by grasping the prey with its first and second pairs of legs. Subsequently, the predatory mite pierced the hysterosoma of the pest mite

either at the anterior or at the posterior end with its chelicerae and the body contents were sucked out completely. The colored body fluid of the nymph/adult stages of the pest mite, *T. neocaledonicus* was clearly visible in the gut of the transparent body of the predatory mite. The duration of egg consumption by the predator was 2-3 minutes whereas 6-7 minutes were taken to kill the nymph/adult stages of the pest. No continuous predatory habit was detected in the mite predator and a small time gap was required by the predator after consuming a prey mite.

A comparative assessment of the rate of predation by the insect predator, *F. acarisuga* and the mite predator, *A. largoensis* revealed that *F. acarisuga* consumed more number of life stages of *T. neocaledonicus* than that of *A. largoensis* (Table. 44.). As represented in the table, the per day consumption of *F. acarisuga* on the eggs, nymphs and adults of the pest mite, *T. neocaledonicus* were 43.07 ± 2.04, 35.19 ± 2.13 & 23. 27 ± 2.17 respectively. Whereas *A. largoensis* was found to consume 27.48 ± 1.92, 18.79 ± 2.05 & 10.47 ± 1.08 eggs, larvae and adults respectively (Table. 44). The consumption rate of the larva of *F. acarisuga* was found relatively higher than that of the adult female of *A. largoensis* and its feeding potential up on statistical analysis was proved to be significant at $p < 0.01$ level.

b) Nature of predation and predatory potential of the natural enemies on *O. biharensis*

During the present study, the feeding potential of two natural enemies *viz*., the adult female of the phytoseiid predatory mite, *E. ovalis* (Plate. 19; Fig. C) and the larval stage of the predatory thrips, *S. asura* on the life stages *viz*. egg, nymph and adult (female) of *O. biharensis* was studied following the leaf disc method on the host plant, *J. adhatoda*.

Adults of *S. asura* were comparatively fast movers and larger in size than the other natural enemies of *O. biharensis* (Plate. 22; Fig. D-G). They were found wandering on the leaf surface in search of the prey and once they came in contact with the prey, they immediately attacked and punctured the body of the prey mite and sucked out the body fluids/contents. *S. asura* killed the various life stages *of O. biharensis* within 2-3 minutes. The newly emerged creamy white-yellow colored larvae of *S. asura* (Plate. 22; Fig. E), also were proved as potential predators on the life stages of *O. biharensis* and their predatory potential was significantly higher ($P < 0.01$) than that of the adult females of the predatory mite, *E. ovalis* (Plate. 19; Fig. A & B). After feeding on the life stages of *O. biharensis*, the colour of *S. asura* larvae assumed a more reddish or darker colour (Plate. 22; Fig. F & G) and the dead mite became blackish/brownish in colour (Plate. 22; Fig. H). The feeding activity of *E. ovalis* was more or less similar to that of the phytoseiid predator,

A. largoensis on the pest mite *T. neocaledonicus* described earlier. Both *S. asura* and *E. ovalis* showed more preference to the eggs of *O. biharensis* and least preference to the adult stages of the pest mite.

Both the insect and mite predators were proved to cause a marked reduction in the mite population. The rate of predation of *S. asura* on the egg, larva and adult stages of the pest mite, *O. biharensis* was 39.61 ± 1.32, 27.15 ± 1.16 & 21. 27 ± 2.13 respectively and that of *E. ovalis* was 21.92 ± 1.09, 14.79 ± 2.05 & 8.47 ± 2.08 (Table. 44).

c) Nature of predation and predatory potential of the natural enemies on *B. phoenicis*

The predatory potential of two species of predatory mites of the families Cunaxidae and Phytoseiidae *viz*. *C. myabunderensis* (adult female and nymph) and *A. largoensis* (adult female) respectively was analysed during the present study on the various life stages *viz*. egg, nymph and adult of the tenuipalpid mite, *B. phoenicis.* Both the predators were found to be fast runners in laboratory cultures and exhibited promising roles in suppressing the population of the pest mite, *B. phoenicis.*

The adult females of *C. myabunderensis* were dark red in colour, with well visible snout like mouthparts (Plate. 23; Fig. A & B), and the nymphs were pale yellow in color prior to feeding on the pest mites. However, after feeding on the different life stages of *B. phoenicis*, the body color of the

larva/nymph of the predatory mite got changed to orange red (Plate. 23; Fig. D & E). The prey mite life stages were found seized by the adults as well as nymphs of the predator, *C. myabunderensis* with their pedipalps and the first and second pairs of legs and the body of the prey mite was found pierced with their long snout like mouthparts (Plate. 23; Fig. B & E).The body fluid of the prey mite was found completely sucked out by the predator leaving behind the dead body of the prey. The adult predatory mite was found to kill the prey mite within 1-2 minutes while the nymph took 3-4 minutes. On completion of predation of one prey mite, the predator was found to attack a new prey.

The rate of consumption by the adult female of *C. myabunderensis* on the egg, larva and adult stages of *B. phoenicis* was 26.03 ± 2.02, 23.61 ± 1.57 & 17.19 ± 2.17 and that of the nymph of *C. myabunderensis* was 19.14 ± 1.83, 14.61 ± 2.04 & 11.61 ± 2.13 (Table. 44). The predatory habit of the phytoseiid mite, *A. largoensis* was similar to that on the pest mite, *T. neocaledonicus* described earlier. The per day consumption by the adult female of *A. largoensis* was 14.32 ± 2.07, 9.92 ± 1.09 & 6.73 ± 1.24 respectively on the egg, larva and adult stages of the pest mite, *B. phoenicis* (Table. 44). In the present study, the adult females of *C. myabunderensis* were observed as the most potential predators on the life stages of the pest mite, *B. phoenicis*, exhibiting significantly high rate of predation ($p < 0.01$).

3. Acaricidal activity of the plant extracts on pest mites

The aqueous extracts of both species of plants selected during the study *viz*. *Glyricidia sepium* and *Chromolaena odorata* were found to possess acaricidal activity, leading to mortality of the adults of the two species of pest mites selected *viz*. *T. neocaledonicus* and *O. biharensis* (Table. 45 & 46). During the present study, the acaricidal activity of three different concentrations *viz*. 2.5, 5.0 and 10.0 per cent of the aqueous extracts of the above species of plants was evaluated at three different exposure periods *viz*. 24, 48 and 72 hours, against the pest mites. The rate of mortality was found relatively high for the aqueous extracts of *G. sepium* on both the species of pest mites when compared to extracts of *C. odorata*. The effect of plant extracts on *O. biharensis* is shown in Plate. 24 and Fig. A & B.

The results of the study revealed that the acaricidal effect of the plant extracts was concentration-dependent. The mortality rate of pest mites followed a linear trend with the concentration of the plant extract, i.e., an increase in the concentration of the extract resulted in an increase in the percentage of mite mortality. All the three concentrations (2.5, 5.0 and 10.0 per cent) of the aqueous extracts of both species of plants were found to induce comparatively high mortality of the adults of *T. neocaledonicus*, than that of *O. biharensis*. Treatments with the crude extracts of both species of

plants were found more effective at higher concentration (10 per cent) against both species of pest mites selected.

As shown in the Table 45 and 46, treatments with 10 per cent of plant extracts (*G. sepium* & *C. odorata*) at 72 hour exposure induced the maximum mortality of the pest mites. Treatment of *T. neocaledonicus* with 10 per cent aqueous extract of *G. sepium* induced the maximum percentage of mortality of 89.31 ± 2.15 at 72 hours of exposure (Fig. 24). Application of 10 per cent concentration of the same extract on *O. biharensis* caused 77.37 ± 1.98 per cent mortality for the same period of exposure (Fig. 24). Whereas exposure to 10 per cent of aqueous extract of *C. odorata* induced a relatively lower mortality rate of 77. 29 ± 2.03 per cent in *T. neocaledonicus* and 65.03 ± 2.09 per cent in *O. biharensis* at an exposure time of 72 hours (Table. 46 & Fig. 25). In the present study, the acaricidal activity was found at the lowest level for the aqueous extract of 2.5 per cent concentration of *C. odorata* on both species of pest mites (Fig. 24 & 25). Treatments with 2.5 per cent aqueous extract of *C. odorata* for an exposure time of 24 hours induced 6.13 ± 1.20 and 9.15 ± 0.93 per cent of mortality in *O. biharensis* and *T. neocaledonicus* respectively (Table. 46).

A gradual increase in the percentage of mortality was observed when the exposure time was increased from 24 to 72 hours in both the species of pest mites, treated with the plant extracts. Treatments with different

concentrations of *G. sepium* extract showed a noticeable variation in the percentage of mortality with an increase in the time of exposure. As shown in Table. 45, treatment with 2.5 per cent of *G. sepium* extract was found to increase the percent mortality of *T. neocaledonicus* as 10.34 ± 1.21, 13.24 ± 2.25 & 15.47 ± 2.10 respectively at increased periods of exposure like 24, 48 & 72 hours. Treatments with the same concentrations of the plant extract on *O. biharensis* induced 7.25 ± 1.17, 10.41 ± 2.19 & 11.21 ± 2.05 per cent of mortality at 24, 48 & 72 hours of the exposure period respectively. Exposure of mites to 5 per cent of *G. sepium* extract to three successive periods of exposure showed a similar increase in the percentage of mite mortality. A high variation was observed in the mortality rate of mites at the three exposure periods when treated with 10 per cent extract of *G. sepium*. Treatment with 10 per cent extract of *G. sepium* on *T. neocaledonicus* induced a mortality rate of 81.83 ± 1.16, 85.83 ± 2.03 & 89.31 ± 2.15 per cent at 24, 48 & 72 hours of the exposure periods respectively (Fig. 26). Similarly, treatment with the above concentrations of extract of *G. sepium* on *O. biharensis* induced 72.52 ± 1.24, 73.98 ± 2. 24 & 77.37 ± 1.98 per cent mortality respectively at 24, 48 and 72 hours of the exposure (Table. 45). The mites treated with 2.5, 5 and 10 per cent extracts of *C. odorata* did not cause much variation in the rate of mortality at the three successive exposure periods mentioned above. Results of the data on acaricidal activity of extracts of both species of plant on the pest mites under study up on statistical analysis

were proved highly significant ($p < 0.01$). The percentage of mite mortality showed variation with respect to the plant extract used/treated. *G. sepium* extract was found to possess more efficient acaricidal property than that of *C. odorata* extract on the pest mites studied and its impact was found significant at $p < 0.02$ level.

DISCUSSION

DISCUSSION

Plants still remain as one of the major sources of drugs in modern as well as traditional systems of medicine inspite of the tremendous advancement occurred in the 20th century in the field of allopathic medicines. The ever increasing interest and support among the public and private sectors for the conservation and propagation of medicinal plants have shown tremendous increase on a global level. This is due, in part, to the growing recognition on the role of medicinal plants in the provision of culturally relevant and affordable health care in creating sustainable livelihood and in the vital conservation of biodiversity. This has also drawn the attention of the world community towards the need for creating mechanisms to ensure sustained development of the sector and to allow sharing of information between countries, organizations and agencies. Demand for medicinal plants is increasing in both developing and developed countries due to increasing awareness on the natural products being non-narcotic, having no side-effects, easily available at affordable prices and sometime the only source of health care available to the poor (Hoareau and DaSilva, 1999; Siakia and Upadhyaya, 2011).

In India, medicinal plant sector has traditionally occupied an important position in the socio-cultural, spiritual and medicinal arena of rural and tribal lives. Recognizing its importance, the Government of India has established

the Department of Indian System of Medicine and Homoeopathy, and more recently the Medicinal Plants Board to develop, promote and regulate the sector for maximizing the benefits to the people as well as to ensure sustainable growth. Kerala has been at the forefront of ayurvedic revolution in the country, endowed with rich biodiversity because of its topography comprising of all the three biomes *viz*. hills, plateaus and coastal regions.

Phytophagous mites are becoming more aggressive as pests on almost all economically important plants due to the environmental changes and the changed agronomic practices through the adoption of novel ways of agricultural production including the application of nitrogenous fertilizers to the soil and indiscriminate use of chemical insecticides for controlling the key pests. Such modern agronomic practices have resulted in drastic alterations, leading to the development of various types of ecological backlashes like the development of Resistance, Resurgence and Replacement of pest populations, called "3R phenomena". Among the mite pests, the tetranychid and tenuipalpid mites are exclusively phytophagous in habit, enjoying a very wide host range and are known to attack an array of economically important plants (Nageshchandra and Channabasavanna, 1974; Ochoa *et al*., 1994; Bolland *et al*., 1998; Childers *et al*., 2001; Childers *et al*., 2003; Kasap and Atlihan, 2011).

Faunal diversity and distribution of mites on medicinal plants

Results of the present investigation on the phytophagous mites injurious to selected medicinal plants cultivated/grown in various localities distributed over 10 districts of Kerala enabled to understand the faunal diversity of these mites, the host range and distribution pattern of these mites as well the nature and extent of damage induced on their respective host plants. The study revealed that majority of the pest mites were representatives of the suborder Prostigmata, and the members of superfamilies *viz*. Tetranychoidea, Tarsonemoidea and Eriophyoidea of the suborder Prostigmata induced visible damages on their respective host medicinal plants. Moreover, these mites showed wide range of distribution on their host plants in all the localities surveyed. A total of 24 species of pest mites belonging to 11 genera could be recorded as most injurious groups of pest mites on the medicinal plants surveyed from the botanical/herbal gardens as well as plants surveyed from natural field conditions. The artificial conditions available in the botanical and herbal gardens also were successfully exploited by these mites for feeding and production of progenies. Of the 136 species of plants, 112, 84, 37 and 18 species showed infestation by members of Tenuipalalpidae, Tetranychidae, Eriophyidae and Tarsonemidae respectively. An interesting observation made during the study was the incidence of multiple infestation by members of more than two families of phytophagous mites on 19 species of medicinal plants screened during the period of

investigation. Incidence of mite infestation by more than one species of mite pest was a common feature observed on majority of the medicinal plants surveyed during the study. However, co-existence of members of mites of different families of phytophagous mites seems to be rare and it could be observed on 19 species of host plants studied currently. This seems to be supportive of the earlier findings (Nagraj and Reddy, 1985) made on one of the most important traditional medicinal plant, *W. somnifera*, which was found attacked by various species of pests. Thus the present study enabled to disclose that the same species of medicinal plant serves as host for mites belonging to several species, several genera and even several families, by revealing co-existence of these. This clearly envisages the fact that mites have become a potential threat to our valuable medicinal flora and which would adversely affect the future of ayurvedic medicine also, as the latter mostly depends on the extracts of medicinal plants for preparation of medicines. This is in agreement with the earlier report (Ghosh and Gupta, 2003) on the recovery of 23 species of pest mites on the medicinal plants of West Bengal, India thereby attesting phytophagous mites as a new threat to medicinally important groups of plants (Joshi *et al*., 1992; Khanjani and Kamali, 1993; Gupta and Gupta, 1994; Childers, 1994; Rai and Singh, 1997; Childers *et al.*, 2001; Ghosh and Gupta, 2003; Lahiri *et al*., 2005; Ghoshal *et al*., 2006; Krishna Rolania and Sharma, 2007; Sheeja and Ramani, 2007; Sharma and Agarwal, 2010; Prabheena and Ramani, 2010, 2013; Ramanna *et al.*, 2010;

Singh and Raghuraman, 2011; Anitha and Ramani, 2012, 2014; Sharma and Pati, 2012; Sheela and Ramani, 2012; Masoudian and Khanjani, 2013; Prabheena and Ramani, 2013; Nasareen *et al*., 2013, Nasareen and Ramani, 2014; Ghoshal, 2013; Ahmed *et al*., 2015).

Among the 24 species of pest mites recovered, wide host range was observed in 4 species of tetranychids *viz*. *T. neocaledonicus* (20 species of plants), *T. ludeni* (11 species of plants), *T. cinnabarinus* (22 species of plants) and *O. biharensis* (17 species of plants); one species of tenuipalpid *viz*. *B. phoenicis* (28 species of plants) and one species of tarsonemid *viz*. *P. latus* (17 species of plants). The tenuipalpid species possesses the maximum host range on 28 species of plants and this observation supports the earlier records that *B. phoenicis* enjoys a wide host range on 37 species of plants in Hawaii (Haramoto, 1969) and 36 species of economically important plants in India (Nageshchandra and Channabasavanna, 1974). Tetranychids also have been recorded as a highly polyphagous group and the world catalogue of tetranychidae infesting economically important crops has listed species like *O. biharensis* and *T. desertorum* as 'polyphagous generalists' infesting 53 and 193 species of host plants respectively. Another member of the family, *T. urticae* has been known to possess extremely wide host range, registering a pest of more than 900 species of host plants (Bolland *et al*., 1998) or even more, on 1200 species (Zhang 2003). The population size of spider mites would be greatly affected by the differences in host plant species, especially

the differences in the nutritional quality of the host plants (Van de Vrie *et al*. 1972). The host plants of spider mites in general exhibit variations in the nutrional quality and such qualitative differences could be accounted either up on the level of primary plant metabolites, or on the quantity and nature of secondary metabolites (Berenbaum (1991).

Results of the field surveys performed during the present study disclosed peak populations of *T. neocaledonicus* and *O. biharensis* during the months of March to May and relatively low population density during the period of June to August. This is a clear indication that the summer months/dry season promotes rapid population build of spider mites, which culminates in peak formation. This finding is in support of the earlier report from Bangladesh (Naher *et al*., 2008) that the most favourable period for mite development is April-May period, during which developmental duration would be shortest on beans at a mean temperature of 28.53 ± 3.17^{o}C. This trend was found followed by false spider mites also, and the species, *B. phoenicis* showed its maximum population density in April and lowest population density during the rainy period (July). Concomitant with the population peaks and numerical density of mite population, the injurious status of these mites also was found enhanced as reflected through the formation of visible symptoms of cellular/tissue level damages on the affected parts of respective host plants. In the current study, heavy damages were evidenced on respective host plants during the months of February to

April/May (Garman, 1923; Lal and Mukharji, 1979; Pillai *et al.*, 1980; Smith-Meyer, 1981; Dhooria and Buttani, 1983; Nageshchandra and Channabasavanna, 1984; Gupta, 1985; Pande and Sharma, 1986; Karmakar *et al*., 1998; Yadav Babu, 2004; Mani *et al*., 2007; Rekha *et al*., 2013; Jafari *et al*., 2014). Prevalence of high temperature along with the low relative humidity leads to a general increase in mite population (Rahman and Sapra, 1946) and such high temperature and associated dry conditions would enhance the development of pest mites (Childers *et al*., 2007; Ma-shue *et al*., 1998). Quite often, mite populations experience fluctuations (Cardwell *et al*., 1997; Stanyard *et al*., 1997; Sclar *et al*., 1998) which depend not only up the temperature –humidity conditions but also on the nature and habit of the host plants as well and alterations usually would get reflected in the peak populations also.

Resembling the spider mite pests, false spider mite pests also were found to develop population peaks (Cardwell *et al*., 1997; Sclar *et al*., 1998; Stanyard *et al*., 1997), but unlike the spider mites which attained peak formation during the summer months, the population density of the false spider mite species, *B. phoenicis* was found to attain peak formation during the period of November-December, thereby supporting the earlier records on the species (Kumari and Sadana, 1995). Field studies on the distribution pattern of selected species of pest mites on selected species of host medicinal plants revealed that these mites could infest almost all age groups of leaves,

but more preference was shown for the middle aged leaves of their host plants. Such preference was confirmed by the recovery of high population densities of the pest mites on the middle aged leaves. Probably, the nutritional components available in the middle aged leaves would have supplemented the ideal conditions essential for the reproductive success and subsequent development of the mite, desirably leading to the formation of population peaks. Leaves which were too old (Dhooria, 1985) or too young (Sobha and Haq, 1999) harboured relatively lower densities of adult mites, although young leaves were found to carry eggs. This type of habitat selection exhibited by pest mite species on respective host plants could be a preventive measure against the chances of loss of eggs during leaf dehiscence or to escape from adverse conditions like the desiccation of eggs on exposure to sunlight during summer months or the decay/washing out of eggs during rainy season under the field conditions.

Biological parameters of phytophagous mites

The pest mite species subjected for the present study were found to avoid the apical 2-3 tender leaves of their respective host plants for colonization. The total exclusion of the most tender leaves of host plants would be a reflection of the non-availability of the specific nutritional components required for the survival and population growth of spider mites. The particular absence of spider mites on younger leaves may also be

accounted for the preference of these mites to the less turgid tissues of mature leaves, thereby supporting the earlier finding on *O. coffeae,* the latter was designated as a less turgidity preferring species (Jeppson *et al.,* 1975). The spider mite species studied currently were found to exhibit microhabitat preference on the laminar area of individual leaf of the host plants, and their preferred sites were areas adjacent to veins or at the junctions where 2-3 veins joined. Such shallow concavities available on the leaf lamina would serve as ideal shelters, cryptic and secluded microhabitats for oviposition. Further, such concealed habitats would ensure protection to eggs from predation as well as direct exposure to sunlight. Moreover, the veins and veinlets would provide a firm grip to the females during oviposition (Banu and Channabasavanna, 1972; Dhooria, 1982), prevent their dislodgement from the leaf surfaces during wind and rain. The habit of concealed niche selection by spider mites is an indication of their high degree of thigmokinesis, thereby favouring the earlier findings (Jeppson *et al.,* 1975).

Feeding biology of pest mites

Based on the results of feeding biology study, the spider mite pests, *T. neocaledonicus* and *O. biharensis* could be included under the category of leaf suckers. Feeding activities of these sucking forms induced visible injuries on the host plants, manifested in the form of chlorosis/ yellowing of the host leaves. This category was entirely represented by all the 5 species of

tetranychids. Individuals of *O. biharensis* were initially found to colonize on the upper surface of the host leaves whereas *T. neocaledonicus* colonised on lower leaf surface. However, when the population density attained the maximum or peak levels, both species were found to extend their distribution to both surfaces of host leaves. Species like *E. orientalis* was known to show preference to the upper surface of different species of host plants (Channabasavanna, 1972; Lal, 1977; Dhooria, 1985). Preference to the lower surface of host plant leaves was reported earlier in *T. neocaledonicus* and *T. cinnabarinus* (Sobha and Haq, 1999; Sangeetha and Ramani, 2007a). The present finding on *T. neocaledonicus* confirms the earlier reports. Almost all the severely infested leaves were found occupied by the different stages of the mite in large numbers, well protected under a web formed of silken threads woven by the adult females across the leaf surface. Such leaves also carried a large number of moulting skins of the various life stages, and feacal pellets which were found entangled with the dust particles among the silken webs/threads, indicating the severity of infestation under field conditions.

The false spider mite, *B. phoenicis* was found to occupy the lower surface of the leaves of both the host plants *viz*. *M. rotundifolia* and *V. negundo,* and induced visible damage on the upper surface of the leaves. Such preference of the species to the lower surface was already in report (Childers *et al*., 2003a, b). The larvae, nymphs and adults of false spider mite species like *B. phoenicis* and *B. obovatus* were shown to feed on the ventral surface of

'Robinson' tangerine leaves, along the midrib and the feeding damages induced by these mites were well visible on the upper leaf surface, opposite to the injured areas on the lower leaf surface (Childers, 1994).

Web formation is a characteristic feature recognized in some genera of spider mites like *Tetranychus*, *Oligonychus*, *Schizotetranychus* and *Eotetyranychus* (Hazan *et al.,* 1974, 1975; Saito 1977a, 1977b and 1979b; Gerson, 1979; Saito, 1983; Duncan and Lindquist, 1989). Webbing was reported to serve as a protecting device for the eggs and immatures of the vegetable mite, as they remained totally confined within the canopy of the webbing. Apart from this, webbing was also found acting as a means of transport for the individuals during their migration. Active feeding by the adults and immature stages of *T. neocaledonicus* and *O. biharensis* resulted in the production of large numbers of black coloured faecal pellets, which appear to be a reflection of the feeding tendency. Oviposition was also met with along with the feeding activity and webbing and the eggs and faecal pellets were often found entangled among the silken threads. Egg cases and moulting skins of the various immature stages were also found attached to the webs, which facilitated accumulation of considerable amount of dust particles, producing a separate coating over the leaf surface. This coating would exert a cumulative effect leading to a decline in the photosynthetic activity by hindering the direct entry of sunlight on the foliar surface and subsequent absorption by the residual chlorophyll left unfed by the mites

(Sadana, 1985; Sumangala and Haq, 2000). Besides these, webbing was also reported to serve as a carrier of sex pheromones and thereby enhancing the potential of the species to compete with other non-spinning phytophagous mites. Apart from serving as suitable substratum for laying faecal pellets (Saito, 1983; Oku, 2008), webs also would enhance accumulation of dust particles on the surface of infested leaves, and which in turn would impair the prey searching efficiency of natural predators (Griffiths and Fischer, 1950).

Spider mites are known to induce varying types of feeding damages on their host plants, ranging from simple mechanical injury of the leaf cells to complex physiological alterations. Laboratory observations on the feeding activity of the pest mites selected during the present study revealed that the adult females and deutonymphs of these mites were more voracious feeders when compared to the other life stages, and induced pronounced feeding symptoms. While feeding, the adult females inserted their feeding stylets into the interior of the leaf tissues and sucked out the cell contents. Some of the major mechanical injuries induced by the feeding activity of the pest mites were found to include flattened epidermal cells, collapse or reduction in the pallisade and spongy parenchyma cells, loss of cell contents, damage and loss of chloroplasts, coagulation of protoplasts, alterations to stomatal apparatus and other visible contents in cells of mesophyll tissue (Geijskes, 1938; Blair, 1951; Avery and Briggs, 1968b; Jeppson *et al.,* 1975; Tanigoshi and Davis, 1978; Mothes and Seitz, 1982; Meena and Sadana, 1983; Tomczyk and

Kropczynska, 1985, Brito *et al*., 1986; Youngman *et al*., 1986; Bondada *et al.,* 1995; Nachman and Zemek, 2002; Skaloudova *et al.,* 2006; Zhang, 2008; Sangeetha *et al*., 2011; Abdel-Khalek *et al*., 2011). Pest mites were found to induce both direct and indirect damages on respective host plants and the direct damages were defoliation and leaf burning while the indirect damage included decreased rate of photosynthesis. This observation seems to be in agreement with the earlier reports regarding the infestation induced by *T. urticae* on its host plant (Brandenburg and Kennedy, 1987).

During initial stages of *T. neocaledonicus* infestation, the feeding symptoms were well visible as small, round or irregular white spots, which were developed on the lower surface of infested leaves. While feeding, the mites sucked out the cellular components/sap from the injured leaf tissue and which led to formation of chlorotic spots on the opposite surface of foliar area of infested leaves. Due to the continuous feeding activity of the various life stages of the mite, the chorotic spots were found coalesced to form large sized white chlorotic patches, and which later on merged together to impart a pale green or yellowish appearance to the infested leaves. Small brownish or necrotic spots were also found developed at the sites where the chlorotic patches were developed. *O. biharensis* also presented similar types of damage symptoms on infested leaves of host plants, but the intensity of damage was found more severe (Sangeetha and Ramani, 2011a). Spider mite infested leaves quite often presented a crinkled or crumpled appearance and as a result

of these sequential events, premature leaf defoliation was also observed on mite infested host plants, thereby supporting the earlier findings (Tomczyk and Kropczynska, 1985; Welter, 1989). The feeding punctures produced by other spider mite species like *T. urticae* were found to exhaust 18 to 22 cells per minute and the puncturing of the cells proceeded from one spot to another in the form of a circle, thereby resulting in the formation of typical, small round suction spots (Liesering, 1960). The feeding damages induced by the species on tomato plants led to considerable chloroplast destruction and thereby exerted a negative impact on photosynthesis (Jayasinghe and Mallik, 2010). Being, a highly polyphagous, this species was reported to infest a large number of vegetables and the infested leaves first showed yellow colouration and then bronzing and stunted growth, leading to reduction in yield and quality of marketable flowers (Sandhu and Gupta, 1977). The results of feeding studies carried out on spider mite species during the present investigation seem to confirm the above findings.

The feeding activity of the false spider mite species, *B. phoenicis* was not found to induce immediate severe damage symptoms on the host leaves as observed in the case of the spider mite species studied. However, once the damage symptoms were initiated, the damaged leaf became deformed within a short period of time. The infested leaf first showed a flecked appearance at the region where the mite inserted its chelicerae for feeding. The damages induced by *B. phoenicis* were observed as light green or yellowish irregular

spots or patches which were developed at the feeding sites. Such yellow spots or lesions developed were later turned in to brown coloured necrotic spots or patches as reported by earlier investigators (Knorr *et al*., 1960; Dean and Maxwell, 1967; Rice and Weinberger, 1981; Chagas *et al.*, 2003; Kitajima *et al.*, 2003). Heavy leaf drop also could be observed in the present study due to infestation by *B. phoenicis* and this observation is in agreement with the earlier finding (Pettersson, 1981) on another species of the genus *viz*. *B. obovatus,* the infestation of which ultimately led to heavy leaf drop.

Results of histological studies on the leaf sections of both the uninfested and infested categories of the leaves of *C. halicacabum* and *L. lavendulifolia* provided clear evidence for the tissue level damages induced by *T. neocaledonicus.* The uninfested leaves presented closely packed palisade parenchyma cells with the normal alignment of tissues in both the species of host plants whereas the lower surface of infested leaves showed a reduced number of chloroplast cells, especially at the feeding sites and adjacent areas. A reduction in the number of chloroplast cells was observed in the leaves of *L. lavendulifolia*, along the midrib region, which formed the major feeding site of the various life stages of *T. neocaledonicus*. Tissue level injury induced by the feeding activity of the mite was detected on both the spongy and palisade parenchyma cells of the leaves and the heavily infested leaves showed irregular and distorted epidermal cells and collapsed palisade parenchyma cells. Large intercellular spaces were formed as result of the loss

of cellular components. The present results are in supportive with the findings of Sangeetha *et al.*, 2011 who conducted histological study on *O. biharensis* induced feeding damages on cassava plant.

These observations are in agreement with the earlier reports that the feeding activity of citrus red mite, *P. citri* on the upper leaf surface of citrus leaf and induced the development of small, whitish or light-colored stipples within the palisade leaf layer where cytoplasmic contents including chlorophyll were found removed. Mite feeding resulted in partially or completely evacuated spongy mesophyll cells while feeding from the lower leaf surface. (Albrigo *et al*., 1981).

The cross sections of the leaves of *J. adhatoda*, infested by *O. biharensis* up on microscopic examination also presented clear evidences for cellular damages. During initial stages of mite infestation, the feeding injuries were found confined solely to the cell layers of the upper surface of the leaf. The uninfested leaf of *J. adhatoda* showed closely packed palisade parenchyma cell layers and uninjured epidermal cells where as in the mite infested leaf, the epidermal cell layers showed a distorted appearance and the palisade parenchyma cell layers at the feeding sites (sites of chlorotic spots or patches) were found punctured and distorted on the upper leaf surface. Similar sorts of cellular damages have been reported earlier in various species of host plants as a result of feeding by spider mites (Blair and Groves, 1952; Mothes

and Seitz, 1982; Kielkiewicz, 2002; Sangeetha *et al*., 2011; Evaristo *et al*., 2013) and the present study confirms the spider mite damage in medicinal plants also, which would be considered seriously as this would lead to a depletion in the medicinal properties of the plants and hence would adversely affect the preparation of plant extract based ayurvedic drugs. Mites are also known to make damage to their host plants by feeding on the cytoplasmic contents present on the adaxial or abaxial epidermis of leaves, especially to the first cell layer under the cuticle or parenchyma cells of the leaf, as their stylets are very short (Lindquist *et al*., 1996).

Results of quantitative estimation of photosynthetic pigments like the chlorophyll (chl *a*, chl *b* and total chlorophyll) and carotenoids present in the uninfested and mite infested leaves of two species of medicinal plants *viz*. *C. halicacabum* and *L. lavendulifolia* enabled to record loss in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids due to infestation by *T. neocaledonicus.* The loss in the above pigments could be noted as 1.26 ± 0.065, 1.12 ± 0.051, 2.39 ± 0.028 and 0.83 ± 0.024 mg/g fresh leaf tissue respectively on *C. halicacabum* which corresponded to induce per cent loss in the tune of 53.16 ± 0.0.085, 59.89 ± 0.099, 56.24 ± 0.104 and 49.11 ± 0.073 respectively. The per cent loss of photosynthetic pigments was calculated as 47.33 ± 0.096, 55.17 ± 0.087, 50.21 ± 0.112 and 49.50 ± 0.069 respectively for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids in *L. lavendulifolia*. *T. neocaledonicus* was already designated as a potential

species to induce significant loss ($p<0.01$) in photosynthetic pigments of host plants like *M. oleifera* (Sangeetha and Ramani, 2007b) and the present study provided further confirmation of its pest status on medicinal plants also like *C. halicacabum* and *L. lavendulifolia.*

Spider mites were proved to exert a negative impact on the physiological processes of host plants by affecting photosynthesis, leaf conductance, and leaf chlorophyll content as evident in peppermint leaves (De Angelis *et al*. 1983). Earlier studies (Tomkiewicz *et al*. 1993) through quantification of the average chlorophyll content per cm^2 of leaf area, by measuring the absorption of chlorophyll extract in a spectrophotometer and the calibration curve on mite insefsted leaves clearly established the role of the cassava green mite, *Mononychellus tanajoa* in the depletion of photosynthetic efficiency of the plant. Spider mite infestation on bean leaves was reported to reduce the value of chlorophyll fluorescence and chlorophyll content (Iatrou *et al*. 1995), and thereby retarding the rate of photosynthesis process. The results of the present study also enabled to record reduced values for chlorophyll fluorescence and photosynthetic pigments thereby supporting earlier findings. However, the results of the present study seem to contradict the earlier findings that spider mite injury could not induce significant reduction in the chlorophyll content of infested leaves, even at relatively high mite densities (Sances *et al.,* 1979). However, this seems to be an isolated observation and most of the studies were proved to establish the adverse role

of spider mites on the photosynthetic efficiency of respective host plants. Severe loss in chlorophyll content (55 per cent to 68 per cent) was recorded in okra leaves infested by *T. macfarlanei* (Haq, 1997), sponge guard leaves infested by *T. ludeni* (> 30 per cent) (Chatterjee and Gupta, 1997, water hyacinth leaves infested by *T. ludeni* ((20 per cent to 54 per cent) (Sumangala and Haq, 2000) and cucumber leaves infested by *T. urticae* (55 per cent to 80 per cent) (Park and Lee, 2002). Apart from inducing loss in chlorophyll content and photosynthetic activity, spider mite infestation also was known to produce severe oxidative stress on the host plant (Sivritepe *et al*. 2009).

The effect of spider mite attack on the photosynthetic response of soybean plants was analysed (Bueno *et al*. 2009) in Portuguese and a significant reduction in the photosynthetic rate due to stomatal limitation was reported but without any significant reduction in leaf chlorophyll contents. This observation seems to contradict the present findings on the significant reduction in all photosynthetic pigments and which supports the earlier observation (Hsu *et al*. 2015) on the spider mite pest, *T. urticae* which induced significant reduction in various parameters like leaf CO_2 assimilation rate, stomatal conductance, transpiration, instantaneous carboxylation efficiency and intracellular CO_2 concentration of its host plant, *Jatropha*. Spider mite infested leaves also were reported to present a reduction in the soluble protein and soluble sugar, without any measurable reductions in chlorophyll or carotenoid contents. Exceedingly high loss in photosynthetic

pigments was found to result from spider mite damage to thorny bamboos (per cent loss of 77, 75, 85.03 and 47.8 for total chlorophyll, chlorophyll *a*, chlorophyll *b* and carotenoids (Vibija and Ramani, 2015).

Feeding activity of false spider mite also was found to result in per cent loss of chlorophyll and carotenoid, as evidenced during the present study. The per cent loss in photosynthetic pigments due to *B. phoenicis* on leaves of *M. rotundifolia* were 46.15 ± 0.082, 55.62 ± 0.065, 50.12 ± 0.091 and 44.81 ± 0.047 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids. The percentage loss observed in *V. negundo* were 40.06 ± 0.038, 45.02 ± 0.052, 41.92 ± 0.073 and 38.80 ± 0.066 respectively, for chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoids. This clearly indicates that tenuipalpid mites also are equally harmful to the medicinal plants of Kerala, thereby supporting the earlier findings (Prabheena and Ramani, 2013) on *B. phoenicis* which induced marked reduction in the amounts of both chlorophyll *a* and *b* pigments in the leaves of another medicinal shrub, *Ocimum gratissimum.*

The chlorophyll content of the leaves is regarded as one of the parameters determining the photosynthetic efficiency of the plant (Maithra and Sen, 1988). In the present study, data on Fv/Fm, a parameter commonly known as the maximum quantum yield of primary photochemistry or maximal electron transport rate (ETR) of the PS-II were recorded to evaluate the

impact of mite infestation on photosynthetic efficiency. The Fv/Fm values for uninfested and infested leaves of *C. halicacabum* were recorded as 0.818 ± 0.021 and 0.407 ± 0.045 respectively and those of *L. lavendulifolia* were recorded as 0.823 ± 0.005 and 0.432 ± 0.023 respectively for uninfested and infested leaves. The values of Fv/Fm for *O. biharensis* infested leaves of *J. adhatoda*, *B. reinwardtii* and *B. acuminata* were 0.325 ± 0.067, 0.464 ± 0. 053 and 0.523 ± 0.062 respectively. The reduced values for chlorophyll fluorescence in mite infested leaves were indicative of reduced rate of photosynthesis. These findings is in agreement with the reduced values recorded in bean leaves (Iatrou *et al*. 1995), infested by spider mites, rasp berry leaves infested by *T. urticae* and *E. carpini* (Bounfour *et al*. 2002).

Spider mite infestation, apart from reducing photosynthetic efficiency (Brandenburg and Kennedy, 1987; Candolfi *et al*., 1993; Larson, 1998; Landeros *et al*., 2004; Reddall *et al*. 2004; Puchalska, 2006; Bueno *et al*., 2009; Jayasinghe and Mallik, 2010; Anitha and Ramani, 2016) was also shown to affect gas exchange, leaf transpiration etc. as detected in almond leaves (Youngman *et al*. 1986) infested by four species of tetranychid mites. The values of Fv/Fm recorded for the tenuipalpid mite (*B. phoenicis*) infested leaves of *M. rotundifolia* and *V. negundo* were found reduced when compared to the uninfested leaves (0.491 ± 0.074 and 0.520 ± 0.025 respectively. Infestation by the tomato russet mite, *A. lycopersici* was known to cause a decrease in gas exchange and leaf transpiration and 50 per cent reduction in

the photosynthetic rate as reported by Royalty and Perring (1989) in tomato leaves.

Results of biochemical studies performed during the present investigation revealed that all the three species of pest mites *viz*. *T. neocaledonicus*, *O. biharensis* and *B. pheonicis* caused quantitative alterations in the biochemical compounds/constituents *viz*. phenol and proline contents in the leaves of their respective host medicinal plants, as recorded earlier in other host plants (Hall and Ferree, 1975). It was found that mite infestation induced drastic increase (87.28 -187.62 per cent) in the proline content of infested leaves. Proline is a universal osmolyte accumulated in response to several stresses and plays a major role in defense mechanism (Oncel *et al*. 2000; Chakraborty *et al*. 2002). The proline contents in some plants become raised many folds as a result of microbial attack in sensitive and resistant cultivars (Gupta, 2001). The increased proline level observed in the infested leaves of the medicinal plants would be a reflection of the stress developed on the plants due to mite infestation and adaptation developed by the plants as a measure to resist herbivory.

An increase in the amount of phenolic content was also observed during the present study in mite infested leaves and which could be recorded as 23.54 - 47.02 per cent. This is support of earlier reports on the increased levels of phenolic contents induced by mite infestation on different host plants

(Meena and Sadana, 1983; Ghoshal *et al*. 2005). The increase in phenol content has been suggested as a mode of host resistance against pest attack (Ananthakrishnan *et al.* 1992). Increased amount of phenolic compounds in plant tissues is considered to be one of the causes of photosynthesis suppression and the increase in phenolic content due to spider mite infestation in 'conica' leaves was proved to result in a reduction of up to 50 per cent in the rate of photosynthesis as shown after three weeks of heavy infestation by *O. ununguis* (Puchalska, 2006). Hence it is feasible to suggest that pest mites could cause marked reduction in photosynthesis by making mechanical damage aggravated by biochemical alterations (Sangeetha and Ramani, 2011a).

Breeding biology of pest mites

Results of studies on the breeding parameters of selected species of pest mites revealed the occurrence of two types of reproduction *viz*. sexual and parthenogentic. Sexual and parthenogentic modes of reproduction were observed in the spider mites *viz*. *T. neocaledonicus* and *O. biharensis.* Although, the tenuipalpid representative, *B. phoenicis* was designated as a bisexual species, in the current study observation was made only on the parthenogentic mode of reproduction of the species, owing to the non-availability of the males in the field, during sampling. In all the three pest species studied, the developmental process was found to comprise the egg,

larva and two nymphal stages before attaining the adulthood. In between each of active stage, (immature stages i.e. larval and nymphal stages) a physically inactive stage known as quiescent stage was also observed.

Various climatic factors operating in the field exert their own impact on the life history of all groups of animals, including mites. Among the physical factors, temperature and relative humidity were known to influence the life history parameters to a greater extent, by altering the durations of the various life stages, total duration, fecundity etc. and the impact of these factors on the developmental biology of various species of phytophagous mites were in record (Boudreaux, 1958; Das and Das, 1967; Tanigoshi *et al*., 1975; Jeppson *et al.*, 1975; Lal, 1977; Maity and Chakrabarti, 1978; Puttaswamy and ChannaBasavanna, 1980a; Boyne and Hain, 1983a; Congdon and Logan, 1983; Pande and Sharma, 1986; Chiavegato, 1986; Bonato *et al.*, 1990; Childers *et al*., 1991; Trinidade and Chiavegato, 1994; Bonato *et al.*, 1995; Liu and Tsai, 1998; Bonato, 1999; Bounfour and Tanigoshi, 2001; Zhang *et al*., 2001 a & b; Fu, *et al.* 2002; Kasap, 2003; Badii *et al.,* 2003; Sakunwarin *et al.*, 2003; Gotoh *et al*., 2004; Kasap, 2004; Sangita and Bhardwaj, 2004; Ji *et al*., 2005 a & b; Teodoro and Reis, 2006; Sangeetha and Ramani, 2008b**;** Prabheena and Ramani, 2010). In the present study, the impact of three temperature-humidity combinations was assessed by rearing the three species of pest mites under controlled conditions in the laboratory at 25 ± 2^{o}C & 80 ± 5 per cent RH, 30 ± 2^{o}C & 70 ± 5 per cent RH and 35 ± 2^{o}C

& 60 ± 5 per cent RH, on each host plant species. The mean duration of pre-oviposition period of mated female of *T. neocaledonicus* on *C. halicacabum* was recognized as 2.14 ± 0.08, 1.71 ± 0.06 and 1.14 ± 0.03 days respectively at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH and that of unmated female on the same host was observed to be 2.01 ± 0.07, 1.62 ± 0.02 and 1.09 ± 0.05 days respectively. The pre-oviposition period was found to decrease with an increase in temperature and a decrease in relative humidty. This is in agreement with the earlier observation (Puttaswamy and Channabasavanna,1980b) made on another species of spider mite, *T. ludeni* infesting French beans by rearing it at two specific temperature- relative humidity combinations (32 ± 1 & 35 ± 1°C and 65 ± 3 per cent & 75 ± 3 per cent RH). The pre-oviposition period of *T. neocaledonicus* was reported to last for 12 hours when the rearing was performed on the leaves of okra plant (Ray and Rai, 1981). Significant differences (at 1 per cent level) were recorded in the duration of pre-oviposition period of the species (Puttaswamy and Channabasavanna, 1982b) on host plants like mulberry, castor, tapioca and *Amaranthus*. Similar variations were observed in the pre-oviposition period of *T. neocaledonicus* and which was recorded as 1.83 + 0.19 days (Mallik and Channabasavanna, 1983), 2.5 + 0.15 days (Ghoshal *et al.,* 2006) and 1.5+ 0.12 days (Sangeetha and Ramani, 2007a). Studies on the breeding biology of *T. neocaledonicus* on *M. oleifera* under three constant temperature-humidity conditions *viz*. 34 ±1°C

& 50 ± 5 per cent RH, 30 ± 1°C & 40 ± 5 per cent RH and 25 ± 1°C & 80 ± 5 per cent RH revealed the shortest duration for pre-oviposition period (1.5 ± 0.12 days) at 34 ± 1°C & 50 ± 5 per cent RH and highest duration (1.9 ± 0.07 days) at 25 ± 1°C & 80 ± 5 per cent RH (Sangeetha and Ramani, 2008b).

The mean duration of oviposition period of the species on *C. halicacabum* for mated and unmated females showed slight variation and which could be recorded as 9.02 ± 0.15, 7.41 ± 0.09 & 7.19 ± 0.14 days and 9.63 ± 0.08, 8.07 ± 0.10 & 7.92 ± 0.13 days respectively for the selected temperature-humidity conditions. On *L. lavendulifolia*, the oviposition periods for mated and unmated females were found averaged to 8.67 ± 0.12, 7.35 ± 0.10 & 6.87 ± 0.17 days and 9.01 ± 0.08, 7.85 ± 0.09 & 7.28 ± 0.11 days respectively. Similar duration of oviposition period (8.4 days) was observed for the species on *M. oleifera* (Sangeetha and Ramani, 2007a) and 8-10 days on lady's finger (Ray and Rai, 1981). When compared to the present study, a shorter duration (4.7 days) was recorded for the oviposition period of *T. neocaledonicus* on *R. mucronata* (Ghoshal *et al.,* 2006) and a comparatively longer duration (13-19 days) was recorded on French bean (Manjunatha and Puttaswamy, 1989). Apart from the variations in the host plants, the developmental time, pre-oviposition period, reproductive period, and life span of *Tetranychus* mites were found influenced by the age of the leaf as well as the stage of development of plant. (Wilson, 1994).

The mean post-oviposition period of *T. neocaledonicus* was found to range from 1.69 – 2.81 days on *C. halicacabum* and 1.83 – 2.57 days on *L. lavendulifolia*. This is in support of the earlier observations (Manjunatha and Puttaswamy, 1989; Ghoshal *et al*., 2006, Sangeetha and Ramani, 2007a) made on the species which revealed similar or lower durations for the post-oviposition period. In addition to the meteorological parameters (temperature and humidity), host plants also play a considerable role on the breeding biology of plant mites (Rasmy, 1978; Jesioter, 1980; Puttaswamy and Channabasavanna, 1981 b & c, 1982b; Dhooria, 1982; Sharma and Kushwaha, 1984; Dhooria, 1985; Tomczyk and Kropczynska, 1985; Manjunatha *et al.,* 1991; Karmakar *et al.,* 1994; Sarkar *et al.*, 1998; Gotoh and Higo, 1997; Bonato *et al.,* 2000; Thongtab *et al.*, 2002; Kasap, 2003; Czajkowska and Puchalska, 2006; Vasquez *et al.*, 2008) bay altering the durations of various periods/instars. This was clearly evident in another species of spider mite, *viz*. *T. cinnabarinus* , the respective durations of its pre-oviposition, oviposition and post-oviposition periods were 1-3 days, 2-17 days and 0-6 days, when it was reared on four varieties of Japanese mint in Ludhiana (Dhooria and Sagar, 1989). The results of the present study also support this, as it disclosed the durations of pre-oviposition period of *O. bihrensis* on three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata* as 0.89 - 1.92, 0.98 - 2.02 and 0.87 – 1.94 days respectively, under the three selected temperature-humidity combinations. The oviposition period

of the above species on the three host plants ranged from 6.22 – 9.26 days, with the shortest duration on *B. acuminata* and longest duration on *B. reinwardtii*. The post-oviposition period ranged from 0.84 – 1.52 days on the three host plants. The post-oviposition period was not showing much variation on the three host plants but showed variations only for the temperature-humidity conditions.

The pre-oviposition period of the tenuipalpid mite, also showed variation with respect to variations in the host plants, and that of *B. pheonicis* ranged from 3.26 – 4.37 and 4.73 - 6.02 days respectively on the host plants *viz*. *M. rotundifolia* and *V. negundo*. Under the three temperature-humidity conditions, the oviposition period on *M. rotundifolia* was recorded as 18.23 ± 0.42, 17.32 ± 0.30 and 16.49 ± 0.23 days respectively and the respective durations of oviposition period on *V. negundo* were found as 15.36 ± 0.35, 14.39 ± 0.29 and 13.87 ± 0.37. The durations of post-oviposition period on the host plants were found to range from 2.90 – 4.03 days. The pre-oviposition period of this mite on citrus fruits and citrus leaves also were found to differ as 1.84 and 2.54 days respectively at 25 ± 2^{o}C and 70 ± 10 per cent RH. Similar variations were noted in the durations of oviposition and post-oviposition periods and which were recorded as 34.90 & 0.86 days (citrus fruit) and 22.0 & 2.79 days (citrus leaves) (Teodoro and Reis, 2006). The above findings suggest that the development of phytophagous mites to a

great extent is determined not only by the climatic factors, but by the host plants and even the different regions/parts of the same host plant.

The longevity of the mated and unmated females of *T. neocaledonicus* also was found varied on the same host, *C. halicacabum* but at different temperature –humidity combinations (25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH). The mean longevity of mated females was found averaged to 13.85 ± 0.23, 11.15 ± 0.15 & 10.01 ± 0.18 days respectively whereas that of unmated females showed a very slight increase as 14.45 ± 0.25, 11.80 ± 0.20 & 10.73 ± 0.17 days respectively. On *L. lavendulifolia*, the longevity was recorded as 13.42 ± 0.17, 11.41 ± 0.22 & 10.38 ± 0.15 days respectively for mated females and 13.69 ± 0.20, 11.72 ± 0.13 & 10.43 ± 0.18 days respectively for unmated females. On both the host plants, the lowest longevity was recorded at 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. This is in conformity with earlier reports on the longevity of spider mites on different hosts at different temperature-humidity combinations were in the range of 24 - 50 days in the case of mated and unmated females (Puttaswamy and Reddy, 1980, Puttaswamy and ChannaBasavanna, 1981c; Manjunatha and Puttaswamy, 1989; Ghoshal *et al.,* 2006).

The mean longevity of *O. biharensis* (unmated females) on three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata* were recorded as

13.01 ± 0.15, 13.19 ± 0.17 and 11.79 ± 0.21 respectively at 25 ± 2°C & 80 ± 5 per cent RH. The mean longevity of the mated females of this mite on all the three species of host plants showed a slight decrease in duration at all the three temperature humidity conditions observed. The longevity of the species was found influenced by the mating status of the females and a shorter life span was recorded for mated females when compared to that of the virgin females (Bonato and Gutierrez, 1999). Supporting this, in the present study, the fecundity and longevity of *O. biharensis* on cow pea was 10.1 ± 0.18 days, indicating that the mated females had a comparatively shorter life span. Thus the study enabled to establish a negative impact of mating on the longevity of female mites. Species wise and plant wise variations were already in report (Dubitzki and Gerson, 1987) for the mean durations of development and female longevity and species like *P. harti* presented a more extended period of development when the breeding biology was traced on detached leaves of *O. corniculata* 12 and 14.3 days respectively.

Tenuipalpid mites were also found to possess variations in longevity and duration of development with respect to temperature-humidity differences as well as variation in host plants. In the present study, the maximum adult longevity of *B. phoenicis* was observed on *M. rotundifolia* (26.63 ± 0.52 days at 25 ± 2°C & 80 ± 5 per cent RH) and minimum on *V. negundo* (21.50 ± 0.39 days at 35 ± 2°C & 60 ± 5 per cent RH). This is comparatively lower than that of values recorded for the species on *C. papaya*, on which the mean longevity

was 47 days at 20°C and a minimum of 7.5 days at 30°C with a relative humidity of 85-90 per cent (Haramoto, 1969) and on citrus, on which the longevity was recorded as 38.45 days on citrus fruit and 27.46 days on citrus leaves at 25 ± 2°C & 70 ± 10 per cent RH (Teodoro and Reis, 2006). Thus the study clearly revealed the impact of host plants, temperature-humidity combinations as well as regions/parts of the host plants.

Under controlled temperature-humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH, the fecundity *T. neocaledonicus* recorded on *C. halicacabum* was 33.76 ± 1.23, 42.63 ± 1.08 & 49.71 ± 0.93 respectively for mated females and 28.42 ± 1.30, 36.67 ± 1.25 & 41.83 ± 1.19 respectively, for unmated females. On *L. lavendulifolia*, the fecundity was noted as 26.76 ± 1.23, 35.63 ± 1.08 & 39.71 ± 0.93 and 22.42 ± 1.30, 32.67 ± 1.25 & 37.83 ± 1.19 respectively for the mated and unmated females. The number of eggs produced by the females of *T. neocaledonicus* was found reduced at higher humidities (80 per cent RH) since high humidities reduced egg production capacity of adults irrespective of temperature ranges. These findings are in support of the results of previous studies (Boudreaux, 1958; Puttaswamy and Channabasavanna, 1980a & b) on spider mites. Life history studies of the carmine spider mite at four constant temperatures between 19°C and 35°C and six relative humidities from zero per cent to saturation enabled to record highest fecundity at 24°C

and 38 per cent RH and lowest mortality at 30°C and 38 per cent or 63 per cent RH (Hazan *et al*., 1973).

The fecundity of *T. neocaledonicus* on a mangrove plant, *R. mucronata*, under laboratory conditions of 30°C was recorded as 39.8 ± 0.85 eggs (Ghoshal *et al*., 2006). Unmated and mated females of *T. ludeni* on French beans were reported to lay an average of 165.88 ± 47.04 eggs and 132.00 ± 28.54 eggs during respective ovipositional periods of 22.83 ± 4.56 days and 27.41 ± 4.75 days (Puttaswamy and Channabasavanna, 1980b) and shortest duration of development was recorded on brinjal (9.24 days), with a maximum fecundity on okra (149.40 eggs) and French bean (148.90 eggs) (Puttaswamy and Channabasavanna, 1981b). The mean fecundity of *T. bioculatus* was 64.4 on black gram (*Vigna mungo*) (Sardar and Sarkar, 1987). A similar variation in fecundity was reported in the carmine spider mite, *T. cinnabarinus* on four varieties of Japanese mint at Ludhiana, which ranged from 0 - 77 eggs (Dhooria and Sagar, 1989). Such impact of host plants on various species of spider mites has been well established in various species like *T. bioculatus* (Taleb and Sardar, 2008), *T. cinnabarinus* (Sangeetha and Ramani, 2011b), *T. urticae* and *E. carpini* (Bounfour and Tanigoshi, 2001). Supporting these findings, in the present study, the fecundity of *O. bihrensis* on three host plants *viz*. *J. adhatoda*, *B. reinwardtii* and *B. acuminata* was under the range of 38.92 – 56.19, 37.75 – 51.23 and 27.26 – 42.58 respectively with the maximum number of eggs on the host plant *J. adhatoda*

and lowest number on *B. acuminata*. However, fecundity of *O. biharensis* (Ji *et al*., 2005) (71.6 eggs/female) was significantly much higher than to that recorded in the present study.

Mated and unmated females of *O. biharensis* were also found to show variation in their fecundity on all the three host plants studied. On *J. adhatoda* the fecundity of mated and unmated females ranged from 43.62 – 56.19 and 38.92 – 49.36 respectively. The fecundity of *O. bihrensis* on cow pea in the laboratory condition at 30 ± 2°C and 70 ± 5 per cent RH was observed as 50.9 ± 4.7 and 40.2 ± 1.4 eggs respectively for mated and unmated females, and thereby supporting the results of earlier studies (Sangeetha, 2013). Studies on the effect of five constant temperatures like 16, 22, 26, 31 and 36°C on biological and demographic parameters of species like *M. progresivus* and *O. gossypii* infesting cassava revealed the maximum fecundity at 26°C (42.1 eggs/female) for *M. progresivus* and 36.3 eggs/female for *O. gossypii* respectively (Bonato *et al*., 1995). An increase in temperature from 23.61°C to 28.64°C was found to lead to an increase in fecundity of the mite, *E. orientalis* (Lal, 1977).

The average daily output of eggs by the mated and unmated females of *O. biharensis* showed variation and on *J. adhatoda* at 25 ± 2°C & 80 ± 5 per cent RH, the fecundity was 4.76 ± 0.08 and 4.05 ± 0.13 respectively whereas that of the mated and unmated females on *B. acuminata* were 3.91 ± 0.17 and

3.26 ± 0.20 respectively. These results are in agreement with fecundity recorded earlier (Vasquez *et al.*, 2008) for the avocado brown mite, *O. punicae* on six grapevine cultivars *viz*., Tucupita, Gillanueva, Red Globe, Sirah, Sauvignon and Chenin Blanc at 27 ± 2°C & 80 ± 5 per cent RH, with the maximum fecundity on Tucupita leaves (2.8 eggs/female/day) during an oviposition period of 11.4 days and a the minimum fecundity on Sirah and Gillanueva leaves, with 0.9 and 1.8 eggs/female/day during 7.9 and 6.7 days respectively.

Variations in the temperature-humidity conditions and host plants were found to influence the rate of egg production in phytophagous mites. In the present study, the fecundity of *B. phoenicis* on the host, *M. rotundifolia* was found to vary depending up on variations in temperature-humidity conditions and it was recorded as 29.82 ± 1.23 at 25 ± 2°C & 80 ± 5 per cent RH, 35.61 ± 1.15 at 30 ± 2°C & 70 ± 5 per cent RH and 31.74 ± 0.89 at 35 ± 2°C & 60 ± 5 per cent RH. On the leaves of *V. negundo*, the fecundity was found slightly decreased and it was recorded as 23.41 ± 0.35, 28.62 ± 0.27 and 25.14 ± 0.42 respectively for the three temperature-humidity conditions. Such variations have already been reported in other species of phytophagous mites and the results of the present study further confirm the earlier findings. The rate of egg production in *B. phoenicis* when reared on tea leaves at 26°C was found averaged to 56.7 (Kennedy *et al.*, 1996). *B. obovatus* at 27°C and 30°C was

found to lay a total of 54.3 or 32.1 eggs per female during the adult life span of 38.1 and 23.4 days respectively (Jeppson *et al*., 1975).

The incubation period of *T. neocaledonicus* on *C. halicacabum* at various temperature-humidity conditions was found ranged from 2.98 – 3.7 days. On *L. lavendulifolia*, it was slightly higher (3.00 – 4.5 days) than that on *C. halicacabum*. The shortest period of incubation was observed at 35 ± 2^{o}C & 60 ± 5 per cent RH on both the host plants and the maximum hatching success (percentage of eggs hatched) was observed on *C. halicacabum* (92.41 per cent at 35 ± 2^{o}C & 60 ± 5 per cent RH) and the minimum on *L. lavendulifolia* (73.87 per cent at 25 ± 2^{o}C & 80 ± 5 per cent RH). A lower incubation period was reported for *T. urticae* on six bean cultivars (2.00 – 2.23 days at 27 ± 2^{o}C & 70 ± 5 per cent RH) and the percentage of egg viability was in the range of 88.25 - 94.20 (Najafabadi and Zamani, 2013). The percentage of egg hatching in *T. neocaledonicus* on *R. mucronata* was recorded as 76.65 per cent at of 30 ± 1^{o}C (Ghosh *et al*., 2006). In *T. ludeni* infesting French beans, the most favorable temperature-humidity conditions for the development and maximum survival of eggs was 32 ± 1 & 35 ± 1^{o}C and 65 ± 3 per cent & 75 ± 3 per cent RH and high humidity (95 ± 3 per cent RH) reduced the fecundity irrespective of temperature ranges (Puttaswamy and Channabasavanna 1980a). The results of the present study also support the above findings thereby confirming the impact of temperature-humidity factors as well as type of host plants on the hatching success.

The egg hatching characteristics observed during the present study were found to involve formation of an equatorial slit on the egg case and splitting up of egg case found to separate into two halves. The present results are in agreement with the earlier reports on the hatching process in several other species of pest mites on various host plants (Lal, 1977; Lal and Mukharji, 1978; Maity and Chakrabarti, 1978; Saito, 1979; Mallik and Channabasavanna, 1983; Jackson *et al.*, 1983; Dhooria, 1985; Goyal *et al*., 1985; Pande and Sharma, 1986; Northcraft and Watson, 1987; Dubitzki and Gerson, 1987; Ali and Sarkar, 1987; Trinidade and Chiavegato, 1990; Rosero *et al*., 1990; Huaguo *et al.*, 1998; Gotoh *et al*., 2003; Sangeetha *et al.*, 2013; Prasad *et al*., 2015).

The total duration of development from the egg to reach the adult stage in pest mites also is under the influence of temperature-humidity conditions, type of host plants and also the mating status. In the present study, the total duration of development from egg to adult of *T. neocaledonicus* on *C. halicacabum* at three temperature humidity conditions included 14.94 ± 0.29, 10.82 ± 0.24 and 10.18 ± 0.27 days under sexual mode of development and 13.78 ± 0.23, 9.54 ± 0.24 and 9.31 ± 0.18 days under parthenogenetic mode. Whereas on *L. lavendulifolia,* the total duration of development under the sexual and parthenogenetic modes of reproduction could be recorded as 16.85 ± 0.24, 13.64 ± 0.35 & 12.78 ± 0.38 days and 15.61 ± 0.29, 11.80 ± 0.25 & 10.92 ± 0.24 days respectively. In another species of the genus *Tetranychus*

viz. *T. macdanieli*, the mean generation time showed a decrease as the temperature got increased (Tanigoshi *et al*., 1975).

Types of host plants play an important role in determining the duration of development of the same species. This was clearly established in the pest mite, *T. neocaledonicus*, the males and females of which were reported to complete their life cycle with an average of 10.44 ± 0.97 days and 10.19 ± 0.84 days respectively on French bean under greenhouse condition (Manjunatha and Puttaswamy, 1989). The total duration of development of *T. neocaledonicus* on the mangrove plant, *R. mucronata*, at 30^{o}C was recorded as 13.5 ± 0.15 days (Ghoshal *et al*., 2006). Availability of preferred hosts for a pest mite support maximum rate of survival of immature stages as well as minimum rate of mortality. In the present study, the maximum rate of immature survival (number of larva reached to adult stage) was recorded on *C. halicacabum* (96.72 per cent at 35 ± 2^{o}C & 60 ± 5 per cent RH) and the minimum on *L. lavendulifolia* (78.72 per cent at 25 ± 2^{o}C & 80 ± 5 per cent RH). In another species of spider mite pest *T. urticae*, the percentage of immature mortality on six bean cultivars was found ranged from 11.65 – 18.75 at 27 ± 2^{o}C & 70 ± 5 per cent RH (Najafabadi and Zamani, 2013). Such high percentage of immature survivability and low percentage of immature mortality in spider mites favour the growth and reproduction of spider mites.

On the host, *C. halicacabum* the maximum developmental duration for male and female of *T. neocaledonicus* could be recorded as 15.21 and 14.67 days at 25 ± 2°C & 80 ± 5 per cent RH and the minimum developmental duration for male and female was 10.68 and 9.68 days respectively at 35 ± 2°C & 60 ± 5 per cent RH. Similar pattern of variation in the duration of development was observed on the host *L. lavendulifolia* also. Similar findings were reported earlier in *T. urticae* which showed differences in the developmental rate of males and females on different bean varieties in Tehran region (Ahmadi *et al*., 2007). A similar difference was reported in *T. ludeni* also, but on the same host plant, French beans and the species required 12.48 ± 0.16 days and 11.96 ± 0.38 days respectively to complete the life cycles of females and males (Puttaswamy and Channabasavanna, 1980b).

The total duration of development from egg to adult in *O. biharensis* on *J. adhatoda*, *B. reinwardtii* and *B. acuminata* was found to range from 6.49 – 9.79, 7.04 – 10.67 and 7.26 - 12.42 respectively. Such host plant wise variation in the durations of development of spider mites was reported in other species like *M. progresivus* and *O. gossypi* (Bonato *et al.*, 1995). The shortest and longest durations of development of the red spider mite, *O. coffeae* infesting rose, were recorded as 5.3 ± 0.16 days at 30.28°C & 70 per cent RH and 12.91 ± 0.21 days at 19.8°C & 75.41 per cent RH respectively (Haque *et al*., 2007). Data on breeding biology study of *E. uncatus* on *B.*

variegata at 26.6°C to 22.47°C showed that the life cycle of the species *E. uncatus* was completed in 8.01 days and 20.32 days (Lal and Mukharji, 1978).

The duration of incubation period of *B. phoenicis* on the host plant, *M. rotundifolia* was observed to be 6.09 ± 0.31 days at 25 ± 2°C & 80 ± 5 per cent RH, 5.17 ± 0.15 days at 30 ± 2°C & 70 ± 5 per cent RH and 5.24 ± 0.21 days at 35 ± 2°C & 60 ± 5 per cent RH. On *V. negundo*, the incubation period was observed slightly increased to 7.27 ± 0.23, 6.38 ± 0.19 and 6.43 ± 0.31 days respectively at three temperature humidity conditions. The maximum percentage of egg viability was recorded on *M. rotundifolia* (88.82 ± 1.37) at 35 ± 2°C & 60 ± 5 per cent RH and minimum on *V. negundo* (76.37 ± 2.31) at 25 ± 2°C & 80 ± 5 per cent RH. The incubation period of *B. phoenicis* on citrus and coffee was recorded as 7.43 ± 0.54 and 10.71 ± 0.83 days respectively. The viability of eggs in *B. phoenicis* was 98.82 per cent on citrus and 97.71 per cent on coffee (Teodoro and Reis, 2006). The incubation period of this mite on papaya at 25°C was 9.4 days (Haramoto, 1969) and 9.53 days on Indian tea leaves at 26°C (Kennedy *et al*., 1996). *B. phoenicis* had a faster developmental rate on citrus fruits than that on citrus leaves and an average period of incubation was observed as 7.71 ± 0.48 days on citric fruit at 25 ± 1°C (Chiavegato, 1986). These results clearly suggested that *B. phoenicis* exhibited a variation in the duration of embryonic period due to the host in which the female develop.

The total duration of development (egg to adult stage) on *M. rotundifolia* was observed as 25.39 ± 0.54, 21.87 ± 0.49 and 22.45 ± 0.34 days at 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH respectively. On *V. negundo*, the same duration was found completed in 28.22 ± 0.62, 24.59 ± 0.46 and 25.36 ± 0.50 days respectively for the three temperature-humidity conditions. All the progenies developed in the present study comprised of female individuals alone. The developmental rates of *B. phoenicis* on the leaves of *C. papaya* were found greatly influenced by temperature, relative humidity, and nature of host plants. The duration of development from egg to the adult of the species on papaya fruits was 29.3 days at 25°C (Haramoto, 1969). The duration of development of the species on tea plants in India, was recorded as 33.5 days at 19.1 - 23.4°C (Oomen, 1982).

In the present study, for the three temperature humidity conditions, the durations of the larva, protonymph and deutonymph of *B. phoenicis* were found to range from 3.30 – 4.15, 3.11 – 3.27 and 3.86 – 4.16 days respectively on *M. rotundifolia*. This is in support of earlier studies made on another species of the genus, *viz*. *B. obovatus* at 27°C and 30°C which enabled to record the durations as 5.3 and 3.5 days for the larvae, 4.0 and 4.1 days for the protonymph and 4.0 and 2.7 days for the deutonymph respectively (Jeppson *et al.*, 1975). The juvenile development of *B. lewisi* was also reported to vary from 16.8 to 27.9 days at 34°C & 35 per cent RH and 22°C & 70 per cent RH

respectively, and the larval and protonymphal stages of the species developed faster, then the deutonymph followed by the egg stage and the entire population was found to comprise only female individuals (Buchanan *et al*., 1980).

The breeding biology study on two species of spider mites, *T. neocaledonicus* and *O. biharensis* clearly showed a high percentage of female population. In both the species of spider mites studied presently, the sex ratio was found biased towards the females, under sexual mode of reproduction on all the host plants studied. The sex ratio (male:female) of *T. neocaledonicus* recorded under sexual mode of development was 2:10 on *C. halicacabum* and 1:10 on *L. lavendulifolia*. However, only male individuals were found produced in parthenogenetic (arrhenotoky type) mode of development, supporting the earlier observations on spider mites (Nandagopal and Gedia, 1995). The sex ratio recorded for *O. biharensis* was 3:10 on the host plants *viz*. *J. adhathoda* and *B. reinwardtii* whereas it was 2:10 on the host *B. acuminata*. Such female biased sex ratios were already reported in other species of spider mites like *T. urticae* (Helle and Pijnacker, 1985). However, unlike the present findings, when the life cycle of *T. neocaledonicus* was traced on the mangrove plant, *R. mucronata*, the male-female ratio was found to be more or less similar, as 1:1.65 (Ghoshal *et al*., 2006). Adoption of both types of reproduction by spider mites may probably be meant for enhancing

the male population, which otherwise would become very low under field conditions.

Unlike the spider mite species studied, an entirely female biased population was detected in the false spider mite species, *B. phoenicis*. The species was found to comprise only female individuals on both the host plants surveyed. *B. pheonicis* has been reported to reproduce mainly by thelytokous parthenogenesis, in which all resulting progenies would become females (Haramoto, 1969; Helle *et al*., 1980; Vacante, 2016). The haploid condition of the species is maintained by the prevalence of an endosymbiotic bacterium belonging to the genus *Wolbachia* (Weeks *et al*., 2001; Otto and Jarne, 2001). Thelytoky is induced in the species of *Brevipalpus*, including *B. phoenicis* due to infection by a bacterium belonging to the genus *Cardinium* by feminizing unfertilized haploid eggs (Groot and Breeuwer, 2016). This must be true in the present study also in which all the progenies of the species collected from the field as well as reared in the laboratory were found to comprise entirely of female individuals.

During the present study, the life span of the female was found higher in both the species of spider mites *viz*. *T. neocaledonicus* and *O. biharensis.* On the host, *C. halicacabum* the maximum durations of adult life span recorded for the males and females were 10.29 and 13.54 days respectively at 25 ± 2^{o}C & 80 ± 5 per cent RH. Similar range of variation for the adult life

span of male and female individuals was recorded on all the other host plants of spider mites. In *T. urticae* the life span of male was found averaged to 14.6 days whereas the females were reported have a higher life span (19.1 days) (Shih *et al*., 1976). The increase in the duration of adult life span of females would be an important adaptation for the pest to maintain its population/generation during adverse conditions (Uckan and Ergin, 2002; Kasap, 2004; Sedaratian *et al*., 2009, 2011).

Results of morphological studies on the various life stages of the three species of pest mites revealed the specific features possessed by the different life stages of the species of pest mites. The dorsal setae of the members of the genus *Tetranychus* were long, pointed, smooth and without tubercles. The position and number of hysterosomal setae showed variation in the different life stages of the species studied. This reveals the importance of chaetotaxy in the identification of species even in the larval and nymphal stages. A progressive increase in body size and number of body setae from larva to deutonymph was observed in all the three species studied. The dorsal chaetotaxy shows variation between genera and species of the family tenuipalpidae. There are three pairs of propodosomal setae but the number of setae on hysterosoma may vary. Palpus with 4 or 5 segments are one of the characteristic feature of the genus *Brevipalpus*. The species, *B*. *pheonicis* possesses five pairs of short hysterosomal dorsolateral setae plus the humeral setae.

Biological control of pest mites

During the present study, a total of 20 species of predatory mites and 5 species of insect predators were collected and identified. The important families of the predatory mites were found belonging to the families Phytoseiidae, Cunaxidae, Bdellidae, Stigmaeidae and Cheyletidae and the genera collected were *Amblyseius*, *Euseius*, *Cunaxa*, *Bdelloides*, *Agistemus* and *Cheyletus*. Presence of 16 species of phytoseiid mites including 4 species with high potential to feed on pest mites was reported from the medicinal plants of Kolkata (Lahiri *et al*., 2005) and members of other families were comparatively lesser. Prevalence of more number of predatory mites was recorded on the medicinal and aromatic plants in India (Gupta and Karmakar, 2011), by listing 56 species of predatory mites under 24 genera and 10 families. The predatory fauna of mites seems to be rich on the medicinal plants of South India especially of Kerala. This is supported by the earlier findings (Sajna and Anithalatha, 2013) on the recovery of 15 species of predatory mites belonging to 6 genera *viz*. *Amblyseius*, *Typhlodromips*, *Euseius*, *Neoseiulus*, *Phytoseius* and *Paraphytoseius* included under Mesostigmata from 32 species of economically important plants belonging to 27 genera and 21 families in North Kerala. The results of the present study also would help to disclose the richness of predatory mites on the medicinal plants of Kerala by revealing the presence of 21 species.

The major families of insect predators recovered during the present study were Cecidomyiidae, Thripidae and Coccinellidae. The important genera of the insect predators collected during the study were *Feltiella*, *Scolothrips* and *Stethorus*. Natural enemies were proved to play a pivotal role in suppressing pest mite population (Chant, 1961; Mallik and Channabasavanna, 1976; Boyne and Hain, 1983b; Havelka and Kindlemann, 1984; Helle and Sabelis, 1985; Chazeau, 1985; Clements and Harmsen, 1990; Selhorst *et al*., 1991; Spicciarelli *et al*., 1992; Daneshvar and Abaii, 1994; Castagnoli *et al.*, 1995; Gilstrap, 1995; Wilson *et al*., 1996; Ho and Chen, 1998; Piatkowski, 2000; Thakur and Dinabandhu, 2005). Results of studies on the feeding potential of the predatory gall midge, *F. acarisuga* (larval stage) and the phytoseiid predatory mite, *A. largoensis* (adult female) on *T. neocaledonicus* disclosed that *F. acarisuga* was more efficient in controlling the pest mite than *A. largoensis*. The daily rate of prey consumption by *F. acarisuga* on the various life stages like the eggs, nymphs and adults of the pest mite, *T. neocaledonicus* could be recorded as 43.07 ± 2.04, 35.19 ± 2.13 & 23. 27 ± 2.17 respectively while those of *A. largoensis* on the respective stages were 27.48 ± 1.92, 18.79 ± 2.05 & 10.47 ± 1.08. The gall midge, *F. acarisuga* was already established as one of the most potential insect predator on spider mites (Oatman *et al*., 1985; Gagné *et al*., 1995; Calvo *et al*., 2003; Mo and Liu, 2007) and the results of the present study further confirms the above findings. It was found that under laboratory conditions of 26.7 ± 2^{o}C,

75 ± 5 per cent R.H, it was observed that the first, second, and third instar larvae of *F. acarisuga* could consume an average of 35.5, 54.0 and 86.9 eggs respectively (Gillespie *et al*., 2000). The daily consumption rate of the larvae of *F. acarisuga* on the eggs, nymphs and adults of red spider mites was at least five times greater than that of *P. persimilus* (Osborne *et al*., 2002). The larval stage of *F. acarisuga* was reported as the most efficient predator on *T. urticae* and a weekly release of 1000 individuals per ha was found effective in controlling spider mites on tomato, pepper and cucumber (Gillespie *et al*., 1998). *F. acarisuga* was reported to suppress 81.2 per cent of *T. urticae* population (Xiao *et al*., 2011).

Among the predatory mites, phytoseiid mites play a major role in controlling the spider mite population (Chant, 1961; Ball, 1980; Havelka and Kindlemann, 1984; Gerson, 1985; Gough, 1991; Daneshvar and Abaii, 1994; Nicetic *et al*., 2001; Opit *et al*., 2004; De Boer and Dicke, 2005; Naher *et al*., 2005; Rhodes *et al*., 2006; Osborne *et al*., 2002). The species, *N. longispinosus* was reported to feed on *T. urticae* on 33 species of economically important plants in Thailand (Kongchuensin *et al*., 2005). The life stages of the predatory mite, *A. largoensis* were found to exhibit more preference to the egg stage of the prey mite, *R. indica* in Florida and its mean consumption rate was 45 eggs per day (Carrillo and Pena, 2012). The prey consumption rates of adult female, deutonymph, protonymph and the adult

male of the *E. ovalis* were recorded as 63, 52, 50 and 33 per cent respectively at 30 ± 2°C and 64 ± 2 per cent RH (Liyaudheen *et al*., 2014).

In the present study, the feeding potential of two natural enemies *viz*., the adult female of the phytoseiid predatory mite, *E. ovalis* and the larval stage of the predatory thrips, *S. asura*, on the life stages *viz*. egg, nymph and adult (female) of *O. biharensis* was assessed. The rate of predation by *S. asura* on the egg, larva and adult stages of the pest mite, *O. biharensis* could be recorded as 39.61 ± 1.32, 27.15 ± 1.16 & 21. 27 ± 2.13 respectively and that of *E. ovalis* was 21.92 ± 1.09, 14.79 ± 2.05 & 8.47 ± 2.08. The feeding activity of *E. ovalis* was more or less similar to that of the phytoseiid predator, *A. largoensis* on the pest mite, *T. neocaledonicus*. Both *S. asura* and *E. ovalis* showed more preference to the eggs of *O. biharensis* and minimum preference was shown towards the adult stages of the pest mite. The predatory habit of thrips on phytophagous mites was already reported on pest mites and all species of the genus *Scolothrips* were reported to possess specialized predation on spider mite pests (Lewis, 1973; Aydemir and Toros, 1990; Pakyari *et al*., 2009). A decrease in prey consumption by *S. sexmaculatus*, a potential predator of spider mites was reported when the temperature increased to more than 30°C. The immatures of *S. sexmaculatus* consumed an average of 11.7 eggs of *T. pacificus* per day at 26°C whereas the adult females of the species had a consumption rate of 39 to 47 eggs/ day as the temperature increased from 18 to 30°C (Gilstrap and Oatman, 1976). The predatory

potential of the phytoseiid mite, *N. longispinosus* was reported to decrease towards the adult stages of *O. coffeae* on tea under laboratory and green house conditions (Rahman *et al*., 2012).

In the present study, the rate of consumption of the adult female of *C. myabunderensis* on the egg, larva and adult stages of *B. phoenicis* was recorded as 26.03 ± 2.02, 23.61 ± 1.57 & 17.19 ± 2.17 and that of the nymph of *C. myabunderensis* was 19.14 ± 1.83, 14.61 ± 2.04 & 11.61 ± 2.13. The adult females of *C. myabunderensis* were recognized as the most potential predators on the life stages of the pest mite, *B. phoenicis*. This observation seems to support the earlier finding on the potential role of cunaxids as efficient natural enemies in suppressing the pest population on economically important plants (Zaher *et al*., 1975; Smiley, 1992). The per day consumption of the adult female of *A. largoensis* on the various life stages of *B. phoenicis* was found to be 14.32 ± 2.07, 9.92 ± 1.09 & 6.73 ± 1.24 respectively on the egg, larva and adult of the pest mite, *B. phoenicis.* The effective use of phytoseiid mites to control the tenuipalpid mite population which vectored the coffee ring spot virus was already reported (Reis *et al*., 2000) and species like *E. alatus* and *Iphiseiodes zuluagai* were established as potential predators on the tenuipalpid mite pest, *B. phoenicis* (Reis *et al.*, 2003). In tea gardens of Guangzhou, the tenuipalpid mite population, especially that of *B. obovatus* was reported to be under the suppressive effect of 13 species of predatory

mites, of which the most abundant predator was *A. hainanensis* and it predatory potential was recorded as 68.6 per cent (Zheng *et al*., 2012).

Many plants are known to possess acaricidal activity against the pest mites (Guirado *et al*., 2001; Park *et al*., 2002; Martinez-Villar *et al*., 2005; Calmasur *et al*., 2006; Sarmah *et al*., 2009; Sertkaya *et al*., 2010; Araújo *et al*., 2010; Patnaik *et al*., 2011; Nong *et al*., 2012; Zaman *et al*., 2012). The aqueous extracts of the two species of plants selected during the present study *viz*. *G. sepium* and *C. odorata* were found to possess acaricidal activity, leading to mortality of the adults of the two species of pest mites selected *viz*. *T. neocaledonicus* and *O. biharensis*. The rate of mortality was found relatively high for the aqueous extracts of *G. sepium* on both the species of pest mites studied when compared to extracts of *C. odorata*. All the three concentrations (2.5, 5.0 and 10.0 %) of the aqueous extracts of both species of plants were found to induce comparatively high mortality on the adults of *T. neocaledonicus*, than that of *O. biharensis*. In both species of selected plants, crude extracts were found more effective at higher concentration (10 per cent) against the two species of pest mites selected.

Treatment of *T. neocaledonicus* with 10 per cent aqueous extract of *G. sepium* induced the maximum percentage of mortality (89.31 ± 2.15) at 72 hours of exposure. Application of 10 per cent concentration of the same extract on *O. biharensis* caused a still lower mortlity rate of 77.37 ± 1.98 per

cent for the same period of exposure. Exposure to 10 per cent of aqueous extract of *C. odorata* induced a relatively lower mortality rate of 77. 29 ± 2.03 per cent in *T. neocaledonicus* and 65.03 ± 2.09 per cent in *O. biharensis* at an exposure time of 72 hours. In the present study, the acaricidal activity was recorded to be at the lowest level for the aqueous extract of 2.5 per cent concentration of *C. odorata* on both species of pest mites. Treatments with 2.5 per cent aqueous extract of *C. odorata* for an exposure time of 24 hours induced 6.13 ± 1.20 and 9.15 ± 0.93 per cent of mortality in *O. biharensis* and *T. neocaledonicus* respectively. Similar to the present findings, aqueous plant extracts of *Acorus calamus*, *Persicaria hydropiper*, *Clerodendrum infortunatum* and *Xanthium strumarium* were found effective against *O. coffeae* both under laboratory and field conditions and extracts of 5 and 10 per cent concentrations showed more than 50 per cent mortality of the mite in the laboratory where as in the field condition 46.9 – 81.8 per cent and 64.7 – 100.0 per cent mite mortality was recorded at 5 per cent and 10 per cent respectively (Sarmah *et al*., 2009).

Several previous studies support the acaricidal/pesticidal activity of the plant, *G. sepium* against various groups of pest population (Sivira *et al*., 2011 against *T. cinnabarinus*; Prabhakaran, 2014 against *O. coffe*ae). The plant *C. odorata* was proved to possess antibacterial, antifungal and antiradical activities (Felicien *et al*., 2012). The insecticidal activity of the leaf extracts of *C. odorata* prepared in different solvents like hexane, chloroform, ethyl

acetate and methanol were reported to be effective against the stored product pest, *Sitophilus zeamis* (Lawal *et al*., 2015). The present findings on the significant acaricidal activity of theses extracts would be considered as a promising step for the formulation of more concentrations and combinations, for their effective application under field conditions also.

SUMMARY

SUMMARY

Medicinal plants play a pivotal role in maintaining the health of the people both in rural and urban areas. Even though the allopathic medical field has experienced tremendous advancement during the last few decades, most of the people of the urban and rural sectors of the world still depend on the traditional system of treatment that mainly depends up on the extracts of medicinal plants. The cultivation/propagation of medicinal plants has received increasing awareness owing to their use not only in the preparation of herbal drugs used in ayurvedic/homoeopathic/unani systems of medicine, but also for the manufacture of various products like cosmetics, neutraceuticals, colouring agents, dyes, biopesticides etc.

Kerala is the state which supports rich diversity of flora and fauna and the Western Ghats has been identified as one of hot spots of biodiversity, protecting and conserving innumerable species of plants with medicinal properties. High species richness along with high species diversity of the medicinal plants makes the state a big reservoir for the ayurvedic treatment for many life threatening diseases throughout the world. The demand for medicinal plants and their products is increasing day by day in the entire world due to increase in the number of needy people along with rapidly increasing population. So the situation demands the high scale conservation of medicinal plants in a sustainable manner.

One of the major steps in the conservation of medicinal plants is to ensure the protection of the existing diversity from the exposure to the increasing incidence of pest attack. Pest problems usually would lead to a reduction or alteration in the medicinal property of these plants and quite often total/partial destruction of plants. Before planning for implementing pest control strategies, one should know about ecological, ethological and developmental aspects of the target pests. Implementation of pest control strategies without gaining knowledge on these aspects would become fruitless and lead to high economic loss. Among the various pest control strategies, biological control utilizing the natural enemies as well as the formulation and application of plant extracts are gaining much importance now a days as an ecofriendly and economically cheaper strategy which is devoid of any environmental hazards.

Considering all the points mentioned above, the present study was undertaken with a view to know the most injurious species of phytophagous mites infesting the medicinal plants of Kerala, to study the feeding and breeding strategies of a few selected, most injurious species and to explore the means for their suppression by identifying the natural enemies and studying their predatory potential and also evaluate plant based extracts capable of inducing mortality of pest mites. In the first part of the thesis, results of extensive surveys were presented providing data on the ecological aspects of pest mites, *viz*. their incidence and distribution pattern on various species of

medicinal plants, host range etc. Data on the seasonal abundance and relative distribution of three species of most injurious pest mites (*T. neocaledonicus*, *O. bihaensis* & *B. pheonicis*) were presented in the first part of the thesis.

In the second part of the thesis, data on various biological parametes like the feeding and breeding biology of the three selected species of pest mites mentioned above were presented. In the feeding biology part, data on various factors like mode of infestation, major feeding sites, damage symptoms produced both at the superficial and tissue levels, damage to photosynthetic apparatus and its efficiency, mite induced biochemical alterations, influence of web and fecal matters of pest mites on the host plant etc. were included. The breeding biology section included data on the modes of development (sexual and parthenogenetic), durations of oviposition period, fecundity, egg viabiliity, duration of immatures, total duration, immature viabiliity, adult longevity, mating, sex ratio, morphological aspects/ characters of life stages etc.

In the third part of the thesis, data pertaining to biological suppression of selected most injurious species of pest mites attacking medicinal plants of local importance were generated. This part included the detection and identification of natural enemies like the predatory mites and insects and studies on the feeding potential of selected species to record data on their consumption rates on the various life stages of the pest mites. Further, studies

were also carried out on the formulation of extracts of selected species of plants like *G. sepium* and *C. odorata* in different concentrations and testing their influence in inducing mortality in pest mites like *T. neocaledonicus* and *O. bihaensis* by making treatments at different exposure times.

During the present study, general surveys were carried out for the collection of mites infesting medicinal plants grown/cultivated in various localities, distributed over ten districts *viz*. Kasaragode, Kannur, Kozhikode, Wayanad, Malappuram, Thrissur, Palakkad, Eranakulam, Pathanamthita and Trivandrum of Kerala. The aerial parts like the leaves and twigs of various species of medicinal plants cultivated/grown in selected botanical/herbal gardens and other localities of Kerala (urban & rural areas, sacred groves, agricultural fields etc. were collected and thoroughly examined under a stereo zoom microscope in the laboratory. A total of 136 species of plants belonging to 114 genera and 50 families showed the incidence of mite infestation by disclosing members of the order Prostigmata**.** Of the various species of medicinal plants screened, 59 per cent showed severe infestation by members of most injurious groups of mites and remaining plants showed mere incidence, without causing severe damage. The members of three superfamilies *viz*. Tetranychoidea, Tarsonemoidea and Eriophyoidea of the order Prostigmata were recognized to induce maximum injury to the medicinal plants surveyed. The most commonly occurring species of pest mites were found to represent four phytophagous families *viz*. Tetranychidae,

Tenuipalpidae, Tarsonemidae and Eriophyidae showing infestation on 84, 112, 18 and 37 species of plants respectively. The major genera of the pest mites recovered during the survey were *Tetranychus*, *Oligonychus*, *Eutetranychus*, *Eotetranychus, Panonychus, Bryobia*, *Aponychus* and *Schizotetranychus* of the family Tetranychidae; *Brevipalpus* and *Tenuipalpus* of the family Tenuipalpidae; *Polyphagotarsonemus, Tarsonemus* and *Steneotarsonemus* of the family Tarsonemidae; *Aceria*, *Anthocoptes*, *Acalitus, Acaphylla, Metaculus, Diptilomiopus* and *Eriophyes* of the family Eriophyidae. On 19 species of plants, multiple infestation by members of more than two phytophagous mite families was detected.

A total of 24 species belonging to 11 genera were recognized as most injurious groups of pest mites on the medicinal plants surveyed. The most important genera of injurious mites inhabiting on the medicinal plants surveyed were *Tetranychus*, *Oligonychus*, *Eutetranychus*, and *Panonychus* of the family Tetranychidae; *Brevipalpus* of the family Tenuipalpidae; *Polyphagotarsonemus* of the family Tarsonemidae and *Aceria* of the family Eriophyidae. The species which showed a wide host range on the medicinal plants studied were *T. neocaledonicus* (20 species of plants), *T. cinnabarinus* (22 species of plants), *T. ludeni* (11 species of plants), *O. biharensis* (17 species of plants), *B. phoenicis* (28 species of plants) and *P. latus* (17 species of plants).

Of the various species of phytophagous mites collected, 3 species of very common and most injurious species *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* were selected for detailed ecological and biological studies. Data were collected on the distribution pattern and seasonal abundance of these mites on their host plants through regular observation on the mite population density under field conditions. The results of population studies revealed that the density of mites attained the peak population (3-4 months) during the dry period of the year, usually from February to May, and then declined to reach low population (2-3 months) during the rainy season from June to August and again showed an increase to reach the moderate population (4-5 months) during September to January months. Results of studies on the relative abundance of the three species of pest mites selected *viz*. *T. neocaledonicus*, *O. biharensis* and *B. phoenicis* enabled to record their incidence in high density on respective plants grown/cultivated in 25, 21 and 28 sites respectively. An interesting observation made during the study was the incidence of *B. pheonicis* on medicinal plants in all the sites surveyed.

Biological studies of *T. neocaledonicus* were performed on host plants, *C. halicacabum* and *L. lavendulifolia*; *O. biharensis* on *J. adhatoda*, *B. acuminata* and *B. reinwardtii*; *B. pheonicis* on *M. rotundifolia* and *V. negundo*. Infestation by *T. neocaledonicus* and *B. phoenicis* was found mostly confined to the lower surface of middle aged leaves of host plants whereas that of *O. biharensis* was evident on the upper surface of the leaf lamina. On

the foliar surface, areas adjacent to the midrib or other veins were found preferred by these species for colonization. The initial symptoms of damage induced by these mites included the development of chlorotic spots, which got transformed to white patches, necrotic spots, crinkled or crumpled appearance, yellowing etc. which were well protected under silken threads of the web woven by the spider mites (*T. neocaledonicus* and *O. biharensis*) while no such webbing was formed by *B. phoenicis.* Mite infested leaves were found to harbor large number of different life stages comprising the eggs, larvae, protonymphs, deutonymphs, adult males and females, quiescent stages of all instars, moulting skins of all life stages and the faecal pellets. The latter were often entangled with the dust particles among the silken threads. The tissue level damages induced by the spider mites were detected in both the spongy and palisade parenchyma cells of the leaves and heavily infested leaves presented irregular and distorted epidermal cells and collapsed palisade parenchyma cells. Large intercellular spaces resulted from the loss of cellular components were also observed in the leaf sections, at the severely injured feeding sites. The uninfested leaves showed closely packed palisade parenchyma cells with the normal alignment of tissues in the host plants.

The feeding activity of pest mites induced several biochemical alterations, including reduction in photosynthetic pigments, reduced photosynthetic efficiency (through measurement of chlorophyll fluorescence) and increased production of proline, polypheonolic compounds etc.

Quantitative estimation of the concentration of major photosynthetic pigments *viz*. chlorophyll (chlorophyll *a*, chlorophyll *b* and Total chlorophyll) and carotenoids present in mite infested and uninfested leaf samples was performed following Arnon's method (1949). The results of the study revealed more than 35 per cent loss in the amount of all the photosynthetic pigments (chlorophyll *a*, chlorophyll *b*, Total chlorophyll, and carotenoids). Severe loss was observed in *J. adhatoda* due to infestation by *O. biharensis*, the per cent loss of photosynthetic pigments could be recorded as 53.85, 60.53, 55.52 and 52.67 respectively for chlorophyll *a*, chlorophyll *b*, Total chlorophyll and carotenoids. The minimum loss was recorded in *V. negundo*, infested by *B. phoenicis* and the per cent of loss due to this mite was recorded as 40.06, 45.02, 41.92 and 38.80 respectively for chlorophyll *a*, chlorophyll *b*, Total chlorophyll, and carotenoids.

Photosynthetic efficiency was calculated by recording the difference in chlorophyll fluorescence by mite infested and uninfested leaves. Data on various parameters of chlorophyll fluorescence like F_0 (minimum/initial fluorescence), Fm (maximum fluorescence), etc. were recorded separately for the uninfested and infested leaves of host plants using the portable Handy fluorescence monitoring system. The values of Fv/Fm (where $Fv=Fm-F_0$), a parameter commonly known as maximum quantum yield of primary photochemistry or maximal electron transport rate (ETR) of PS II ranged from 0.807 – 0.833 and 0.325 – 0.523 respectively for the uninfested and

infested leaves of the host plants. Among the 3 species of pest mites studied, *O. biharensis* was found to induce severe loss in photosynthetic efficiency (0.325) on its host *J. adhatoda*.

Results of biochemical estimations such as proline (Bates *et al.*, 1973) and phenol (Malick and Singh, 1980) revealed notable differences in their quantities in mite infested leaves when compared to that of the uninfested leaves. Both the compounds showed an increase in their quantity in mite infested leaves. The per cent increase in the amount of proline was found to range from 114.26 - 128.44, 98.23 - 187.22 and 87.28 - 116.65 respectively in the infested leaves of *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*. The increase in the percentage of phenolic compounds was recorded as 32.35 - 35.30, 25.61 - 47.02 and 23.54 - 31.18 respectively in the infested leaves of *T. neocaledonicus*, *O. biharensis* and *B. phoenicis*. The highest percentage of proline and phenol could be recorded on the host plant, *J. adhatoda* infested by *O. biharensis*.

Results of studies on the breeding biology of selected species of pest mites enabled to gather information on oviposition, fecundity, hatching, percentage of egg viabiliity, developmental durations of the immatures, percentage of immature viabiliity, durations of the adults, sex ratio, modes of development (parthenogenetic and sexual),s morphological characters of life stages of the pest mites etc. The developmental biology of pest mites studied

following the leaf disc method at three temperature humidity conditions *viz*. 25 ± 2°C & 80 ± 5 per cent RH, 30 ± 2°C & 70 ± 5 per cent RH and 35 ± 2°C & 60 ± 5 per cent RH. *T. neocaledonicus* showed high fecundity (49.71 eggs) with the rate of egg production (6.91 eggs/female/day), egg viability (92.41 per cent) and immature survivorship (96.72 per cent) on the host *C. halicacabum* than *L. lavendulifolia* at 35 ± 2°C & 60 ± 5 per cent RH. *T. neocaledonicus* showed the shortest developmental duration of 10.68 days (female) and 9.68 days (male) on *C. halicacabum* than *L. lavendulifolia* (13.59 days for female and 11.97days for male) at 35 ± 2°C & 60 ± 5 per cent RH, thereby justifying that *C. halicacabum* is the most favorable host for *T. neocaledonicus*. Similarly, among the three host plants studied (*J. adhatoda*, *B. reinwardtii* and *B. acuminata*) for *O. biharensis*, *J. adhatoda* and *B. reinwardtii* were proved as the more preferred hosts for the mite. Data on developmental studies of *O. biharensis* on the host, *J. adhatoda* revealed that the species had a fecundity (56.19 eggs), rate of egg production/day (7.57 eggs/female/day), egg viability (89.26 per cent) and immature survivorship (97.51 per cent) at 35 ± 2°C & 60 ± 5 per cent RH. On *J. adhatoda*, *O. biharensis* showed the shortest developmental duration and which could be recorded as 7.04 days (female) and 6.75 days (male) at 35 ± 2°C & 60 ± 5 per cent RH.

Both the species of spider mites, *T. neocaledonicus* and *O. biharensis* were found to follow two modes of reproduction *viz*. parthenogenetic and

sexual. In parthenogenetic reproduction, all the progenies produced were males (arrhenotoky) whereas in sexual reproduction both the male and female individuals were produced. The sex ratio of *T. neocaledonicus* was recorded as 2 : 10 on *C. halicacabum* and 1 : 10 on *L. lavendulifolia*. The sex ratio in *O. biharensis* was 3 : 10 on the host plants *viz*. *J. adhatoda* and *B. reinwardtii*. The sex ratio was found to be 2 : 10 on the host *B. acuminata*. Among the two hosts (*M. rotundifolia* and *V. negundo*) of *B. phoenicis*, *M. rotundifolia* was proved more favorable to the species. *B. phoenicis* exhibited high fecundity on *M. rotundifolia,* (35.61 eggs) and rate of oviposition (2.06 eggs/female/day) at 30 ± 2^{o}C & 70 ± 5 per cent RH. Whereas on the same host, high rate of egg viability (88.82 per cent) and immature survivorship (90.11 per cent) was shown at 35 ± 2^{o}C & 60 ± 5 per cent RH and 30 ± 2^{o}C & 70 ± 5 per cent RH respectively. The population was found to be comprised of 100 per cent females in the case of *B. pheonicis*, on both the host plants studied and the mode of reproduction was thelytokous parthenogenesis, with the resulting progenies comprised of females alone.

Results of morphological studies on the various life stages of the three species of pest mites revealed that they all exhibited specific characteristic features. The dorsal setae of the genus *Tetranychus* were long, pointed, smooth and without tubercles. The dorsal chaetotaxy varied between genera and species of the family Tenuipalpidae. There were three pairs of propodosomal setae, but the number of setae on hysterosoma showed

variation. Palpus was found to bear 4 or 5 segments, characteristic feature of the genus *Brevipalpus*. The species, *B. pheonicis* was found to possess five pairs of short hysterosomal dorsolateral setae plus the humeral setae.

In the third part of the thesis, data were included on the biological measures adopted for the suppression of pest mites using natural enemies and biopesticides. During the study, collection and identification of natural enemies comprised of some species of predatory mites and insects feeding on the pest mites infesting the medicinal plants were carried out. A total of 20 species of predatory mites and 5 species of insect predators were identified. The major families of predatory mites recovered during the survey were Phytoseiidae, Cunaxidae, Bdellidae, Stigmaeidae and Cheyletidae and the major families of insect predators detected during the study were Cecidomyiidae, Thripidae and Coccinellidae. The important genera of predatory mites recorded during study were *Amblyseius*, *Euseius*, *Cunaxa*, *Bdelloides*, *Agistemus* and *Cheyletus*. The important genera of insect predators recorded were *Feltiella*, *Scolothrips* and *Stethorus*. The results of the study also enabled to add new host records for 15 species of predatory mites and 5 species of insect predators. Wide host range could be recorded in phytoseiid mites and their distribution on host plants could be recorded as *A. largoensis* (20 plants), *A. channabasavannai* (11 plants), *N. longispinosus* (14 plants) and *E. ovalis* (19 plants). Wide host range could be observed in the

insect predators also as shown by *F. acarisuga* (12 plants) and *S. punctillum* (14 plants).

In the present study, the feeding potential of the predatory gall midge, *F. acarisuga* (larval stage) and the phytoseiid predatory mite, *A. largoensis* (adult female) on *T. neocaledonicus* was assessed and it was observed that *F. acarisuga* was more efficient in controlling the pest mite when compared to *A. largoensis*. The per day consumption by *F. acarisuga* on the eggs, nymphs and adults of the pest mite, *T. neocaledonicus* was recorded as 43.07 ± 2.04, 35.19 ± 2.13 & 23. 27 ± 2.17 respectively. The rate of consumption by *A. largoensis* was recognized to be lower than that of the insect predator, the average consumption rate could be recorded as 27.48 ± 1.92, 18.79 ± 2.05 & 10.47 ± 1.08 eggs, larvae and adults respectively.

The feeding potential of the two natural enemies *viz*., the adult female of the phytoseiid predatory mite, *E. ovalis* and the larval stage of the predatory thrips, *S. asura* on the life stages *viz*. egg, nymph and adult (female) of *O. biharensis* was assessed during the study. The rate of predation by *S. asura* on the egg, larva and adult stages of the pest mite, *O. biharensis* was 39.61 ± 1.32, 27.15 ± 1.16 & 21. 27 ± 2.13 respectively and that of *E. ovalis* was 21.92 ± 1.09, 14.79 ± 2.05 & 8.47 ± 2.08. Both *S. asura* and *E. ovalis* showed more preference to the eggs of *O. biharensis* and minimum preference to the adult stages of the pest mite. The rate of consumption of the

adult female of *C. myabunderensis* on the egg, larva and adult stages of *B. phoenicis* was recorded as 26.03 ± 2.02, 23.61 ± 1.57 & 17.19 ± 2.17 and that of the nymph of *C. myabunderensis* was 19.14 ± 1.83, 14.61 ± 2.04 & 11.61 ± 2.13. The consumption rate of the adult female of *A. largoensis* was found to be comparatively lower, averaging to 14.32 ± 2.07, 9.92 ± 1.09 & 6.73 ± 1.24 respectively on the egg, larva and adult of the pest mite, *B. phoenicis.* The adult female of *C. myabunderensis* was proved as the most potential predator on the life stages of the pest mite, *B. phoenicis*.

The formulation of plant based biopesticides in different concentrations which could be effectively applied against selected species of injurious mites and evaluation of the rate of mortalitiy of the pest mites formed another important achievement made during the study. The aqueous extracts of the leaves of two species of plants *viz*. *Glyricidia sepium* and *Chromolaena odorata* were found to possess acaricidal activity, causing mortality of the adults of the two species of pest mites selected *viz*. *T. neocaledonicus* and *O. biharensis*. The rate of mortality was found to be relatively high with the aqueous extracts of *G. sepium* on both the species of pest mites when compared to the extracts of *C. odorata*. All the three concentrations (2.5, 5.0 and 10.0 per cent) of the aqueous extracts prepared of the leaves of both species of plants mentioned above were found effective in inducing high mortality of the adults of *T. neocaledonicus*, when compared to those of *O. biharensis*. Treatments with the crude extracts of both species of

plants were found more effective at higher concentration (10 %) against both species of pest mites selected. Treatment of *T. neocaledonicus* with 10 per cent aqueous extract of *G. sepium* induced the maximum percentage of mortality of 89.31 ± 2.15 at 72 hours of exposure. Application of 10 per cent concentration of the same extract on *O. biharensis* induced 77.37 ± 1.98 per cent mortality with the same period of exposure. Whereas the exposure to 10 per cent of aqueous extract of *C. odorata* induced a relatively lower mortality rate of 77. 29 ± 2.03 per cent in *T. neocaledonicus* and 65.03 ± 2.09 per cent in *O. biharensis* at an exposure time of 72 hours. In the present study, the minimum acaricidal activity was recorded for the aqueous extract at 2.5 per cent concentration of *C. odorata* on both the species of pest mites. Treatments with 2.5 per cent aqueous extract of *C. odorata* for an exposure time of 24 hours, induced 6.13 ± 1.20 and 9.15 ± 0.93 per cent of mortality in *O. biharensis* and *T. neocaledonicus* respectively. The present findings on the significant acaricidal activity of these extracts would be considered as a promising step for the formulation of more concentrations and combinations, for their effective application under field conditions also.

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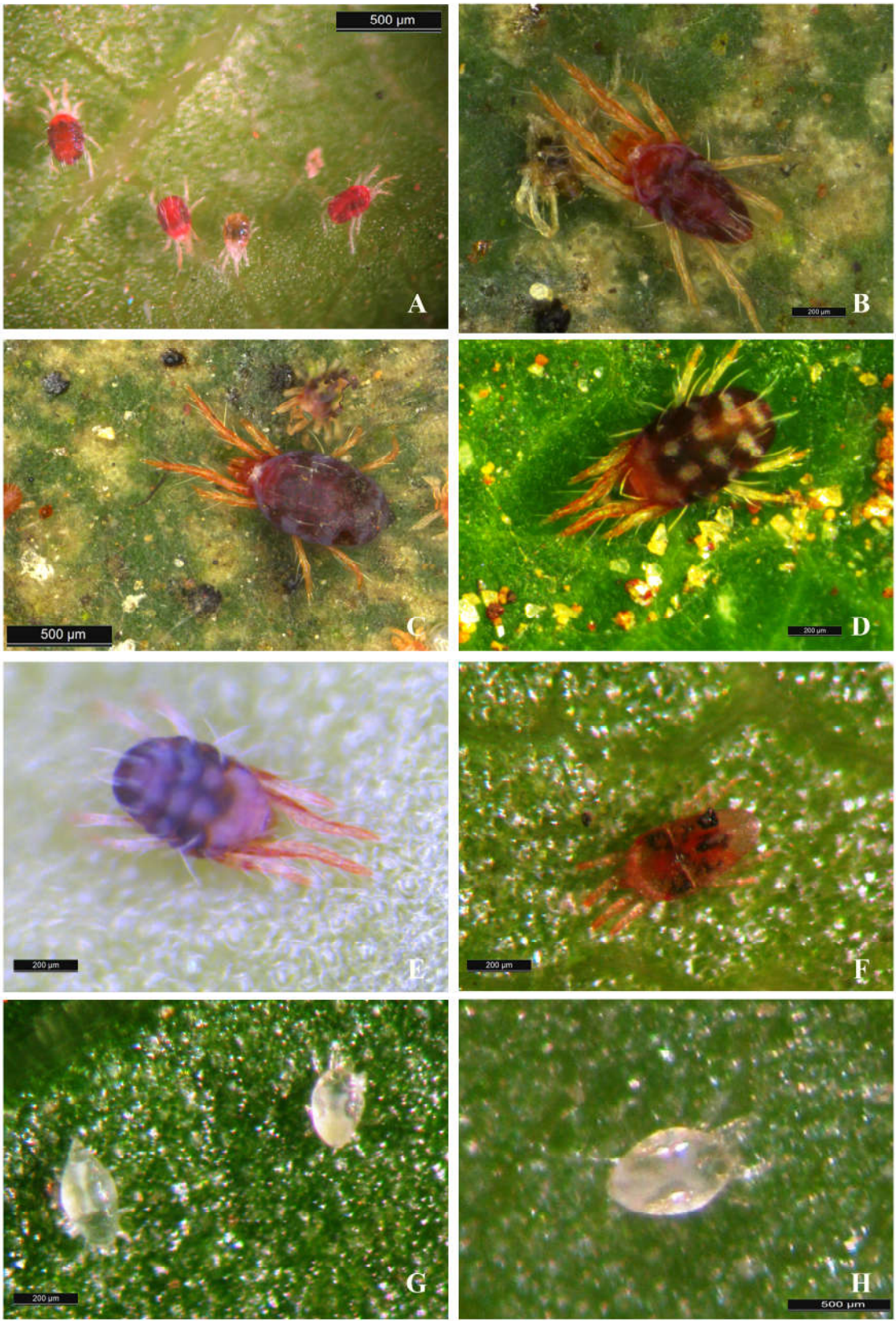
PLATE 1
Sampling districts of Kerala

Botanical/Herbal Gardens

1. Calicut University Botanical Garden
2. Kottakal Arya Vaidya Sala Botanical Garden
3. Parappanangadi Herbal Garden
4. Malabar Botanical Garden
5. Thekumthara (Syam) Herbal Garden
6. Kerala Forest Research Institute
7. Jawaharlal Nehru Tropical Botanical Garden

PLATE 2

Species of phytophagous mites injurious to medicinal plants



A. *Tetranychus cinnabarinus*; **B.** *Oligonychus coffeae* male; **C.** *O. coffeae* female; **D.** *Panonychus ulmi*; **E.** *P. citri*; **F.** *Brevipalpus phoenicis*; **G.** *Polyphagotarsonemus latus*-chrysalis and female; **H.** *P. latus*- female.

PLATE 3

Species of phytophagous mites injurious to medicinal plants

A. *Polyphagotarsonemus latus* - male; **B & C.** *P. latus* - egg; **D** *Aceria* sp.; **E.** *Eotetranychus* sp. Female; **F.** *Eotetranychus* sp. male

PLATE 4

Species of host plants selected for the biological study of pest mites

A & B. *Cardiospermum halicacabum*; **C.** *Leucas lavendulifolia*; **D.** *Justicia adhatoda*; **E.** *Biophytum reinwardtii*; **F.** *Bauhinia acuminata*; **G.** *Mentha rotundifolia*; **H.** *Vitex negundo*

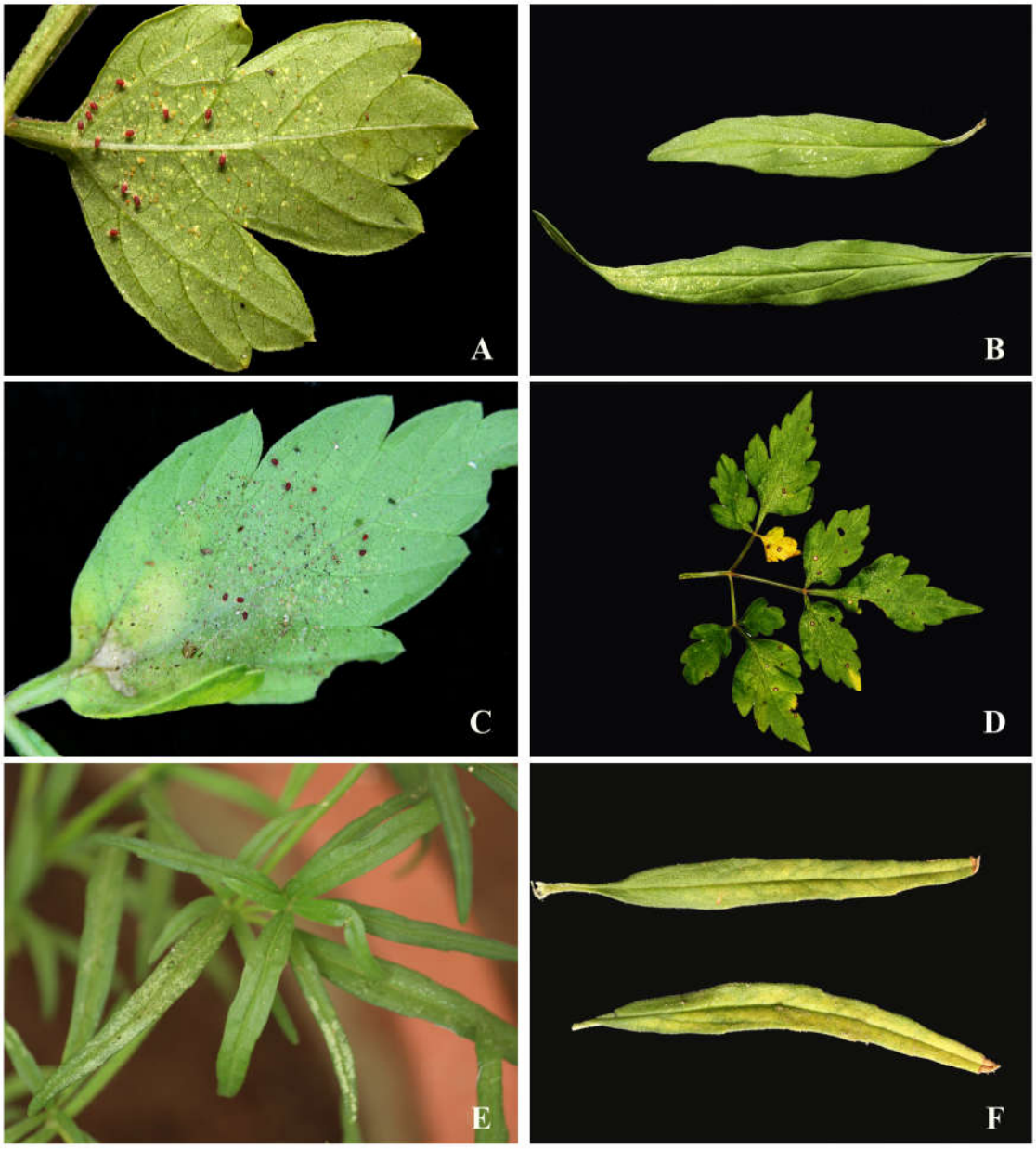
PLATE 5

Mite rearing (leaf disc method) and Chlorophyll Fluorometer

A. Rearing of mites under laboratory condition; **B.** Chlorophyll Fluorometer (Handy PEA); **C.** Leaf samples kept in leaf clips for dark adaptation; **D.** Leaf disc method for breeding biology study

PLATE 6

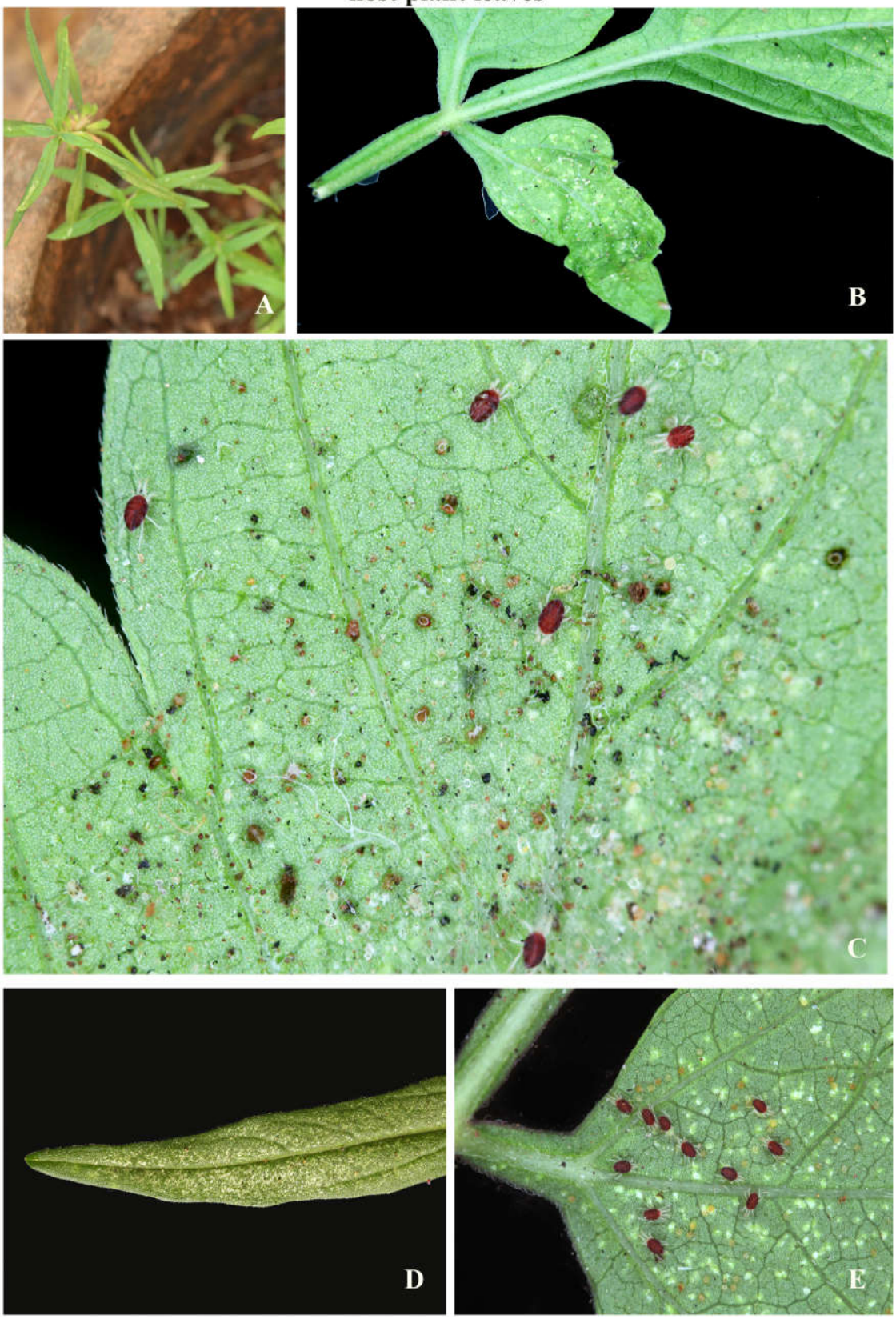
Feeding damages induced by *Tetranychus neocaledonicus* on host plant leaves



A. Chlorotic spots on *C. halicacabum* leaf; **B.** chlorotic spots on the leaves of *L. lavendulifolia*; **C.** web of *T. neocaledonicus*; **D.** chlorotic and necrotic spots; **E.** chlorotic spots or patches; **F.** infested leaf turned to yellowish

PLATE: 7

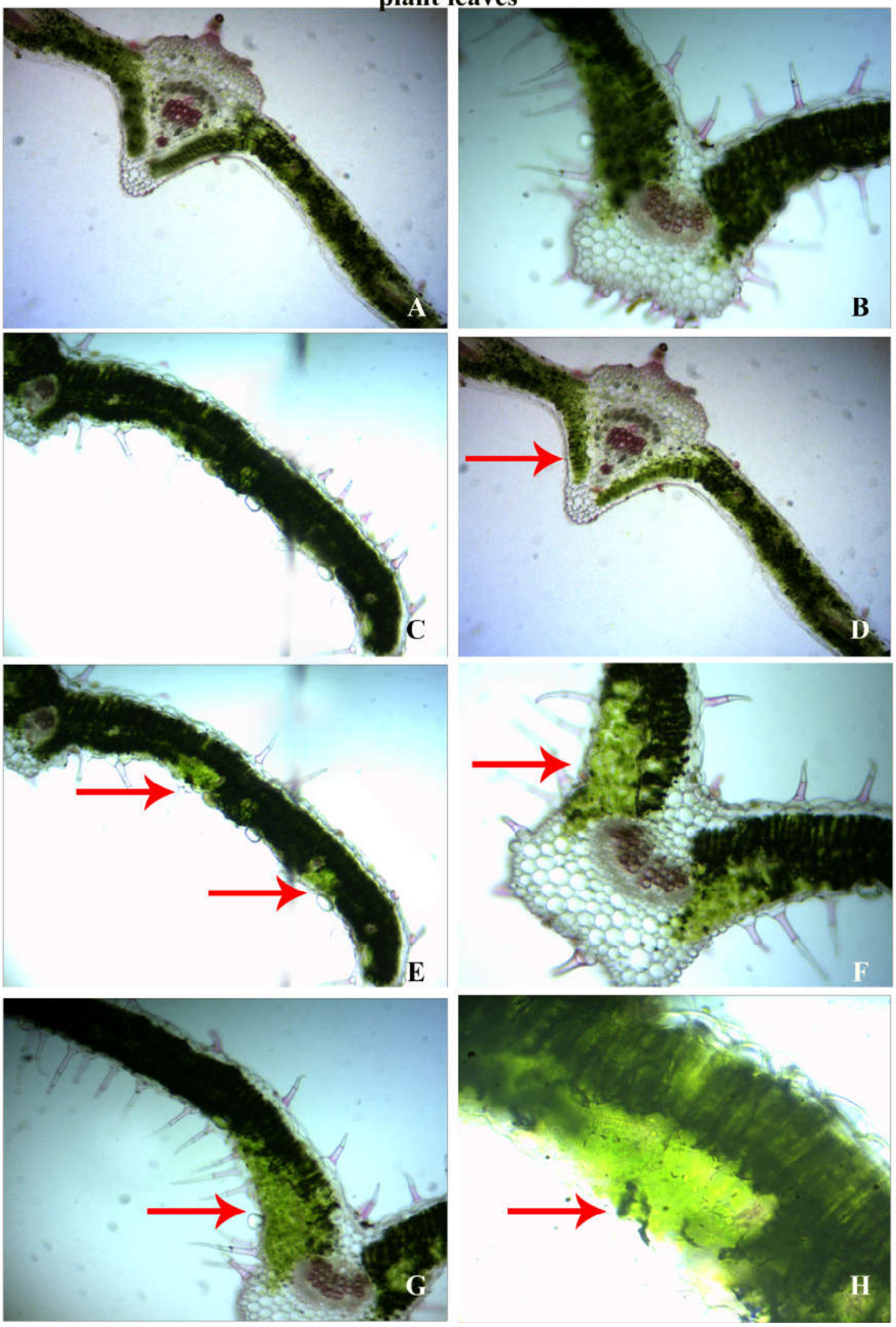
Feeding damages induced by *Tetranychus neocaledonicus* on host plant leaves



A. Yellowing and drying of infested leaves; **B.** shrinking and curling of *C. halicacabum* leaf; **C.** web of *T. neocaledonicus* with feacal matter and dust particles; **D & E.** chlorotic spots or patches

PLATE: 8

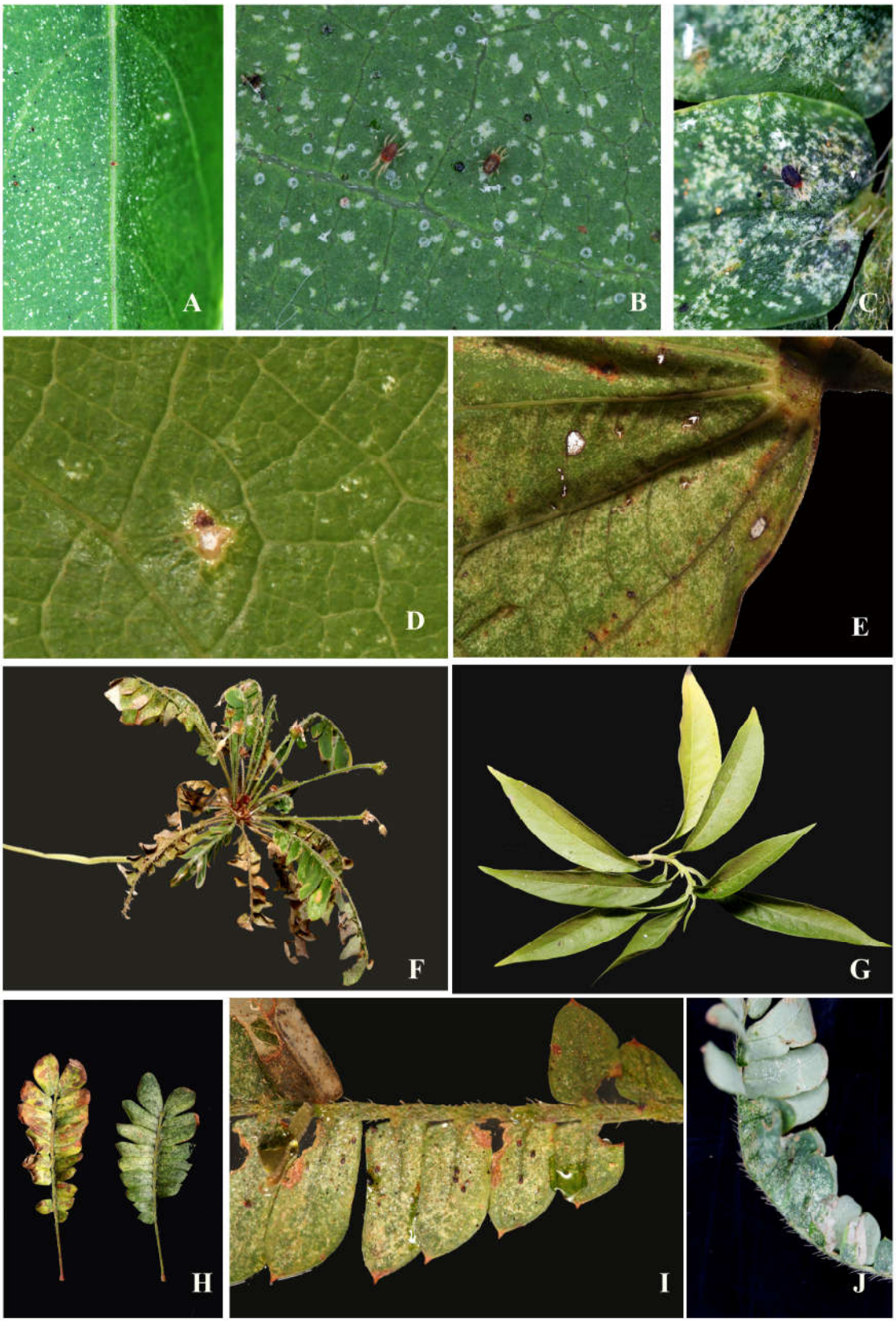
Tissue level damages induced by *Tetranychus neocaledonicus* on host plant leaves



A. Uninfested leaf section of *C. halicacabum*; **B.** midrib region in the uninfested leaf of *L. lavendulifolia*; **C.** uninfested leaf of *L. lavendulifolia*; **D.** mite feeding sites on the lower surface of the leaf in *C. halicacabum*; **E.** mite feeding site on the lower surface of the leaf; **F.** midrib region of *L. lavendulifolia* with reduced chloroplast cells; **G.** reduced chlroplast cells; **H.** mite induced injury on leaf of *L. lavendulifolia*

PLATE: 9

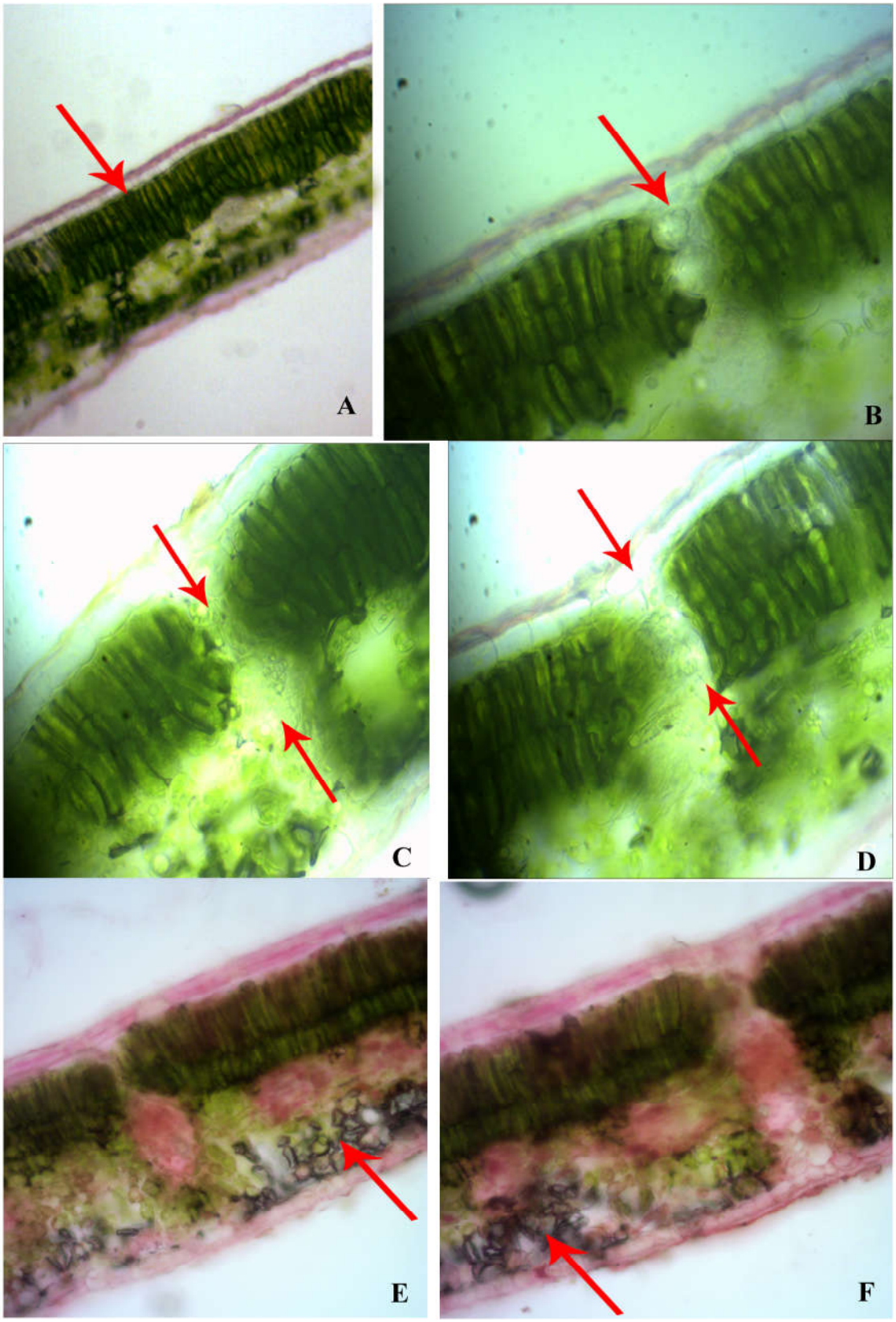
Feeding damages induced by *Oligonychus biharensis* on host plant leaves



A. chlorotic spots on *J. adhatoda* leaf; **B.** chlorotic patches on *J. adhatoda*; **C.** chlorotic spots and patches on *B. reinwardtii* leaf; **D.** necrotic spots; **E.** severely infested leaf of *B. acuminata*; **F.** drying up of leaves in *B. reinwardtii*; **G.** infested twig of *J. adhatoda*; **H.** heavily infested leaves of *B. reinwardtii*; **I.** moulting skins and feacal pellets; **J.** moulting skins and leaf curling in *B. reinwardtii*

PLATE 10

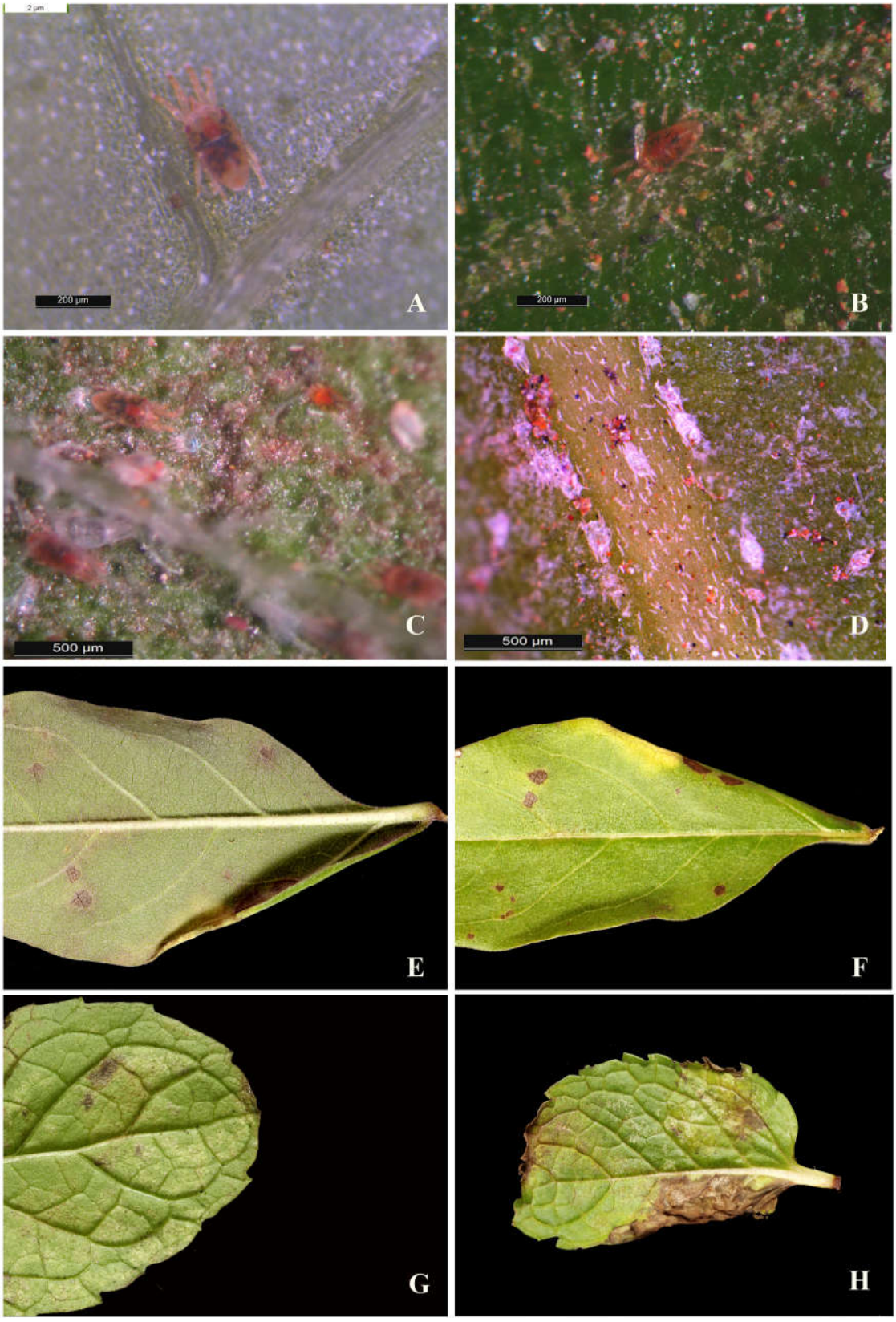
Tissue level damages induced by *Oligonychus biharensis* on *Justicia adhatoda* leaf



A. closely packed palisade parenchyma cells in uninfested leaf; **B.** punctured palisade cells at the regions of cholorotic spots area on infested leaf; **C.** punctured palisade and reduced chloroplast cells; **D.** distorted epidermal cells and palisade cells; **E & F** necrotic cells formed in the infested leaf

PLATE: 11

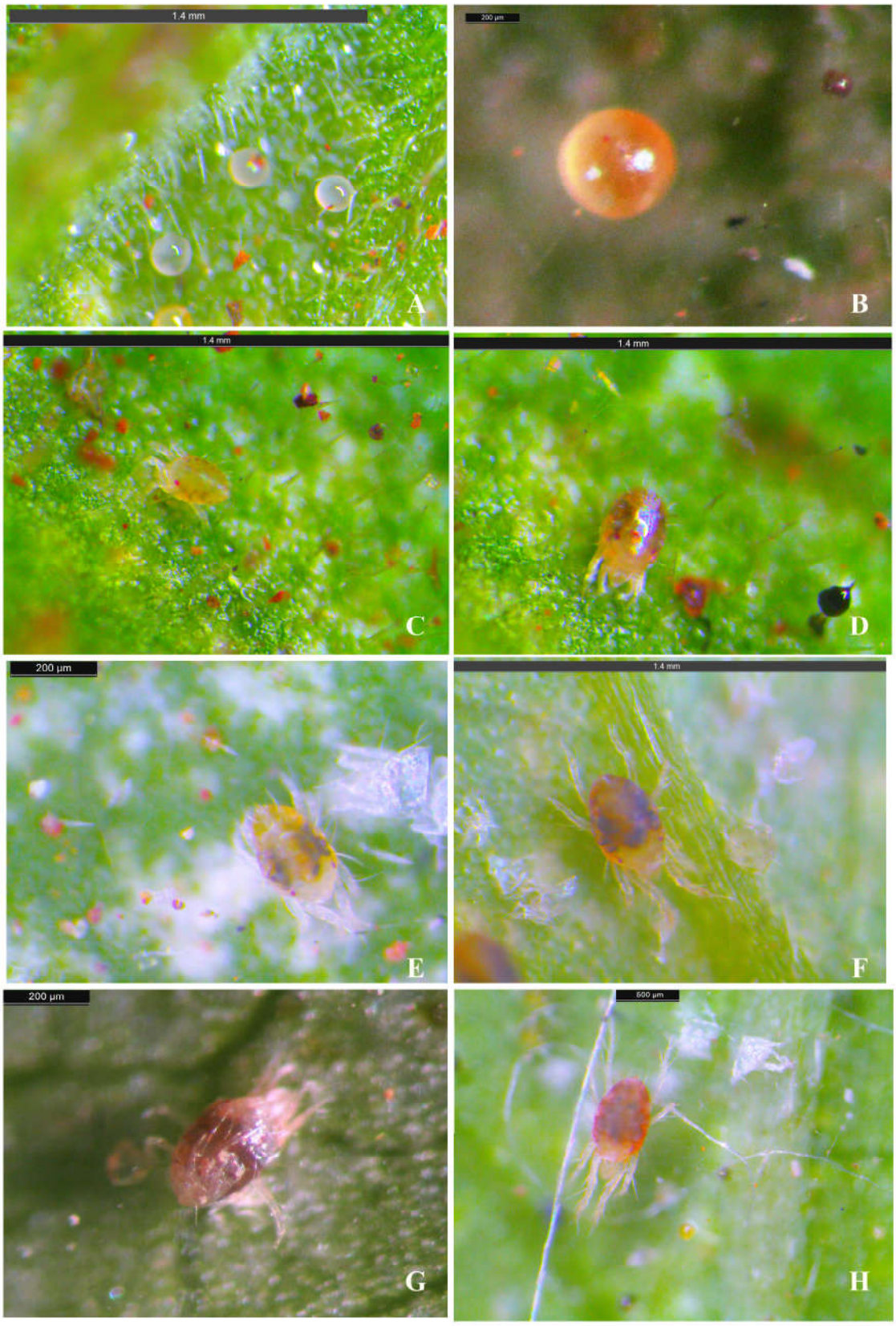
Feeding damages induced by *Brevipalpus phoenicis* on host plant leaves



A. *B. phoenicis* feeding on lower leaf surface; **B.** mite feeding on upper surface of the leaf; **C.** life stages of mite feeding along the mid rib region; **D.** moulting skin on *V. negundo*; **E.** necrotic spots on *V. negundo*; **F.** necrotic spots & yellowing of leaf ; **G.** *B. phoenicis* infested leaf of *M. rotundifolia*; **H.** yellowing and drying up of leaf in *M. rotundifolia*

PLATE 12

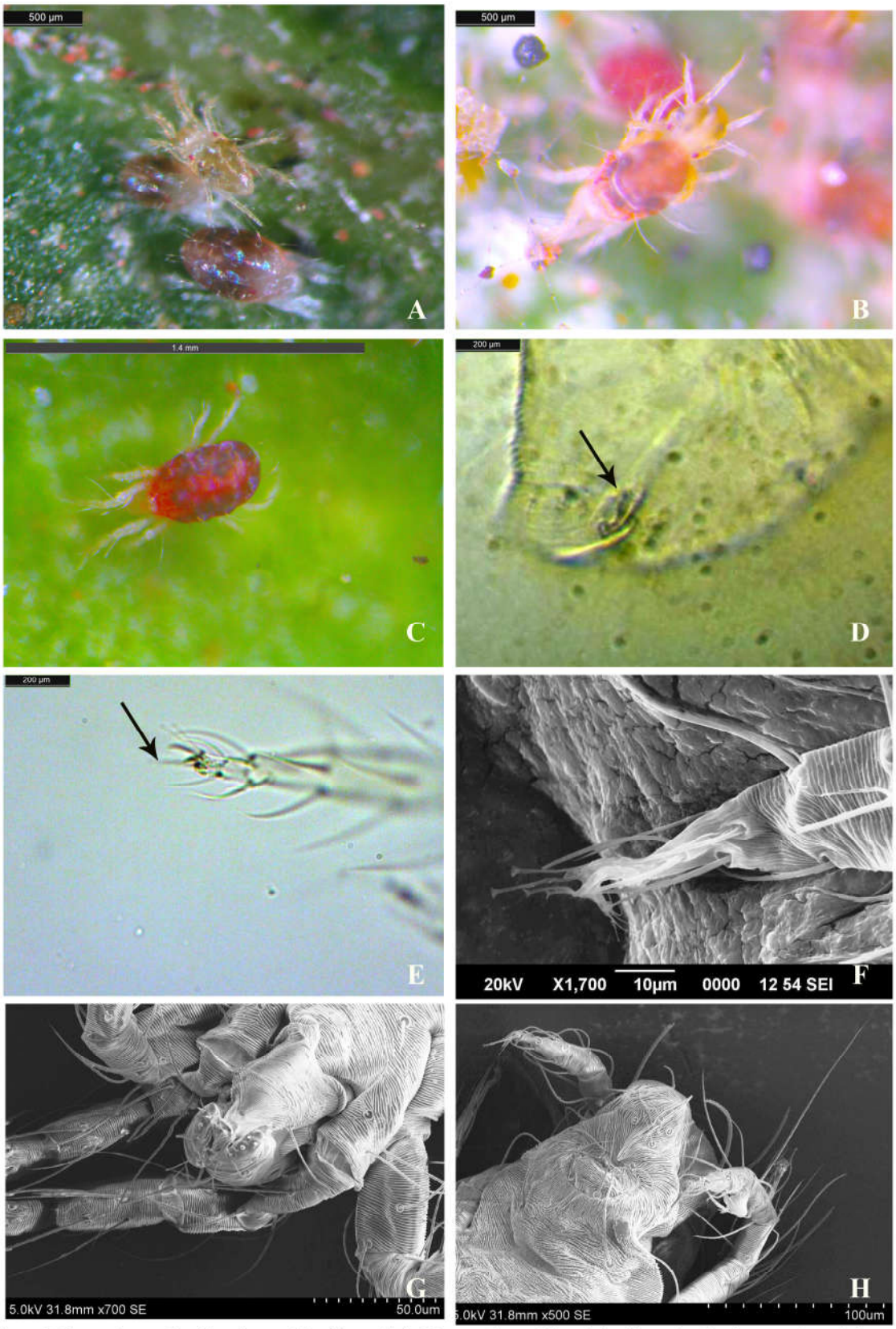
Life stages of *Tetranychus neocaledonicus*



A. Egg; **B.** egg with eye spot; **C.** larva; **D.** protochrysalis; **E.** protonymph; **F.** deutonymph; **G.** teliochrysalis ; **H.** newly moulted female

PLATE: 13

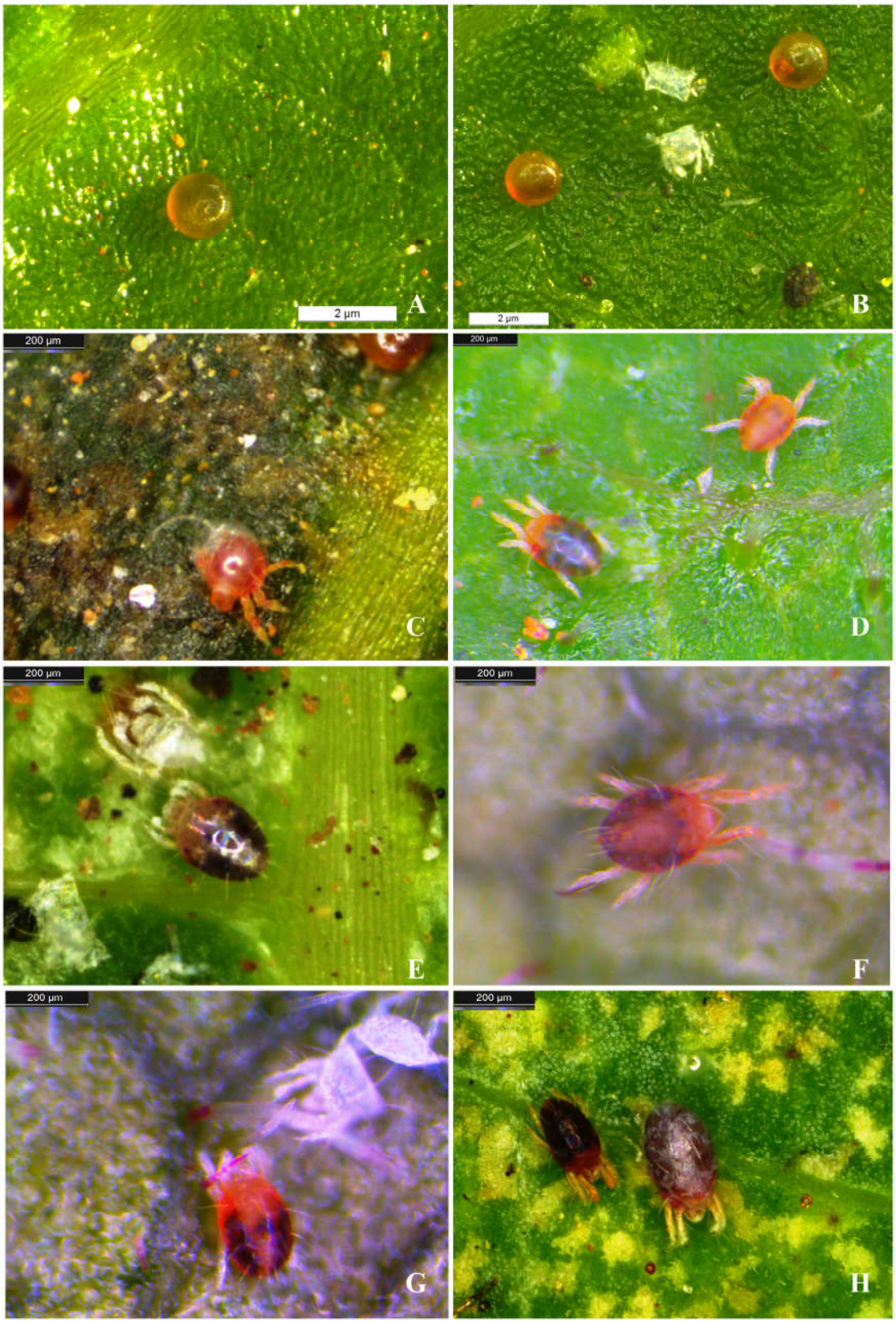
Life stages and specific characters of *Tetranychus neocaledonicus*



A. adult male and teliochrysalis (female); **B.** mating; **C.** adult female during oviposition period; **D.** aedeagus of male; **E.** empodium with proximoventral hairs; **F.** S.E.M image of empodium with proximoventral hairs; **G.** ventral view of mouth parts; **H.** ventral view of adult female

PLATE 14

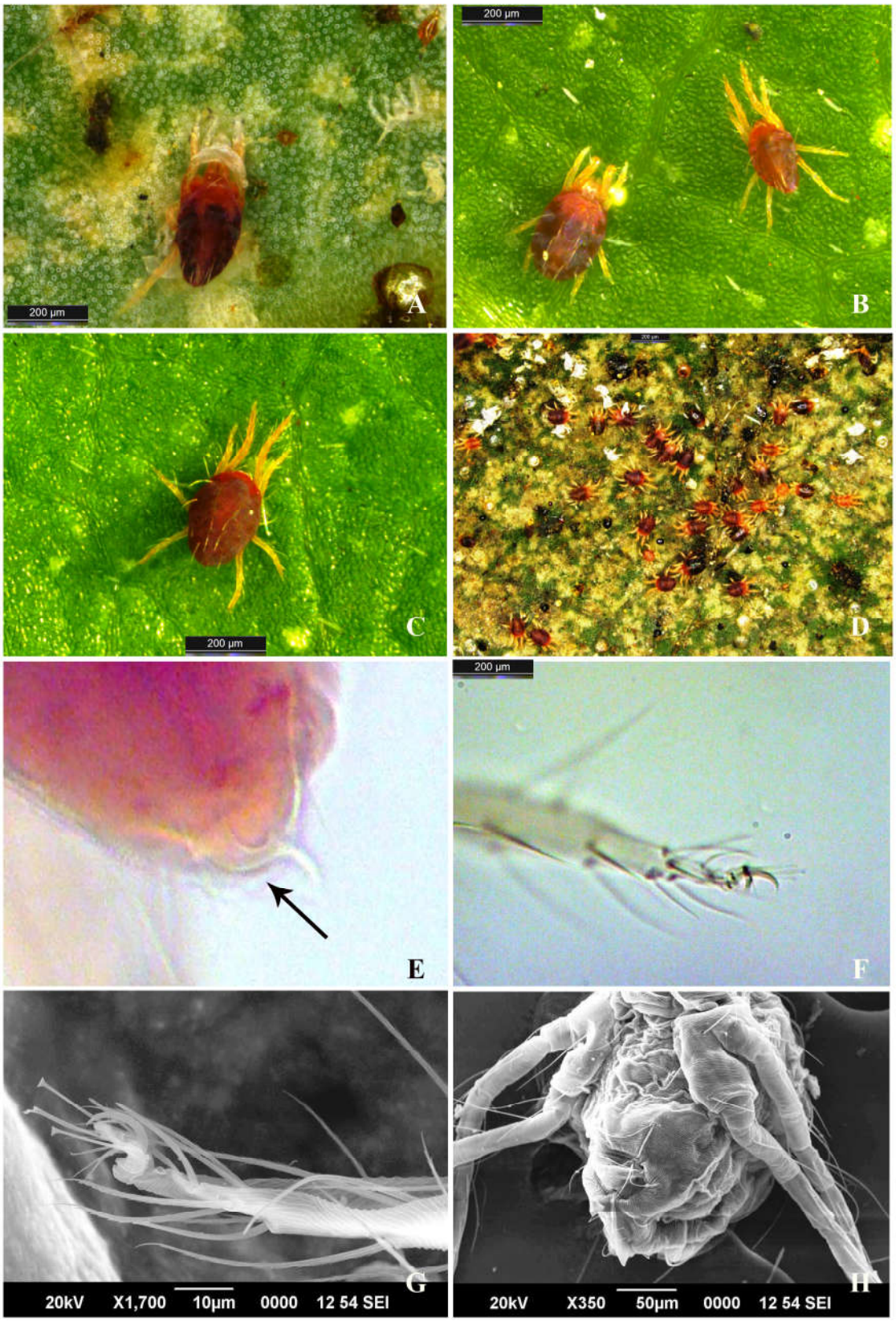
Life stages of *Oligonychus biharensis*



A. Egg; **B.** egg with eye spot; **C.** hatching process; **D.** newly hatched and matured larvae; **E.** protochrysalis; **F.** protonymph; **G.** newly moulted protonymph; **H.** deutonymph and teliochrysalis.

PLATE: 15

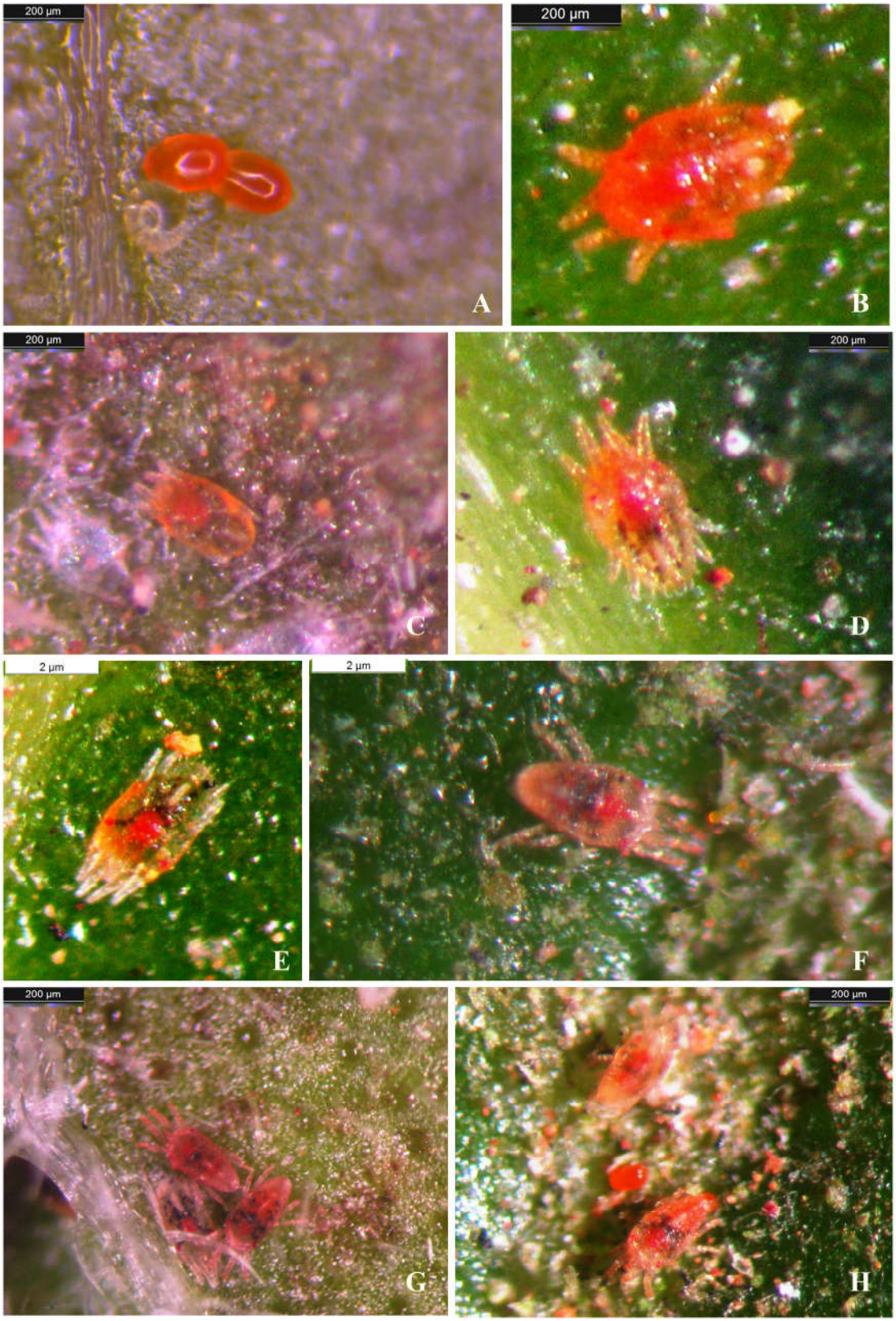
Life stages and specific characters of *Oligonychus biharensis*



A. moulting of quiescent male deutonymph; **B.** adult male and female; **C.** female during oviposition stage **D.** mite colony; **E.** aedeagus of male; **F.** empodium with claw; **G.** S.E.M image of empodium with claw; **H.** ventral view of adult female

PLATE: 16

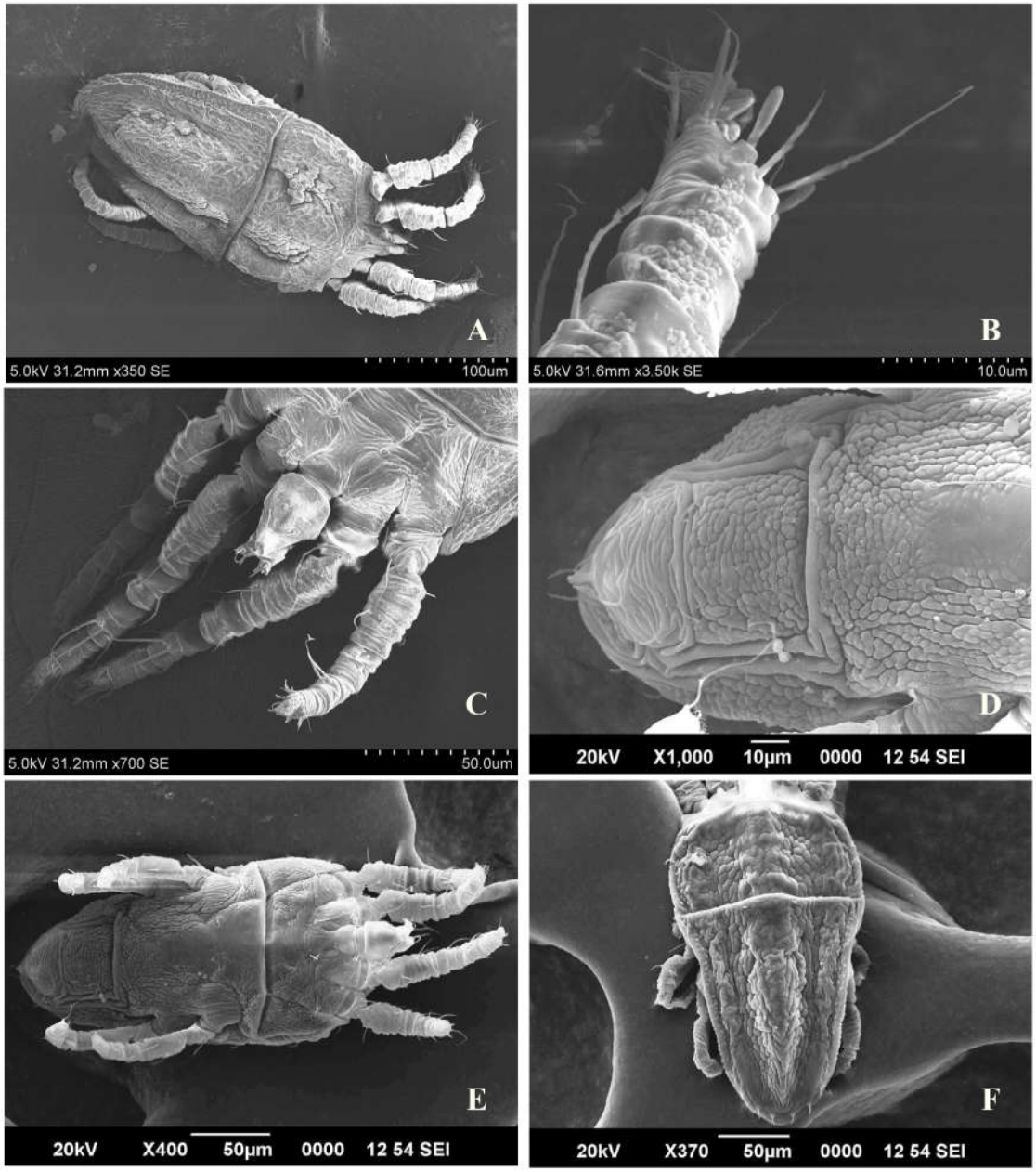
Life stages of *Brevipalpus phoenicis*



A. Egg; **B.** larva; **C.** protochrysalis **D.** protonymph; **E.** deutochrysalis; **F.** deutonymph; **G.** newly moulted adult female; **H.** egg laying female

PLATE: 17.

Scanning electron microscopic images of *Brevipalpus phoenicis*



A. dorsal view; **B.** tarssus II showing two sensilla; **C.** ventral view of mouth parts; **D.** ventral view of posterior portion; **E.** ventral view; **F.** dorsal view

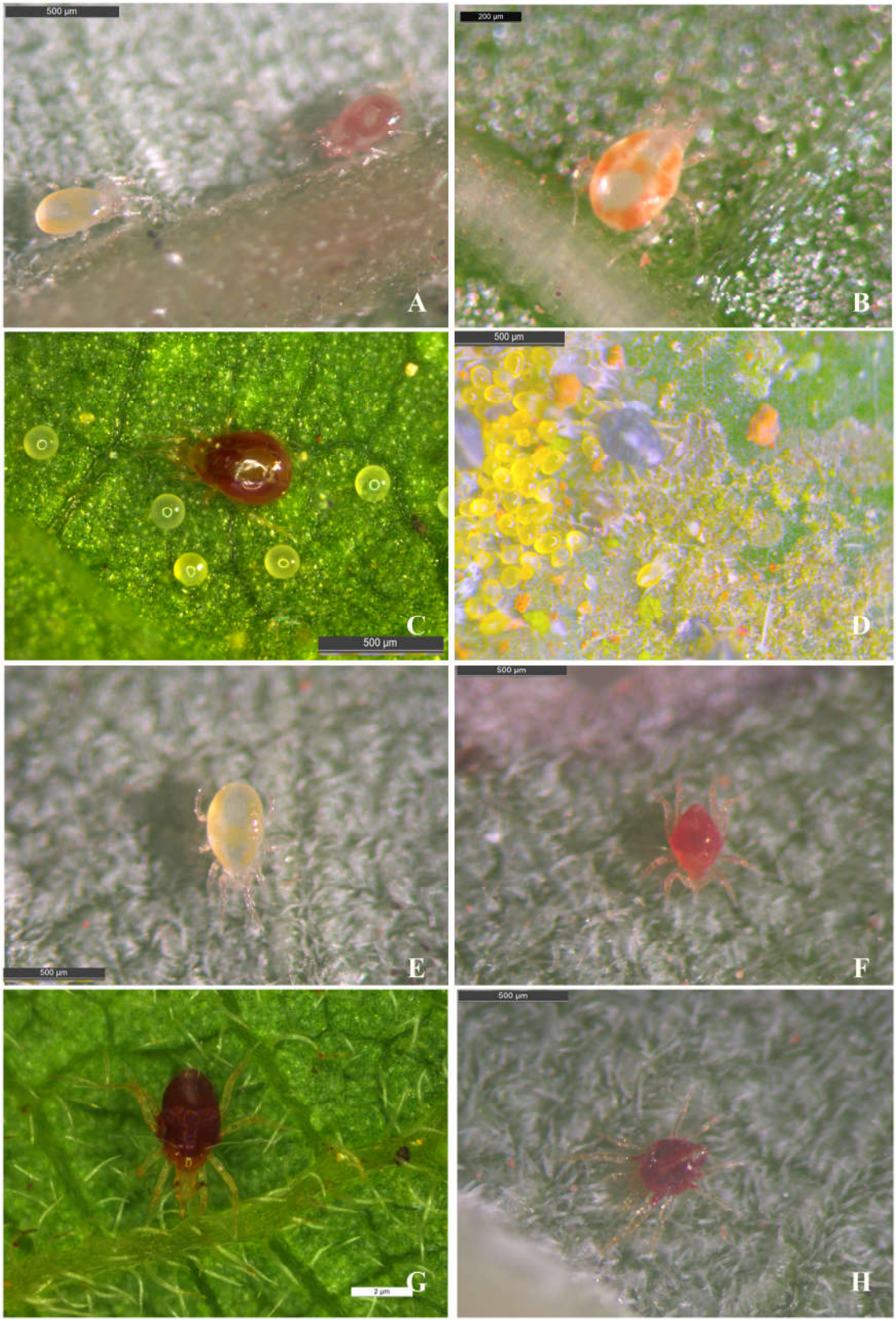
PLATE: 18.

Species of plants selected for testing the acaricidal activity

A & B. *Glyricidia sepium*; **C & D.** *Chromolaena odorata* (L.)

PLATE 19

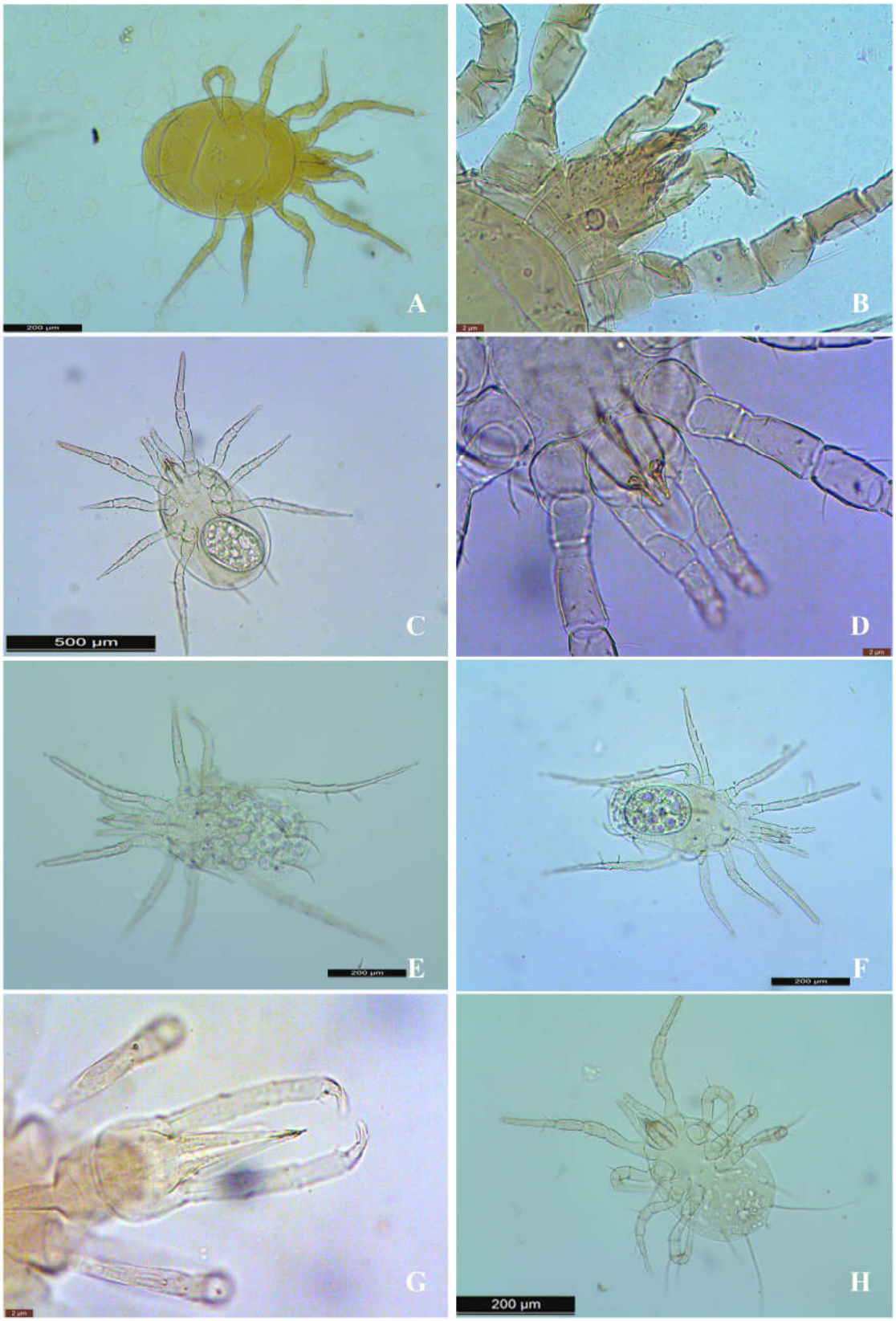
Species of predatory mites collected during the survey



A. Adult and nymph of *Amblyseius largoensis*; **B.** *A. herbicolus*; **C.** *Euseius ovalis* **D.** *Agistemus* sp., **E.** nymph of *A. largoensis*; **F & G.** *Bdellodes* sp.; **H.** *Cheyletus malaccensis*

PLATE 20

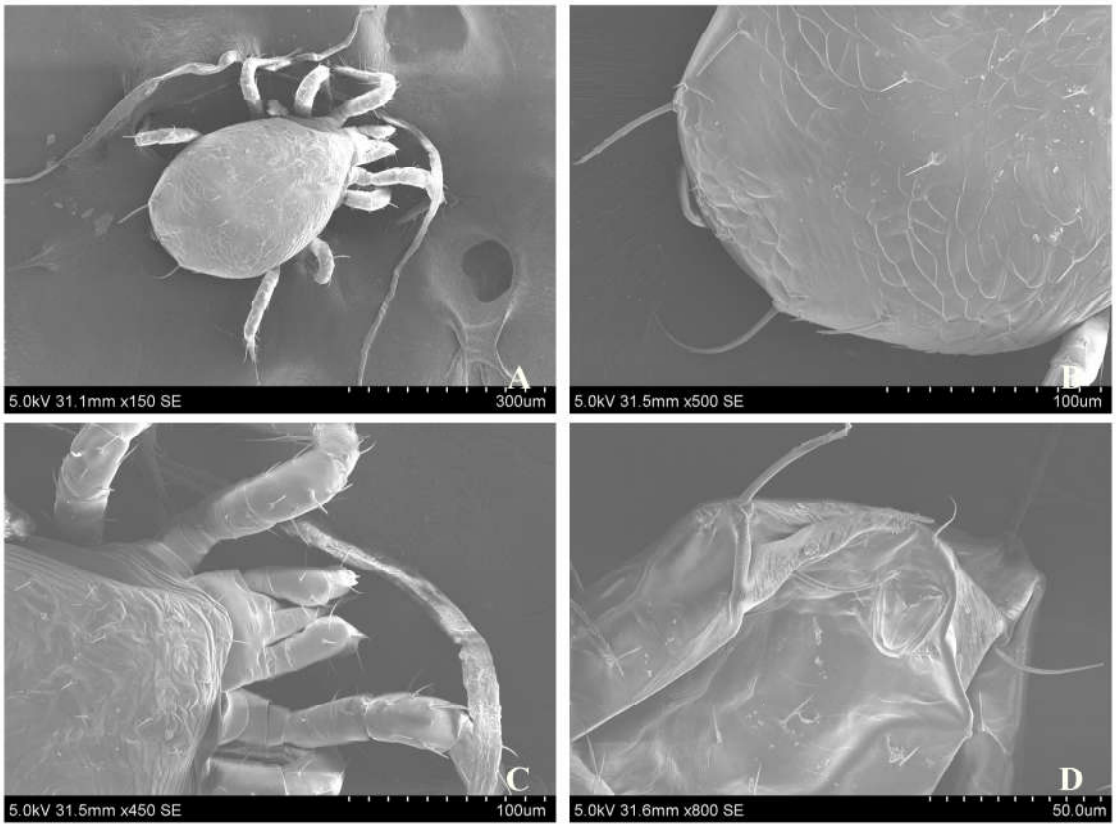
Slide mounted specimens of predatory mites collected during the survey



A. *Amblyseius channabasavannai*; **B.** *A. channabasavannai* - male; **C.** *E. rhododendronis*; **D.** mouthparts of *E. rhododendronis*; **E & F.** *Paraphytoseius orientalis*; **G.** *Cunaxa myabunderensis* mouthparts; **H.** *Amblyseius largoensis*

PLATE: 21

Scanning electron microscopic images of *Euseius finlandicus*



A. dorsal view; **B.** dorsal view of posterior part of hysterosoma - male; **C.** Anterior appendages; D. ventral view of posterior part

PLATE: 22

Species of insect predators used for the study of feeding potential on pest mites

A. larvae of *Feltiella acarisuga* on *Cardiospermum halicacabum*; **B.** Larval stage of *F. acarisuga* along with various life stages of *T. neocaledonicus*; **C.** Pupa of *F. acarisuga* **D.** Adult stage of *Scolothrips asura* on *Justicia adhatoda* **E.** newly emerged larva of *S. asura* ; **F.** larval stage of *S. asura* after feeding *O. biharensis* life stages **G.** larval stage of *S. asura* and egg cases of *O. biharensis*; **H.** prey/pest killed by *S. asura*

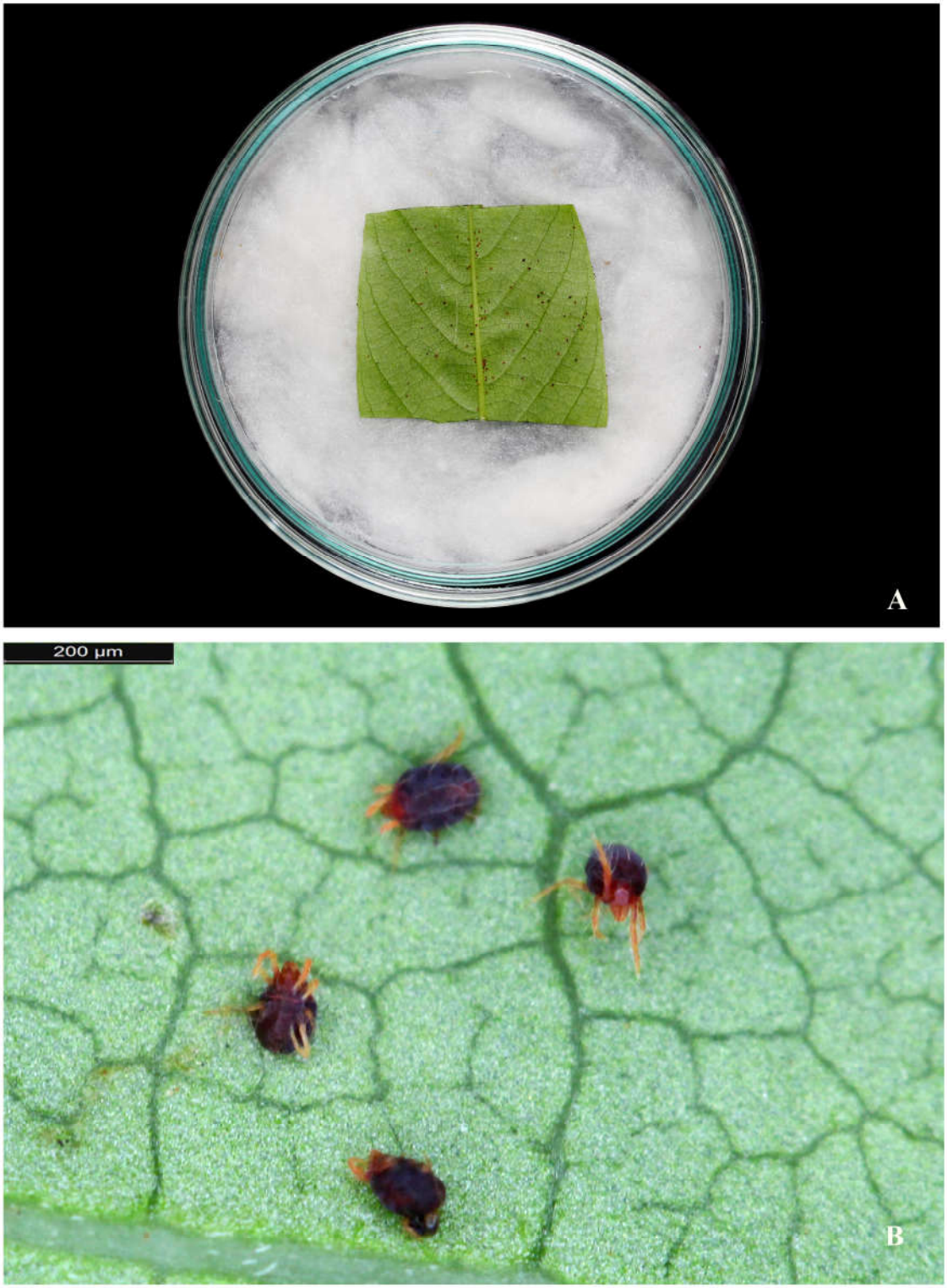
PLATE 23

Feeding activity of adult and nymphal stages of *Cunaxa myabunderensis* on *Brevipalpus phoenicis*

A. adult stage of *C. myabunderensis*; **B.** *C. myabunderensis* feeding on adult stage of *B. phoenicis*; **C.** adult and eggs of *C. myabunderensis*; **D.** *C. myabunderensis* (nymph) and *B. phoenicis* (adult) **E.** nymph of *C. myabunderensis* feeding on adult stage *B. phoenicis*; **F.** *B. phoenicis* and eggs of *C. myabunderensis*

PLATE 24

Elucidation of acaricidal activity of plant extracts on *Oligonychus biharensis*



A. leaf disc method used for conducting acaricidal test on adult females of *O. biharensis*; **B.** dead females of *O. biharensis* after the acaricidal treatment

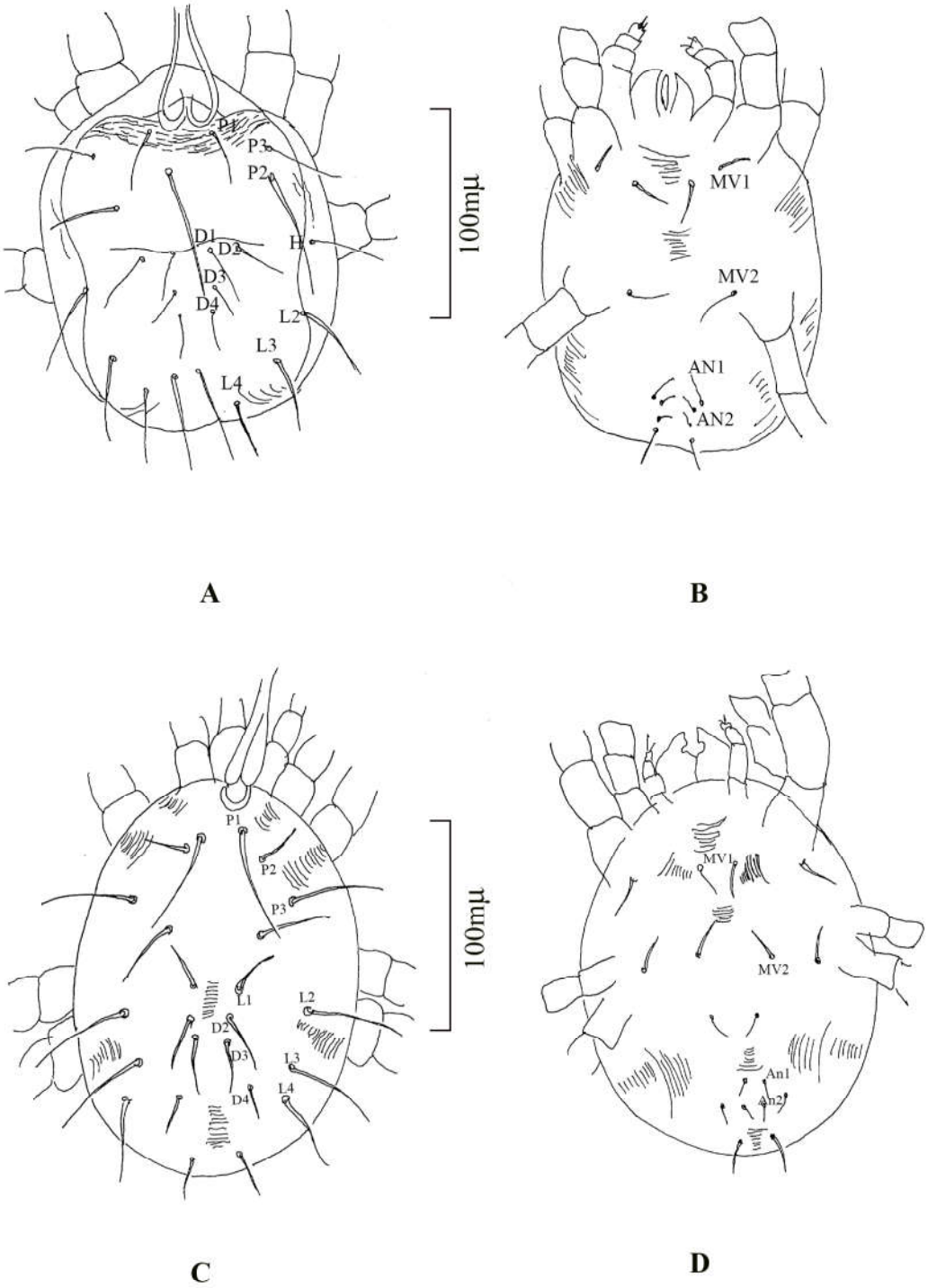


Figure 16. Morphological features of *Tetranychus neocaledonicus*

A. Larva - Dorsal view; **B.** Larva - Ventral view; **C.** Protonymph - Dorsal view; **D.** Protonymph ventral view

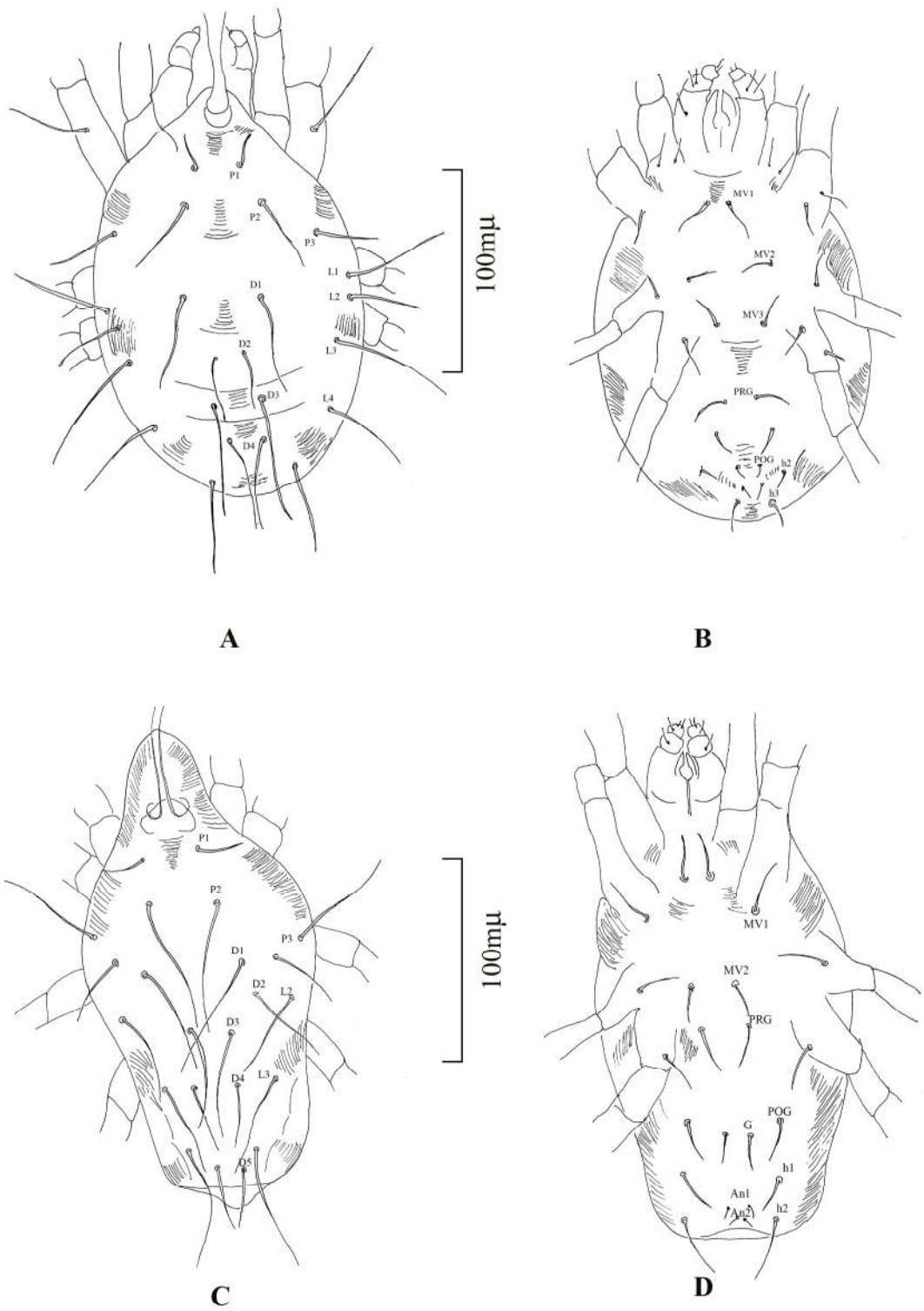


Figure 17. Morphological features of *Tetranychus neocaledonicus*

A. Duetonymph - Dorsal view; **B.** Duetonymph - Ventral view; **C.** Adult female - Dorsal view; **D.** Adult female - ventral view

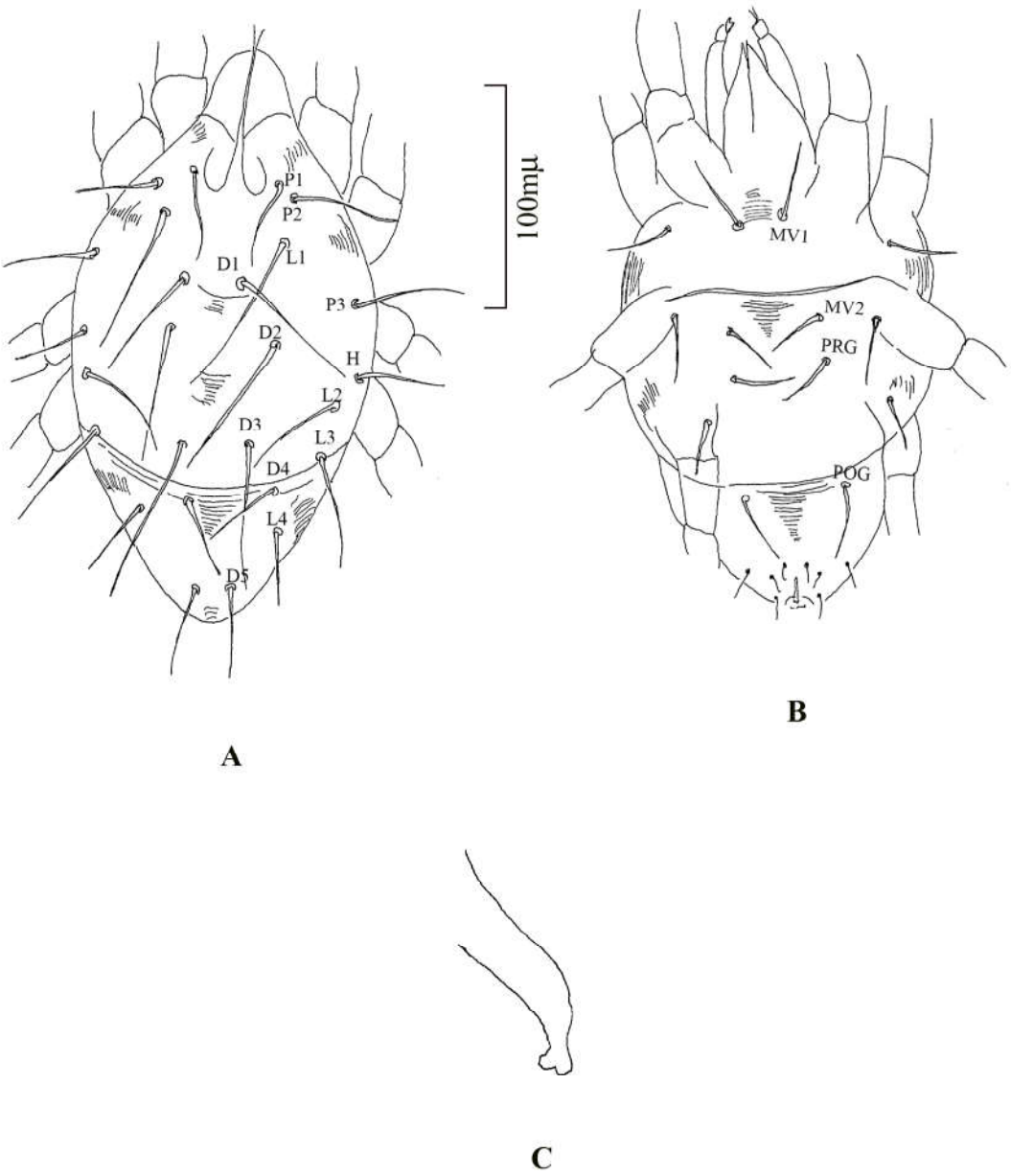


Figure 18. Morphological features of *Tetranychus neocaledonicus*

A. Adult male - Dorsal view; **B.** Adult male - ventral view; **C.** Aedeagus

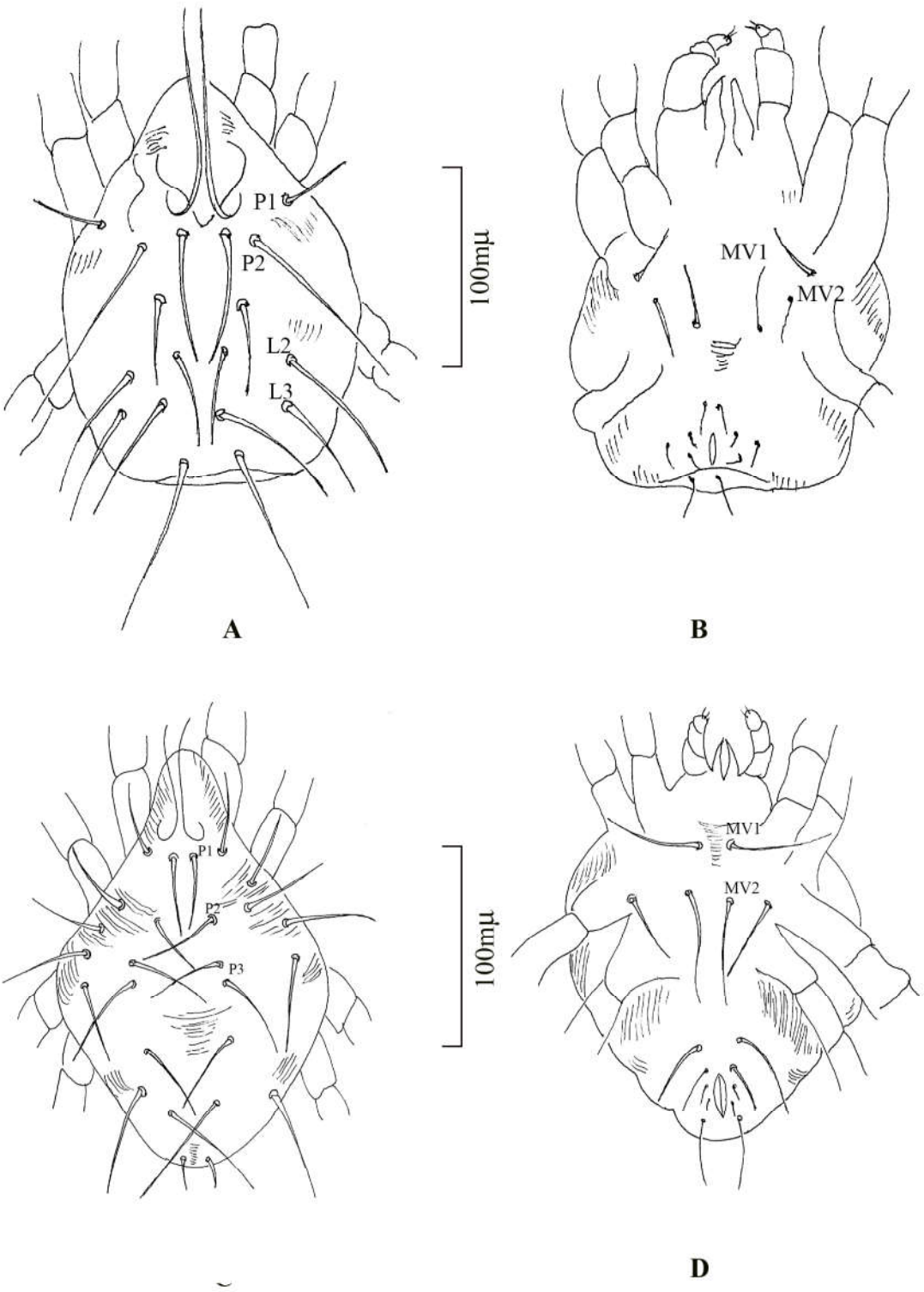


Figure 19. Morphological features of *Oligonychus biharensis*

A. Larva - Dorsal view; **B.** Larva - Ventral view; **C.** Protonymph - Dorsal view; **D.** Protonymph ventral view

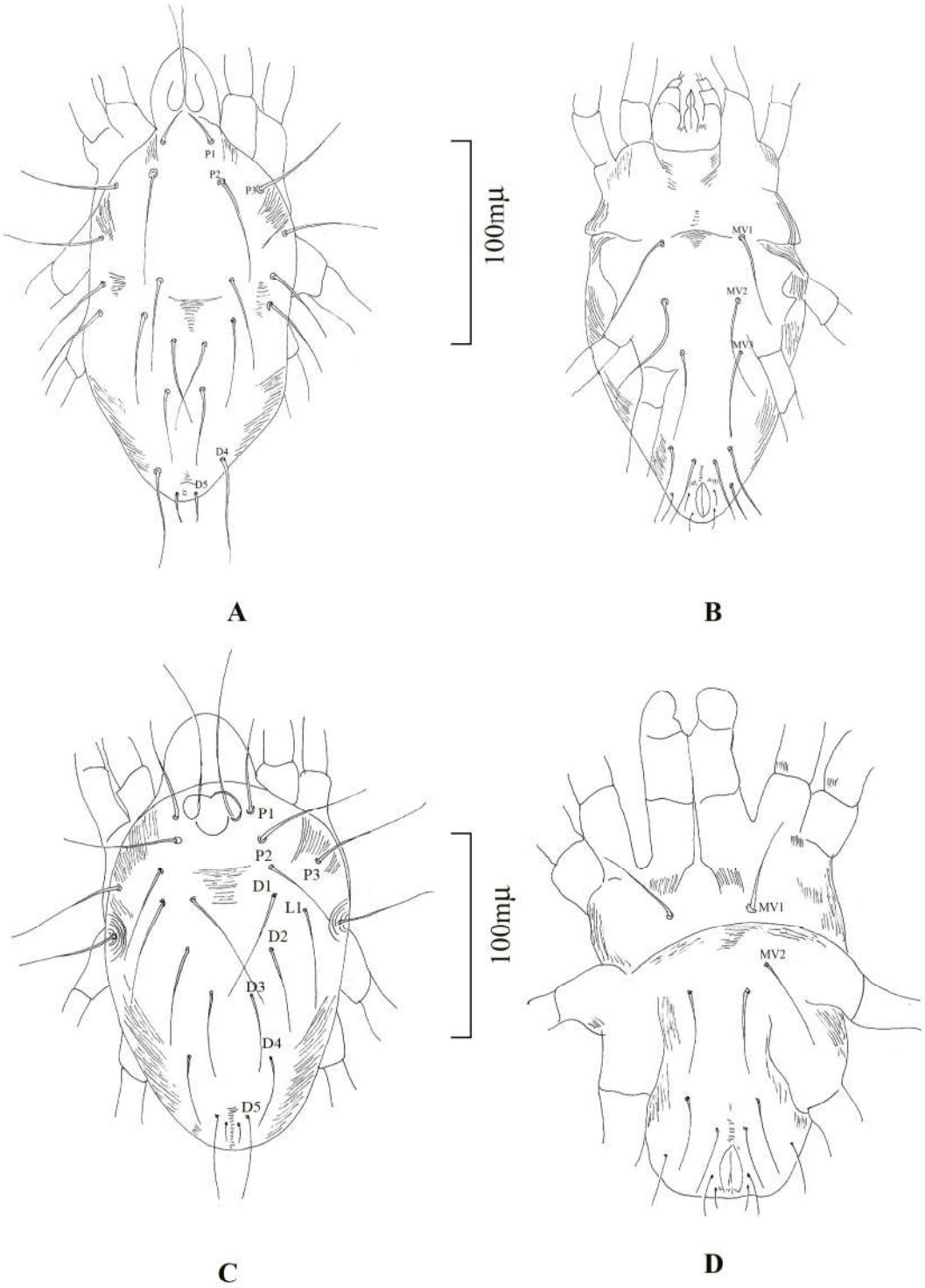


Figure 20. Morphological features of *Oligonychus biharensis*

A. Duetonymph - Dorsal view; **B.** Duetonymph - Ventral view; **C.** Adult female - Dorsal view; **D.** Adult female - ventral view

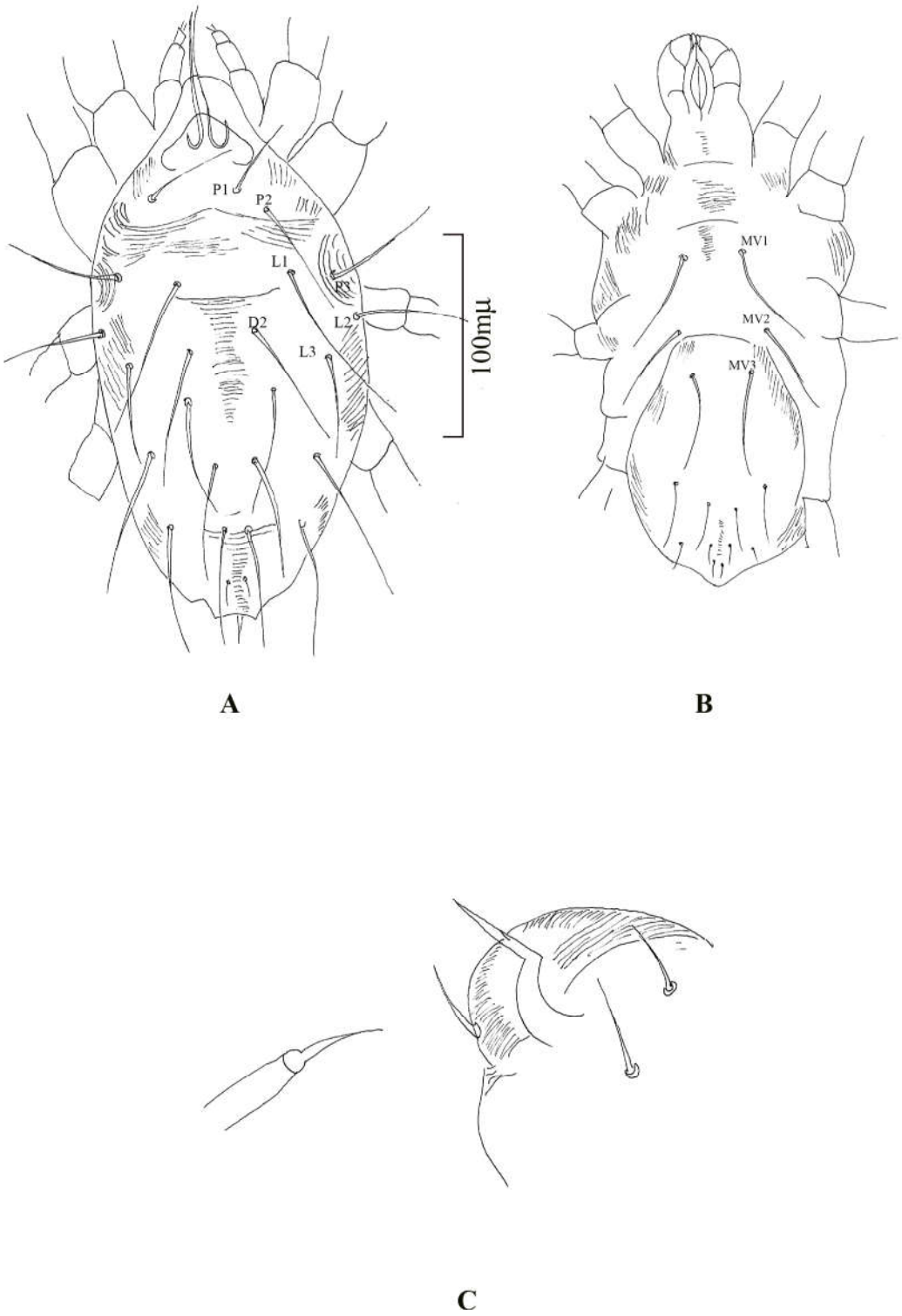


Figure 21. Morphological features of *Oligonychus biharensis*

A. Adult male- Dorsal view; **B.** Adult male - Ventral view; **C.** Aeadaugus of male

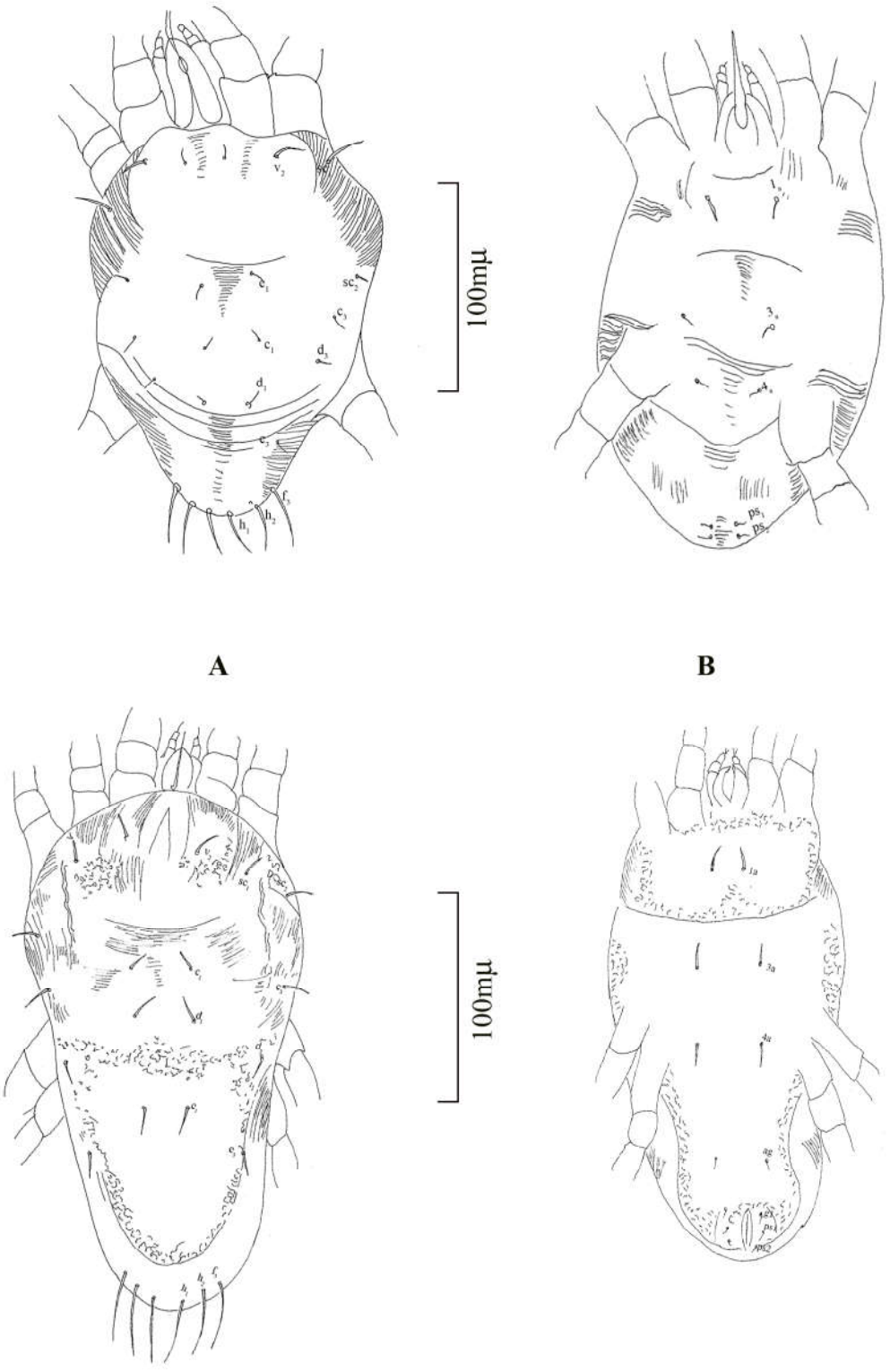


Figure 22. Morphological features of *Brevipalus phoenicis*

A. Larva - Dorsal view; **B.** Larva - Ventral view; **C.** Protonymph - Dorsal view; **D.** Protonymph - Ventral view;

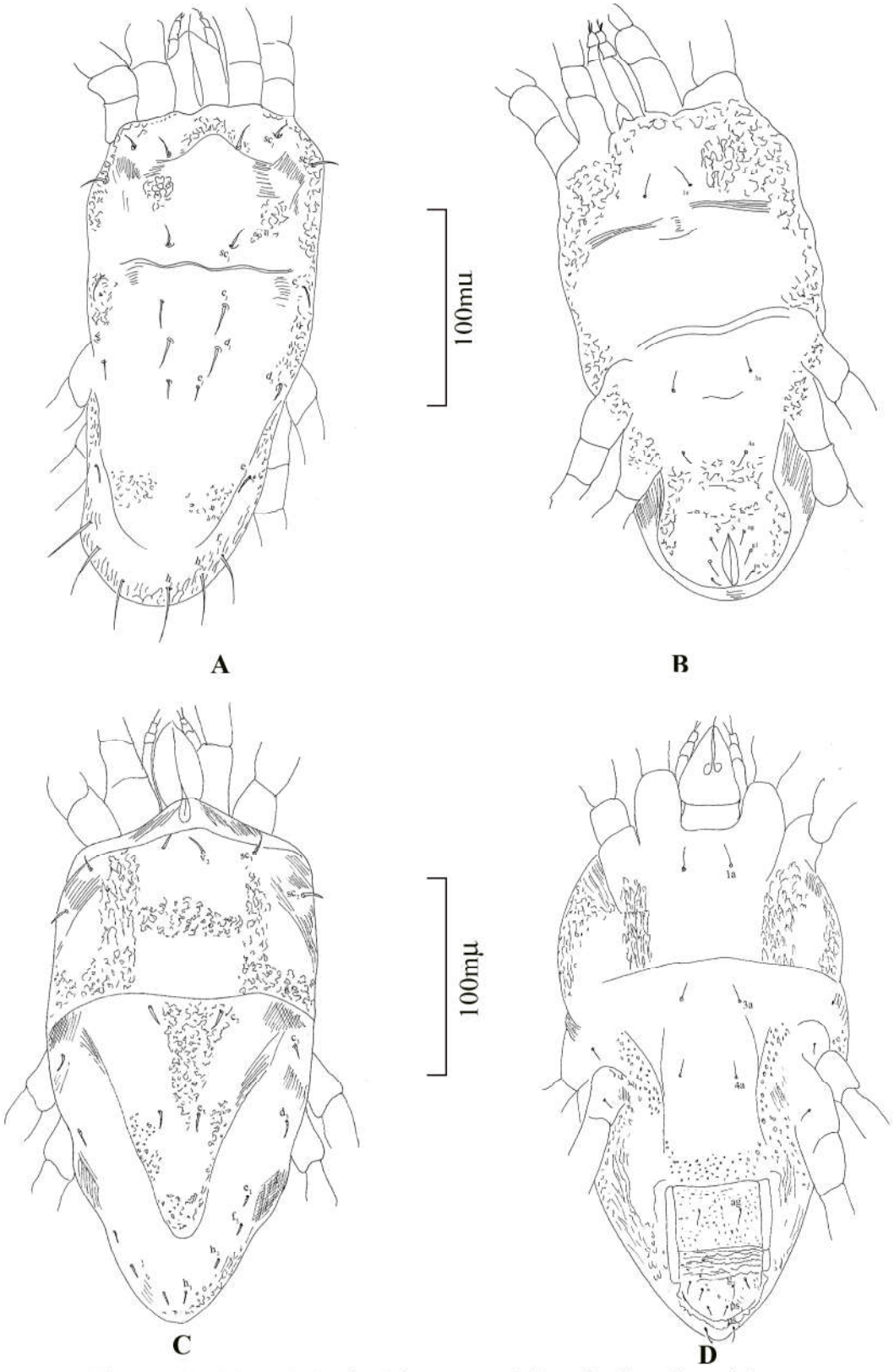


Figure 23. Morphological features of *Brevipalus phoenicis*

A. Duetonymph- Dorsal view; **B.** Duetonymph - Ventral view; **C.** Adult female - Dorsal view; **D.** Adult female - Ventral view

Figure: 1. Most injurious mites of four phytophagous mite families

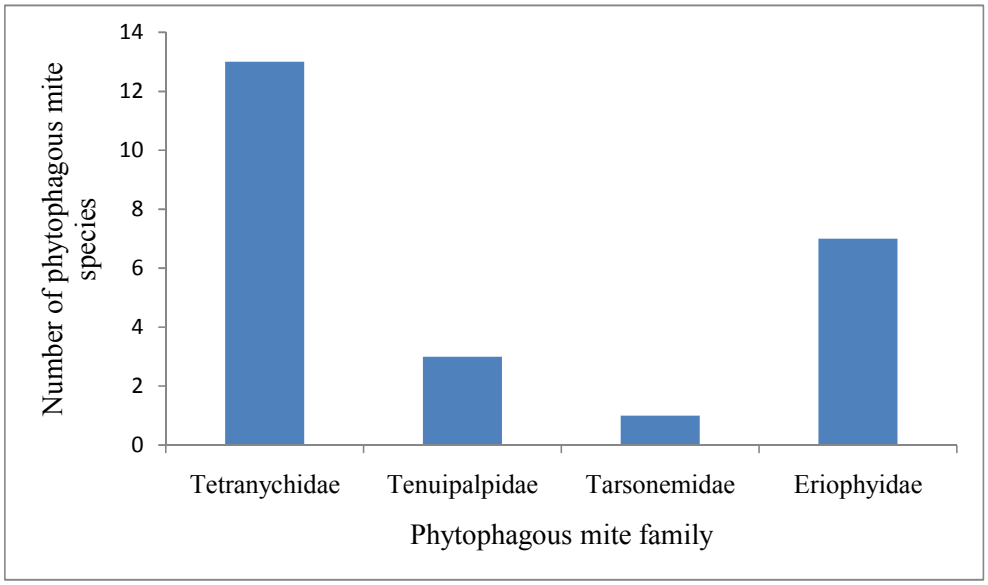


Figure: 2. Number of species of medicinal plants showing the incidence of mites of four phytophagous mite families

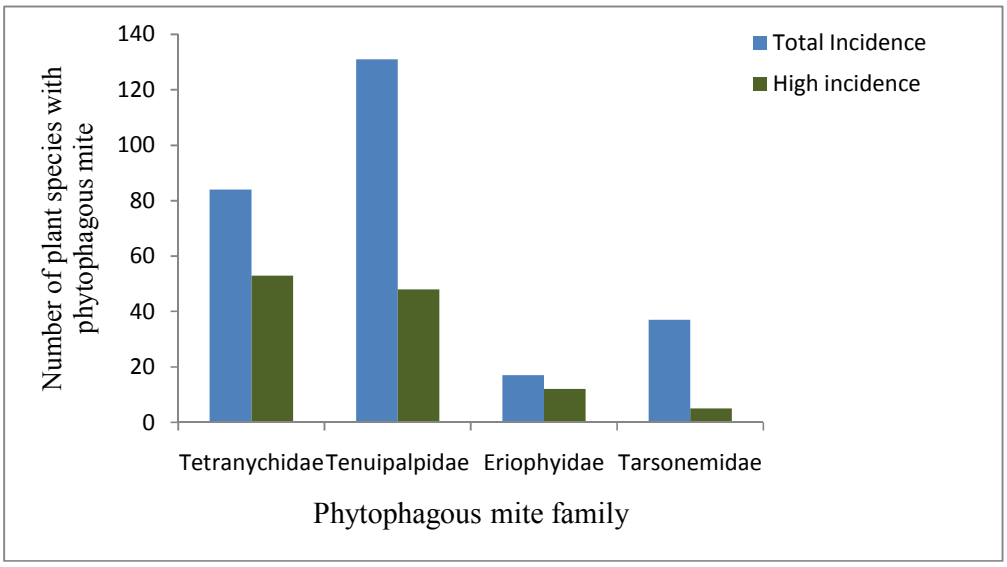


Figure: 3. Percentage of major genera of phytophagous mites recovered during the survey

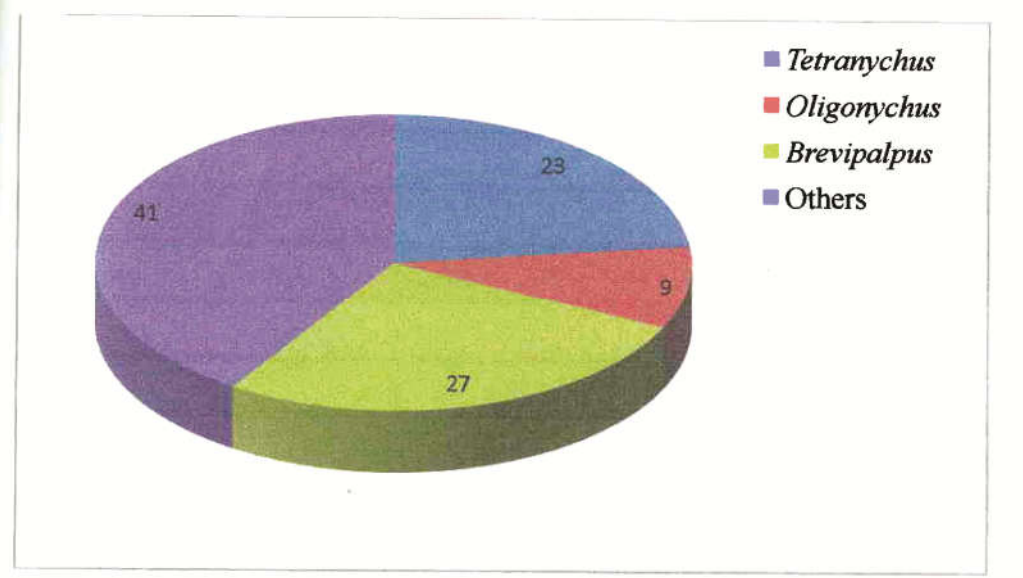


Figure: 4. Percentage variations in the concentrations of major photosynthetic pigments in *Tetranychus neocaledonicus* infested host plants

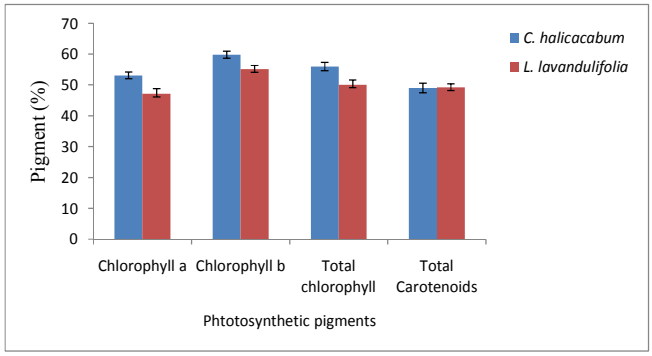


Figure: 5. Percentage variations in the concentrations of major photosynthetic pigments in *Oligonychus biharensis* infested host plants

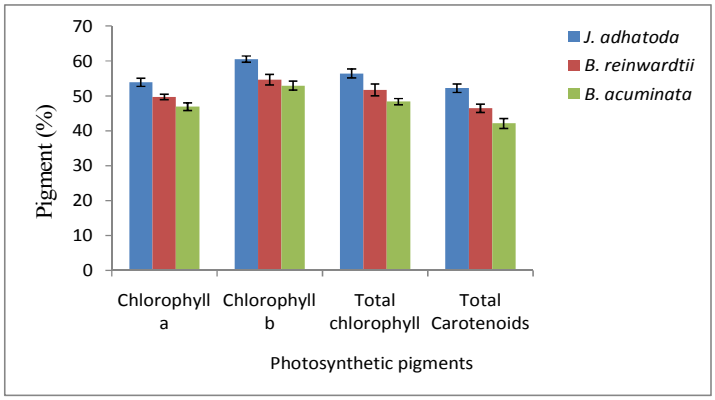


Figure: 6. Percentage variations in the concentrations of major photosynthetic pigments in *Brevipalpus phoenicis* infested host plants

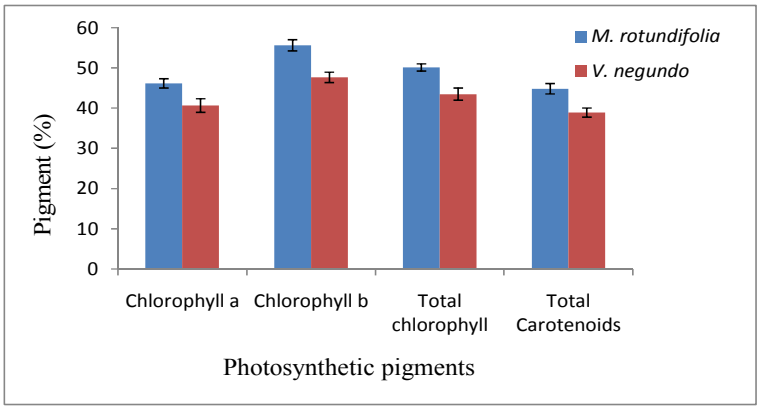


Figure: 7. Variations in Fv/Fm values in *Tetranychus neocaledonicus* infested host plants

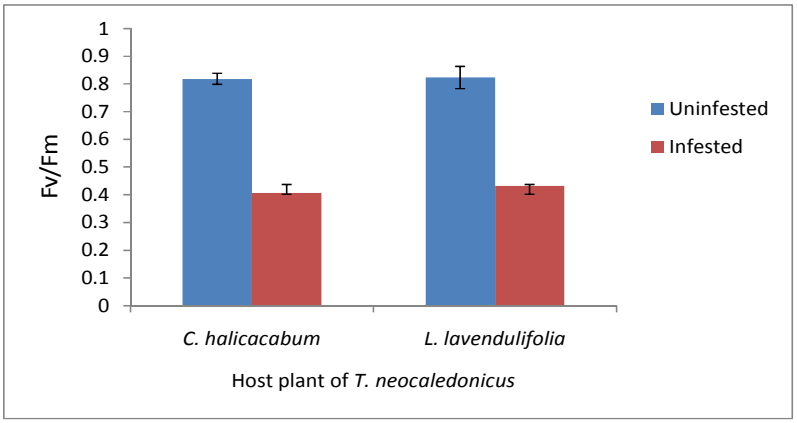


Figure: 8. Variations in Fv/Fm values in *Oligonychus biharensis* infested host plants

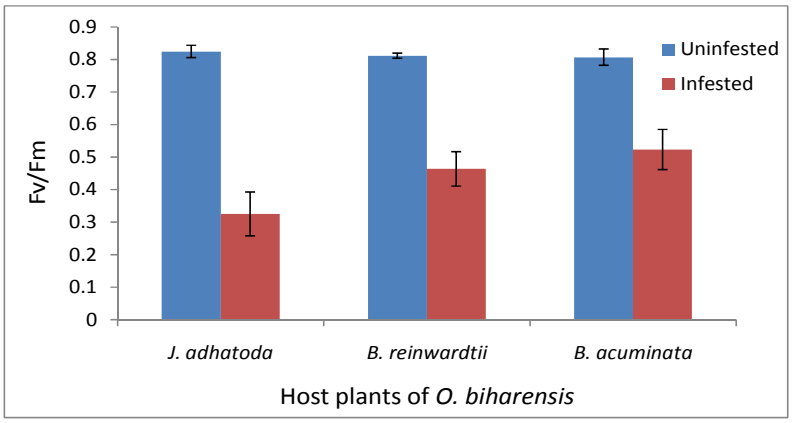


Figure: 9. Variations in Fv/Fm values in *Brevipalpus phoenicis* infested host plants

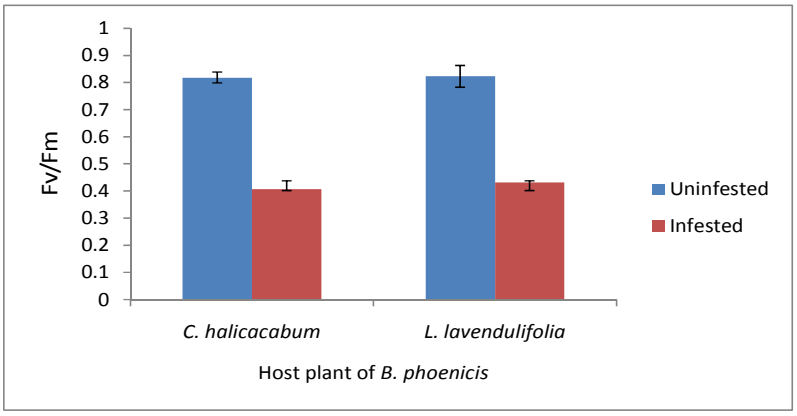


Figure: 10. Variations in the amount of proline (µmol/g fresh weight) in *Tetranychus neocaledonicus* infested host plants

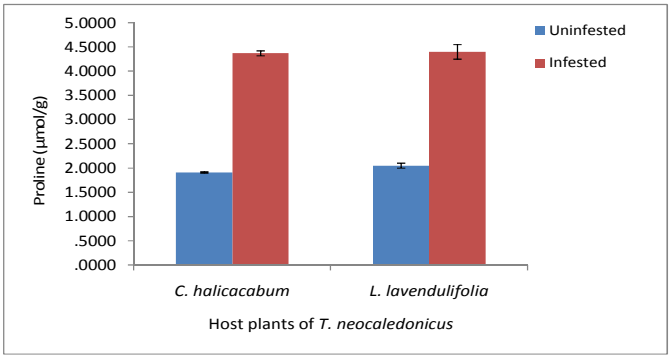


Figure: 11. Variations in the amount of proline (µmol/g fresh weight) in *Oligonychus biharensis* infested host plants

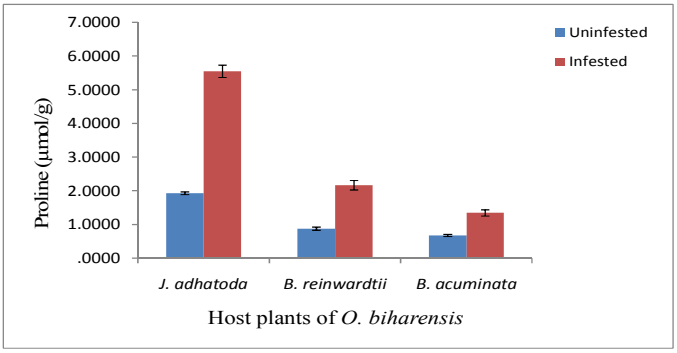


Figure: 12. Variations in the amount of proline (µmol/g fresh weight) in *Brevipalpus phoenicis* infested host plants

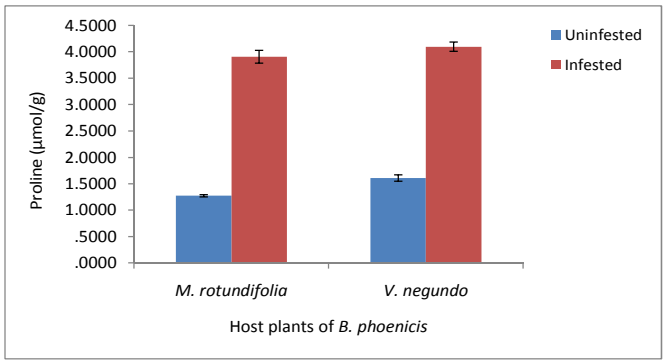


Figure: 13. Variations in the amount of phenol (mg/100g fresh weight) in *Tetranychus neocaledonicus* infested host plants

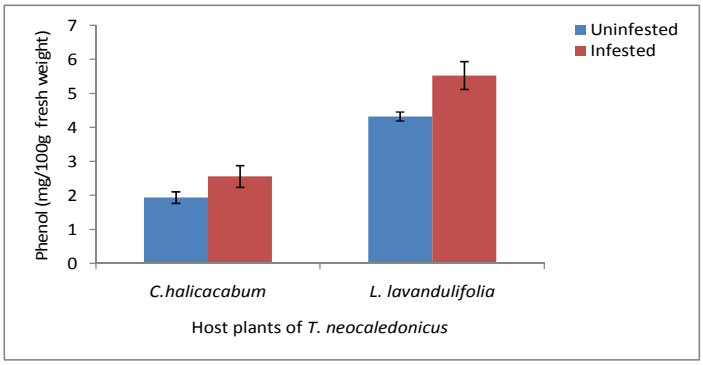


Figure: 14. Variations in the amount of phenol (mg/100g fresh weight) in *Oligonychus biharensis* infested host plants

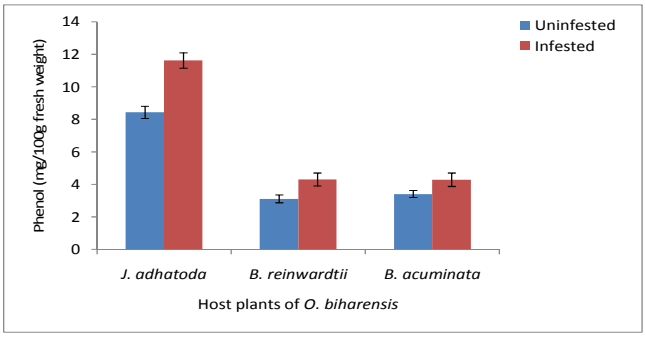


Figure: 15. Variations in the amount of phenol (mg/100g fresh weight) in *Brevipalpus phoenicis* infested host plants

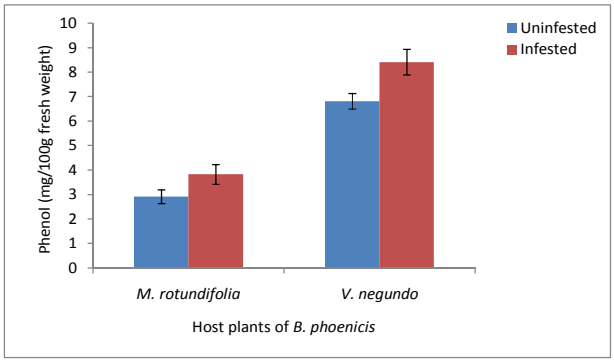


Figure: 24. Percentage mortality of selected species of pest mites at 72 h exposure period by *Glyricidia sepium* leaf extract

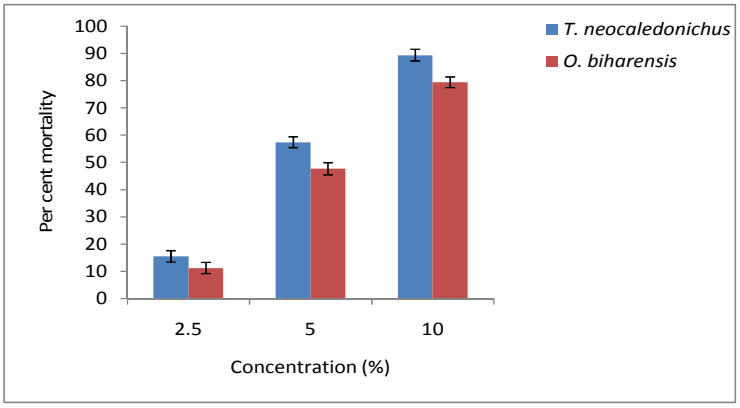


Figure: 25 Percentage mortality of selected species of pest mites at 72 h exposure period by *Chromolaena odorata* leaf extract

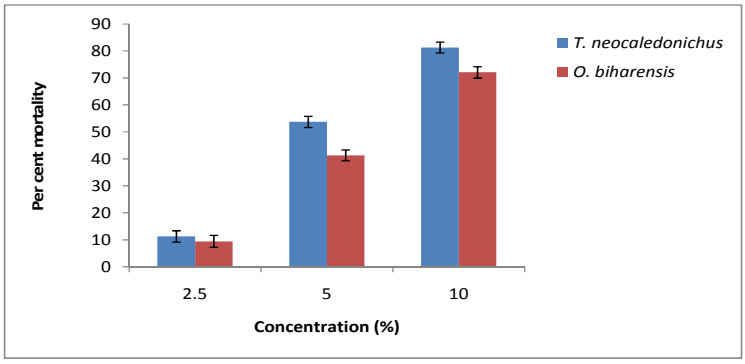


Figure: 26. Percentage mortality of *Tetranychus neocaledonicus* at 24, 48 and 72 hours of exposure period by *Glyricidia sepium* leaf extract

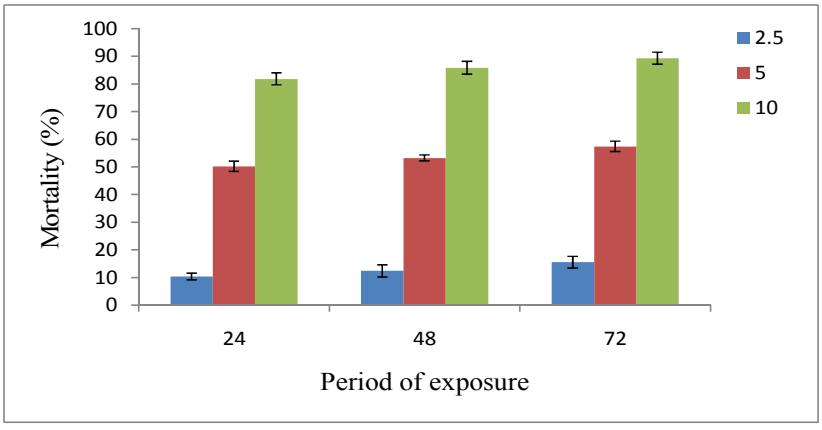


Table.1. Botanical/herbal gardens selected for sampling of mite infested leaves

Sl: No	Name of Botanical / Herbal garden		Latitude and longitude	Name of the District
1	Calicut University Botanical Garden	CUBG	11° 35'-45' N 75° 40'-50' E	Malappuram
2	Kottakal Arya Vaidya Sala Botanical Garden	KAVSBG	10°59'48" N and 76° 0'38" E	Malappuram
3	Parappanangadi Herbal Garden	PHG	11°3'0" N and 75°52'0" E	Malappuram
4	Malabar Botanical Garden	MBG	11°14'24"N and 75° 49'38" E	Calicut
5	Thekumthara (Syam) Herbal Garden	SHG	11.622550° N and 76.081252° E	Wayanad
6	Kerala Forest research Institute	KFRI	10°31'48" N and 76°20'50" E	Thrissur
7	Jawaharlal Nehru Tropical Botanical Garden	JNTBG	8°45'47" N and 77°2'15" E	Trivandrum

Table.2. Sampling localities in various districts of Kerala

Sl:No	Sampling localities		Type of locality	District
1	Kanhangad	KSD-1	Rural and Urban	Kasaragode
	Cheruvathur	KSD-2	Rural & home yards	Kasaragode
2	Edakkad	KAN-1	Rural	Kannur
3	Anjarakandi	KAN-2	Rural & Agricultural fields	Kannur
4	Ambalavayal	WAY-1	Sacred groves & Agricultural fields	Wayanad
5	Meenangadi	WAY-2	Agricultural fields	Wayanad
6	Pookode	WAY-3	Semi forest	Wayanad
7	Feroke	KOZ-1	Rural & Urban	Calicut
8	Ramanattukara	KOZ -2	Sacred groves,Rural & Urban	Calicut
9	Kadalundi	KOZ -3	Rural & Sacred groves	Calicut
10	Nadakkavu	KOZ -4	Urban	Calicut
11	Kunnamangalam	KOZ -5	Rural	Calicut
12	Perambra	KOZ -6	Rural, Homeyards& Sacred groves	Calicut
13	Thenjipalam	MLP-1	Sacred groves, Urban, Rural & Agricultural fields	Malappuram
14	Tirur	MLP-2	Urban & Rural	Malappuram
15	Thavanoor	MLP-3	Rural & Temple	Malappuram
16	Thirunavaya	MLP-4	Rural & Agricultural fields	Malappuram
17	Kanjiramukku	MLP-5	Sacred groves, Rural & Agricultural fields	Malappuram
18	Nilamboor	MLP-6	Semi forest	Malappuram

19	Peringode	PKD-1	Rural & Sacred groves	Palakkad
20	Mannarkad	PKD-2	Rural, homeyards& Semi forest	Palakkad
21	Nelliyampathi	PKD-3	Semi forest	Palakkad
22	Cheruvathani	TCR-1	Rural	Thrissur
23	Mundoor	TCR-2	Rural & Urban	Thrissur
25	Edappally	ERK-1	Rural & Urban	Ernakulam
25	Paravoor	ERK-2	Urban	Ernakulam
26	Elanthur	PAT- 1	Rural	Pathanamthita
27	Parakode	PAT- 2	Rural	Pathanamthita
28	Pattom	TVM-1	Rural & Urban	Trivandrum
29	Perroorkara	TVM-2	Rural	Trivandrum

Table. 3. Pest mites and their host medicinal plants selected for the seasonal abundance and relative distribution study

Sl .No.	Name of the pest	Host plant		Medicinal uses/properties of the host plant	Plant parts used
		Scientific name	Common names		
1	*Tetranychus neocaledonicus* Andre, 1933	*Cardiospermum halicacabum* L.	Balloon vine, heart's pea	Used as analgesic, antimicrobial, antifungal, rubifacient, antipyretic, diuretic, laxative, stomachic, anti-rheumatic and anti-inflammatory.	Whole plant
2	*Oligonychus biharensis* (Hirst), 1925	*Justicia adhatoda* L.	Vasaka, Adhatoda	Used for treating bronchitis, asthma, dental aiments, peptic ulcer, piles, menorhaggia, tumor, heart disorders, muscular spasm and cramps.	Leaves, flowers and bark
3	*Brevipalpus phoenicis* (Geijskes), 1939	*Vitex negundo* Linn.	Chast tree, Negundo	Used as anti-convulsant, astringent, antibacterial, antitumor, anthelmintic, anti-inflammatory, anti-rheumatic, anti-pyretic, antiallergic, febrifuge, hepatoprotective and sedative.	Leaves, roots, flowers and seeds

Table.4. Incidence of various groups of phytophagous mites on selected medicinal plants of Kerala

Sl:No:	Name of the plant species		Family of the plant species	Incidence and intensity of occurrence of the members of major phytophagous mite families on their host plants			
	Scientific Name	Common Name and (type of habit)		Tetranychidae	Tenuipalpidae	Eriophyidae	Tarsonemidae
1.	*Abelmoschus esculentus*	Okra- (S)	Malvaceae	+ + +	+	-	+
2.	*A. moschatus*	Musk mellow- (S)	Malvaceae	+ + +	+	-	-
3.	*Abrus precatorius*	Bead Vine - (C)	Fabaceae	+ + +	+ +	-	-
4.	*Acalypha indica*	Indian acalypha- (H)	Euphorbiaceae	+ + +	+ +	-	+
5.	*Adenanthera pavonina*	Red bead plant- (C)	Fabaceae	+ +	+ +	-	-
6.	*Aegle marmelos* (Linn)	Bengal quince- (S)	Rutaceae	+	+ + +	+	+ +
7.	*Aerva lanata*	Polpala- (H)	Amaranthaceae	+ + +	+ +	-	-
8.	*Ageratum conyzoides* Linn	Appa grass- (H)	Asteraceae	+ + +	+ +	-	+
9.	*Albizzia lebbeck*	Lebbek tree- (T)	Fabaceae	+ + +	-	-	-
10.	*Aloe vera*	Indian aloe-(H)	Liliaceae	-	+ +	-	-
11.	*Alangium salvifolium*	Ankola -(S)	Cornaceae	-	+ +	+ + +	-
12.	*Alstonia scholaris*	Devil tree- (T)	Apocynaceae	+ + +	+	-	-
13.	*Andrographis paniculata*	Green chiretta- (H)	Acanthaceae	-	+ + +	-	+ +
14.	*Annona squamosa* Linn	Sugar apple- (T)	Annonaceae	+ + +	+ + +	-	-
15.	*Artemisia nilagirica*	Flea bane-(S)	Asteraceae	-	+ + +	-	+ +
16.	*Aristolochia bracteolate* Lam	Worm killer- (H)	Aristolochiaceae	+ + +	+ +	-	-
17.	*Artabotrys zeylanicus*	Ceylon Green Champa- (C)	Annonaceae	-	+ +	-	-
18.	*Artocarpus hirsutus*	Wild Jack- (T)	Moraceae	+ + +	-	-	-

19.	*Azadiracta indica*	Neem- (T)	Meliaceae	+ +	+ +	-	-
20.	*Bacopa monnieri*	Bacopa- (H)	Scrophulariaceae	-	++	-	+ +
21.	*Bambusa arundinacea*	Bamboo- (S)	Poaceae	+ + +	-	-	-
22.	*Bauhinia accuminata* L.	White bauhinia- (S)	Fabaceae	+ + +	+ +	-	-
23.	*B. variegata*	Variegated bauhinia- (T)	Fabaceae	+ + +	+ + +	-	-
24.	*Biophytum reinwardtii*	Reinwardt's tree plant - (H)	Oxalidaceae	+ + +	+	-	-
25.	*Boerhaavia diffusa* Linn	Hogweed- (H)	Asclepiadaceae	-	+ + +	-	+ +
26.	*Cardiospermum halicacabum*	Balloon vine - (H)	Sapindaceae	+ + +	+ +	-	+ +
27.	*Carica papya*	Papaya - (S)	Caricaceae	+ + +	+ +	-	-
28.	*Cassia fistula* Linn	Indian laburnum - (T)	Fabaceae	+ + +	+	-	-
29.	*Catharanthus roseus*	Vinca - (H)	Apocynaceae	-	+ + +	-	-
30.	*Centella asiatica*	Gotu kola- (H)	Apiaceae	-	+ +	-	-
31.	*Cerbera odollum*	Sea mango - (T)	Apocynaceae	-	+ +	-	-
32.	*Ceriscoides turgida*	Mountain gardenia - (T)	Rubiaceae	-	-	+ + +	-
33.	*Chromolena odorata*	Siam weed - (S)	Asteraceae	+	+ +	+ + +	-
34.	*Cinnamomum verum* Presl	Cinnamon - (T)	Luraceae	-	-	+ + +	-
35.	*Clerodendrum infortunatum*	Hill glory bower - (S)	Verbenaceae	+	+ +	-	-
36.	*C. paniculatum*	Clerodendron -(S)	Verbenaceae	-	+ +	+	-
37.	*C. inerme* (L.)	Embrert - (S)	Verbenaceae	-	-	+ + +	-
38.	*Clitoria ternatea* Linn	Butterfly pea - (C)	Fabaceae	+ + +	+	-	-
39.	*Citrus limon*	Lemon - (T)	Rutaceae	+ + +	+ +	-	-

40.	*C. medica*	Wild lemon-(S)	Rutaceae	+ + +	+	-	-
41.	*Coffea arbica* Linn	Coffee - (S)	Rubiaceae	+ + +	+ +	-	-
42.	*Coscinium fenestratum* (Gaertn)	Turmeric - (C)	Menispermaceae	-	+ + +	-	-
43.	*Crataeva magna* (Lour)	Garlic pear tree - (T)	Capparaceae	-	+ +	-	+ +
44.	*Crotalaria retusa* Linn	Rattleweed - (H)	Fabaceae	+ + +	+ +	-	-
45.	*Curcuma aromatica*	Wild turmeric - (H)	Zingiberaceae	+ +	+ + +	-	-
46.	*C. longa*	Turmeric - (H)	Zingiberaceae	-	+ + +	-	-
47.	*Cyathula prostrata* (Linn)	Small pricky chaff flower- (H)	Amaranthaceae	+ + +	+ +	-	+
48.	*Cyclea peltata*	Raj patha - (C)	Menispermaceae	-	+ +	-	-
49.	*Cymbopogon citratus*	Lemon grass - (H)	Poaceae	+ +	+	-	-
50.	*Dalbergia lanceolaria* ssp. Paniculata	Takoli - (T)	Fabaceae	-	+ +	-	-
51.	*Datura metel* Linn	Devils weed - (S)	Solanaceae	+ + +	+ + +	-	+ +
52.	*Desmodium gangeticum*	Salwan - (H)	Fabaceae	+ + +	-	-	-
53.	*D. motorium*	Indian telegraphic plant - (S)	Fabaceae	+ + +	-	-	-
54.	*Demostachya bipinnata* (Linn)	Sacrificial grass - (H)	Poaceae	-	+ +	-	-
55.	*Eclipta alba*	False daisy - (H)	Asteraceae	+ +	+ +	-	+
56.	*Ecobolium viride*	Green Ice Crossandra - (S)	Acanthaceae	-	+ +	+ + +	-
57.	*Elaecarpus recurvatus*	Nilgiri Rudraksh - (T)	Elaecarpaceae	-	+ +	-	-
58.	*Emilia sonchifolia*	Red tasselflower - (H)	Asteraceae	+ +	+	-	+

59.	*Eucalyptus globulus* Labill	Southern blue-gum - (T)	Myrtaceae	-	+ + +	-	-
60.	*Evolvulus alsinoides* Linn	Dwarf morning glory - (H)	Convolvulaceae	+	+ +	-	-
61.	*Ficus bengalansis* Linn	Benyan tree - (T)	Moraceae	-	+ + +	-	-
62.	*F. racemosa*	Cluster fig - (T)	Moraceae	+ + +	-	-	-
63.	*F. religiosa*	Sacred fig - (T)	Moraceae	+ + +	+	-	-
64.	*Gloriosa superba*	Glory lily - (C)	Liliaceae	+ +	+ +	-	-
65.	*Gliricidia sepium* (Jacq.)	Quickstick - (S)	Fabaceae	+ + +	+	-	-
66.	*Gymnema sylvestre*	Small Indian Ipecae - (C)	Asclepiadaceae	+ + +	-	+	-
67.	*Helianthus annus* Linn	Sunflower - (S)	Asteraceae	+ +	+ + +	-	+
68.	*Helicteres isora* Linn	East Indian screw tree - (S)	Sterculiaceae	+ + +	+ +	-	-
69.	*Hemidesmus indicus* (Linn)	False sarsaparilla - (C)	Periplocaceae	-	+ +	-	-
70.	*Hibiscus aculeatus*	Comfort root - (S)	Malvaceae	+ + +	+ + +	-	+
71.	*H. rosa-sinensis*	Chinese rose - (S)	Malvaceae	-	+ + +	-	+
72.	*H. vitifolius*	Grape Leaved Mallow - (S)	Malvaceae	-	-	+ + +	-
73.	*Impatiens balsamina*	Jewel weed - (H)	Balsaminaceae	+ +	+ + +	-	+
74.	*Indigofera tinctoria* Linn	Bengal indigo - (S)	Fabaceae	+ + +	+	-	+ +
75.	*Inula racemosa*	Pushkarmoola - (H)	Asteraceae	+ + +	+	-	-
76.	*Ipomoea mauritiana Jacq*	Giant potato - (C)	Convolvulaceae	-	-	+ + +	-
77.	*Ixora coccinia*	Needle flower - (S)	Rubiaceae	-	+	+ + +	-
78.	*Justicia adhatoda* L.	Vasaka - (S)	Acanthaceae	+ + +	+ +	-	-

79.	*J. gendarussa*	Dauna Rusa (S)	Acanthaceae	++	+	-	-
80.	*Lantana camara*	Wild sage - (S)	Verbenaceae	++	+ +	+ + +	-
81.	*Lawsonia inermis* Linn	Henna - (S)	Lythraceae	-	+ + +	-	-
82.	*Leucas aspera*	Thumba - (H)	Lamiaceae	+ +	+ +	-	-
83.	*L. lavendulifolia*	Thumba - (H)	Lamiaceae	+ + +	+	-	+ +
84.	*Lycopersicon esculentum*	Tomato - (H)	Solanaceae	+ + +	+ +	-	+ +
85.	*Malus sylvestris*	Apple- (T)	Rosaceae	+ + +	+	-	-
86.	*Mentha rotundifolia* L.	Mint - (H)	Lamiaceae	-	+ + +	-	-
87.	*Mitragyna parvifolia* (Roxb.)	Kadamb - (T)	Rubiaceae	+ + +	+ + +	-	-
88.	*Moringa oliefera* Lam	Drumstick tree - (S)	Moringaceae	+ + +	+	-	-
89.	*Mussaenda frondosa* Linn	Schizomussaenda - (S)	Rubiaceae	+ + +	+ +	-	-
90.	*Nageia wallichiana*	Nageia - (T)	Podocarpaceae	-	+ + +	-	-
91.	*Ocimum sanctum* Linn	Sacred basi - (H)	Lamiaceae	-	+ + +	-	-
92.	*O. gratissimum*	Lemon basil - (H)	Lamiaceae	-	+ + +	-	-
93.	*Operculina turpethum* (Linn)	Indian jalap - (H)	Convolvulaceae	+ +	+ +	-	-
94.	*Oxails corniculata* L.	Creeping oxalis - (H)	Oxalidaceae	+ ++	+	-	-
95.	*Phyllanthus amarus*	Phyllanthus - (H)	Euphorbiaceae	+ +	+ + +	-	-
96.	*P. emblica*	Indian gooseberry - (T)	Euphorbiaceae	-	+ +	-	-
97.	*P. reticulatus*	Black honey shrub - (T)	Euphorbiaceae	+ ++	-	-	-

98.	*Piper longum*	Long pepper - (S)	Piperaceae	+ + +	-	-	+
99.	*P. nigrum*	Black pepper - (C)	Piperaceae	+ +	+ +	-	-
100.	*Plectranthus amboinicus* (Lour.) Spreng	Indian borage - (H)	Lamiaceae	-	+ + +	-	+ +
101.	*Plumbago indica* Linn	Fire plant - (S)	Plumbaginaceae	+ + +	+ + +	-	-
102.	*Pongamia pinnata* (Linn.)	Hongay oil tree - (T)	Fabaceae	-	-	+ + +	-
103.	*Premna corymbosa* Rottl	Bastard Guelder - (S)	Verbenaceae	+ +	++	-	-
104.	*Pseudarthria viscida* (Linn)	Salaparni - (S)	Fabaceae	+ + +	+	-	-
105.	*Psidium guajava* Linn	Guava - (T)	Myrtaceae	-	+ + +	-	-
106.	*Rauvolfia serpentina* (Linn.)	Sarpagandha - (S)	Apocynaceae	-	+ + +	-	-
107.	*Ricinus communis* Linn	Castor - (S)	Euphorbiaceae	+ + +	+ + +	-	-
108.	*Rosa centifolia* Linn	Provence rose - (S)	Rosaceae	+ + +	+ +	-	+
109.	*R. indica*	Rose- (S)	Rosaceae	+ + +	+	-	-
110.	*Salacia reticulata* Wight	Saptarangi - (S)	Hippocrateaceae	-	+ + +	-	+ +
111.	*Santalum album* Linn	Sandal tree - (T)	Sanatalaceae	-	+ + +	-	-
112.	*Saraca asoca*	Asoka tree - (T)	Fabaceae	-	+ + +	-	-
113.	*Scoparia dulcis*	Sweet broomweed - (H)	Scrophulariaceae	+ + +	+ +	-	+
114.	*Sesamum indicum* Linn	Sesame - (S)	Pedaliaceae	+ +	+ + +	-	-
115.	*Sida rhombifolia* Linn	Broomjute sida - (H)	Malvaceae	+ + +	+ + +	-	-
116.	*Solanum nigrum* Linn	Black nightshade - (H)	Solanaceae	+ + +	+	-	+ +
117.	*Strychnos nux-vomica* Linn	Poison nut - (T)	Loganiaceae	+ + +	+ + +	-	-
118.	*Tabernaemontana divaricata* (Linn.)	East India rosebay - (S)	Apocynaceae	-	+ + +	-	+ +

119.	*Terminalia arjuna*	White murdah - (T)	Combretaceae	-	+ +	-	-
120.	*T. bellirica*	Bedda nut tree - (T)	Combretaceae	+	+ +	-	+
121.	*T. chebula*	Gall nut - (T)	Combretaceae	-	+ + +	-	-
122.	*Thea sinensis*	Tea plant - (S)	Theaceae	+ + +	+ + +	+ + +	-
123.	*Thottea siliquosa*	Chakrani - (S)	Aristolochiaceae	+ + +	-	-	-
124.	*Tinospora cordifolia*	Moon creeper - (C)	Menispermaceae	-	+ +	-	+
125.	*Tragia involucrate*	Indian stinging nettle - (H)	Euphorbiaceae	-	+ +	-	-
126.	*Trichopus zeylanicus*	Healthy green - (H)	Trichopodaceae	-	+ +	-	-
127.	*Utricularia reticulate*	Net veined bladderwort - (S)	Lentibulariaceae	+ +	+ +	-	+
128.	*Vernonia cinerea (*Linn.)	Dandotapala - (H)	Asteraceae	+ +	+ + +	-	+ + +
129.	*Vitex negundo*	Chaste tree - (S)	Verbenaceae	-	+ + +	+ +	-
130.	*V. trifolia*	Arabian Lilac - (S)	Verbenaceae	-	+ + +	-	-
131.	*Vitis vinifera* Linn	Grape vine- (C)	Vittaceae	+ + +	+ +	-	-
132.	*Withania somnifera* (Linn.)	Winter cherry - (S)	Solanaceae	+ + +	+	-	-
133.	*Woodfordia fruticosa* (Linn.) Kurz	Fire flame bush - (S)	Lythraceae	-	+ + +	-	-
134.	*Wrightania tinctoria*	Pala indigo - (T)	Apocynaceae	+	+ +	-	-
135.	*Zingiber officinale* Rosc	Ginger - (H)	Zingiberaceae	+ +	+ + +	-	-
136.	*Ziziphus oenoplia* (Linn.) Mill	Jackal jujube - (C)	Rhamanaceae	-	+ + +	-	+

(+ + +) = High, (+ +) = Moderate, (+) = Low, (-) = Absent; (C) = Climber, (H) = Herb, (S) = Shrub, (T) = Tree

Table. 5. Species of phtophagous mites infesting on medicinal plants surveyed

Sl. No.	Phytophagous Mite		Species of plants showing mite infestation	Major Host plants of the mite species
	Name of the species	Family		
1.	*Tetranychus neocaledonicus* Andre, 1933	Tetranychidae	*Cardiospermum halicacabum*, *Leucas lavendulifolia**, *Abrus precatorius*, *Acalypha indica**, *Moringa oliefera*, *Crotalaria retusa*, *Gloriosa superba**, *Helianthus annus*, *Mussaenda frondosa**, *Phyllanthus amarus*, *Ricinus communis*, *Scoparia dulcis**, *Desmodium gangeticum**, *Sesamum indicum*, *Adenanthera pavonina**, *Sida rhombifolia*, *Indigofera tinctoria*, *Cassia fistula*, *Dalbergia lanceolaria** & *Thottea siliquosa*	*C. halicacabum*, *L. lavendulifolia*, *A. precatorius*, *A. indica*, *C. retusa*, *M. oliefera*, *A. pavonina*, *C. fistula*, *I. tinctoria* & *R. communis*
2.	*T. cinnabarinus* (Biosduval), 1867	Tetranychidae	*Justicia adhatoda*, *R. communis*, *Datura metel*, *C. halicacabum**, *H. annus*, *Adenanthera pavonina**, *Biophytum reinwardtii**, *Boerhaavia diffusa*, *Emilia sonchifolia**, *Clerodendron infortunatum*, *Mentha rotundifolia*, *Clitoria ternatea*, *M. frondosa*, *A. indica*, *Aerva lanata*, *Strychnos nux-vomica*, *Vernonia cinera*, *Pseudarthria viscida**, *S. rhombifolia*, *Rosa centifolia*, *D. motorium** & *Withania somnifera*	*J. adhatoda*, *D. metel*, *C. halicacabum*, *M. rotundifolia*, *M. frondosa*, *A. indica*, *C. ternatea*, *P. viscida* & *S. rhombifolia*
3.	*T. ludeni* Zacher, 1913	Tetranychidae	*D. metel*, *Tinospora cordifolia*, *Utricularia reticulata*, *Abelmoschus esculentus*, *Citrus lemon*, *M. oliefera*, *Hibiscus aculeatus*, *Trichopus zeylanicus*, *Sida rhombifolia*, *Oxails corniculata* & *C. ternatea*	*H. aculeatus*, *A. esculentus* & *D. metel*
4.	*T. macfarlanei* Baker & Pritchard, 1960	Tetranychidae	*S. indicum*, *S. trilobatum* & *A. esculentus*	*S. indicum*, *Solanum nigrum* & *A. esculentus*
5.	*T. fijiensis* Hirst, 1924	Tetranychidae	*Inula racemosa*, *Carica papya*, *H. annus*, *Eclipta alba*, *F. religiosa* & *Thottea siliquosa*	*I. racemosa*, C. *papya* & *H. annus*

6.	*Oligonychus biharensis* (Hirst), 1925	Tetranychidae	*J. adhatoda**, *B. reinwardtii**, *Bauhinia acuminata**, *A. pavonina*, *Rosa indica*, *R. centifolia*, *S. dulcis*, *Annona squamosa*, *Desmodium gangeticum*, *D. motorium**, *Ecobolium viride*, *C. ternatea*, *C. retusa*, *Psidium guajava*, *Tinospora cordifolia*, *Cyathula prostrata* & *Operculina turpethum*	*J. adhatoda*, *B. reinwardtii*, *B. acuminata* & *D. motorium*
7.	*O. coffeae* (Nietner), 1861	Tetranychidae	*Malus sylvestris*, *D. gangeticum*, *Thea sinensis*, *Coffea Arabica* & *R. indica*	*C. arabica*, *M. sylvestris*, *T. sinensis* & *R. indica*
8.	*O. indicus* (Hirst), 1923	Tetranychidae	*Artocarpus hirsutus**, *Citharexylum spinosa* & *Demostachya bipinnata**	*A. hirsutus*
9.	*O. mangiferus* (Rahman & Sapra), 1940	Tetranychidae	*Vitis vinifera*, *P. guajava*, *Cassia fistula* & *A. squamosa*	*V. vinifera* & *A. squamosa*
10.	*Eutetranychus orientalis* (Klien),1936	Tetranychidae	*Azadiracta indica*, *C. papya*, *Aegle marmelos*, *B. variegata*, *Wrightania tinctoria*, *M. frondosa** , *Plumbago indica*, *R. communis* & *C. fistula*	*A. indica*, *C. papya* & *M. frondosa*
11.	*E. banksi* (McGregor)	Tetranychidae	*Ziziphus oenoplia*, *Artocarpus hirsutus* & *P. reticulatus*	*P. reticulatus*
12.	*Eotetranychus* sp.	Tetranychidae	*C. halicacabum**, *R. communis* & *J. adhatoda**	*R. communis*
13.	*Panonychus citri* (McGregor),1916	Tetranychidae	*Citrus lemon* & *Mitragyna parvifolia** & *Carica papya*	*C. papya*, *C. lemon*, & *M. parvifolia*
14.	*P. ulmi* (Koch), 1836	Tetranychidae	*M. sylvestris*, *B. acuminata** & *B. variegata*	*M. sylvestris*
15.	*Brevipalpus phoenicis* (Geijskes), 1939	Tenuipalpidae	*Premna corymbosa**, *Vitex negundo*, *Lawsonia inermis**, *V. trifolia**, *A. lanata J. adhatoda*, *M. rotundifolia* C. halicacabum**, *R. communis*, *Tragia involucrata*, *H. rosa-sinensis*, *L. lavendulifolia**, *A. precatorius**, *Rauvolfia serpentina**, *A. indica*, *V. cinera**, *Aegle marmelos*, *Aloe vera*, *Andrographis paniculata**, *Alangium salvifolium*, *S. trilobatum*, *Piper longum*, *Ipomea mauritiana*, *V. vinifera*, *Zingiber officinale*, *P. guajava*, *W. somnifera** & *B. acuminata*	*V. negundo*, *L. inermis*, *V. trifolia* & *P. guajava*

16.	*B. obovatus* Donnadieu, 1875	Tenuipalpidae	*Ocimum sanctum*, *I. mauritiana*, *Plumbago indica*, *Plectanthus amboinicus*, *R. serpentina*, *Artemisia nilagirica*, *Oroxylum indicum**, *Elaecarpus recurvatus*, *Phyllanthus amarus* & *Datura metel*	*O. sanctum*, *D. metel* & *P. amarus*
17.	*B. californicus* (Banks), 1904	Tenuipalpidae	*B. variegata*, *I. mauritiana*, *P. emblica*, *P. reticulatus*, *R. centifolia*, *H. rosa-sinensis*, *H. annus* & *V. vinifera*	*B. variegata*, *H. rosa-sinensis* & *H. annus*
18.	*Polyphagotarsonemus latus* (Banks), 1904	Tarsonemidae	*I. tinctoria*, *D. metel*, *C. halicacabum**, *L. lavendulifolia**, *A. esculentus*, *A. paniculata**, *Bacopa monnieri*, *B. diffusa*, *H. rosa-sinensis*, *Impatiens balsamina*, *Plectanthus amboinicus*, *S. dulcis**, *Tabernaemontana divaricata*, *Solanum nigrum*, *V. cinera* C. prostrata** & *Salacia reticulata**	*D. metel*, *C. halicacabum*, *V. cinera* & *L. lavendulifolia*
19.	*Aceria pongamiae*, Channabasavanna, 1966	Eriophyidae	*Pongamia pinnata*	*P. pinnata*
20.	*Anthocoptes vitexae* Mohanasundaram, 1981	Eriophyidae	*V. negundo*	*V. negundo*
21.	*Aceria* sp.	Eriophyidae	*Ceriscoides turgida** & *Ecobolium viride**	*C. turgida* & *E. viride*
22.	*A. clerodendronis*, Farkas, 1960	Eriophyidae	*Clerodendrum inerme* (L.)	*C. inerme*
23.	*Acalitus hibisci* Mondal & Chakrabarti, 1982	Eriophyidae	*H. vitifolius*	*H. vitifolius*
24.	*Eriophyes alangii* Nalepa, 1982	Eriophyidae	*Alangium salvifolium*	*A. salvifolium*

*** New record**

Table. 6. Seasonal abundance of phytophagous mites on their respective host medicinal plants during the period of survey

Sl. No.	Months	Average number of pest mites/leaf of the host plant			Average temperature (°C)	Average humidity (%)	Average rainfall (mm)
		T. neocaledonicus on *C. halicacabum*	*O. biharensis* on *J. adhathoda*	*B. phoenicis* on *V. negundo*			
1	January	69.32 ± 1.02	82.61 ± 2.03	78.52 ± 2.14	29.32	70.53	11.00
2	February	73.58 ± 1.17	89.57 ± 1.98	91.34 ± 2.03	29.46	72.67	18.00
3	March	136.23 ± 2.53	159.67 ± 2.53	145.61 ± 3.12	32.75	71.05	11.00
4	April	163.25 ± 2.72	196.45 ± 3.07	173.84 ± 2.69	34.34	67.93	152.00
5	May	128.76 ± 3.01	181.31 ± 3.14	179.58 ± 2.85	33.09	70.52	56.00
6	June	39.58 ± 1.96	48.52 ± 2.36	96.47 ± 1.86	27.52	88.03	604.00
7	July	27.61 ± 1.52	32.41 ± 1.73	43.03 ± 2.17	26.54	90.62	472.00
8	August	38.54 ± 0.97	49.42 ± 1.54	47.52 ± 2.20	29.67	86.37	478.00
9	September	46.55 ± 1.22	54.85 ± 1.69	50.19 ± 1.87	30.07	82.55	403.00
10	October	52.73 ± 1.81	78.72 ± 1.52	59.65 ± 2.03	31.54	77.61	274.00
11	November	61.65 ± 2.09	91.65 ± 1.71	74.73 ± 1.96	30.87	71.24	142.00
12	December	64.83 ± 1.86	97.48 ± 2.06	86.95 ± 2.19	30.42	70.53	7.00

Table. 7. Relative distribution of phytophagous pest mites on their respective host medicinal plants during the period of survey

Sl: No	Species of pest mite	Relative abundance of pest mites in different collection localities			
		High	Moderate	Low	Absent
1	*T. neocaledonicus*	SHG, CUBG, KAVSBG, KFRI, KSD-1, KSD-2, MLP-1, MLP-3, MLP-4, KOZ -2, KOZ -3, KOZ -5, KOZ -6, WAY-1, WAY-3, PKD-1, PKD-2, PKD-3, TCR-2, PAT- 1, PAT-2, TVM-1, TVM-2, ERK-1 & ERK-2	PHG, JNTBG, MBG, MLP-2, , KAN-2, KOZ-1 & TCR-1	MLP-5, MLP-6 & WAY-2	KAN-1 & KOZ -4
2	*O. biharensis*	SHG, PHG,CUBG, KAVSBG, KSD -2, MLP-1, MLP-2, MLP-3, MLP-4, KAN-1, KAN-2, WAY-1, WAY-2, KOZ -3, KOZ -4, KOZ -6, PKD-2, ERK-1, ERK-2, PAT- 1 & TVM-1	JNTBG, KFRI, KSD-1, WAY-3, MLP-5, MLP-6, KOZ -2, TCR-1, PKD-1 & PAT- 2	MBG, KOZ -1, PKD-3 & TVM-2	KOZ -5 & TCR-2
3	*B. phoenicis*	CUBG, KAVSBG, KFRI, JNTBG, SHG, PHG, MBG, MLP-1, MLP-3, MLP-4, MLP-5, KSD-1, KSD-2, KAN-2, KOZ -2, KOZ-3, KOZ -4, KOZ -6, WAY-1, WAY-2, PKD-1, PKD-2, TCR-2, ERK-1, ERK-2, PAT- 1, TVM-1 & TVM-2	MLP-2, MLP-6, KAN-1, KOZ-1, KOZ-5, WAY-3 & PAT- 2	TCR-1 & PKD-3	-

CUBG - Calicut University Botanical Garden; KAVSBG - Kottakal Arya Vaidya Sala Botanical Garden; PHG - Parappanangadi Herbal Garden; MBG - Malabar Botanical Garden; SHG - Thekumthara (Syam) Herbal Garden; KFRI - Kerala Forest research Institute' JNTBG - Jawaharlal Nehru Tropical Botanical Garden

KSD-1- Kanhangad; KSD-2- Cheruvathur; KAN-1- Edakkad; KAN-2- Anjarakandi; WAY-1- Ambalavayal; WAY-2- Meenangadi; WAY-3- Pookode; KOZ-1- Feroke; KOZ -2- Ramanattukara; KOZ -3- Kadalundi; KOZ -4- Nadakkavu; KOZ -5- Kunnamangalam; KOZ -6- Perambra; MLP-1- Thenjipalam; MLP-2- Tirur; MLP-3- Thavanoor; MLP-4- Thirunavaya; MLP-5- Kanjiramukku; MLP-6- Nilamboor; PKD-1- Peringode; PKD-2- Mannarkad; PKD-3- Nelliyampathi; TCR-1- Cheruvathani; TCR-2- Mundoor; ERK-1- Edappally; ERK-2- Paravoor; PAT- 1- Elanthur; PAT- 2- Parakode; TVM-1- Pattom; TVM-2- Perroorkara

Table. 8. Quantitative difference in photosynthetic pigments (mg/g fresh weight) induced by *Tetranychus neocaledonicus* in host medicinal plants

Sl. No.	Species of medicinal plant	Photosynthetic pigment	Concentration of photosynthetic pigments (mg/g fresh weight) Mean ± SE			Per cent loss in photosynthetic pigment
			Uninfested	Infested	Loss in pigment	
1	*Cardiospermum halicacabum*	chlorophyll *a*	2.37 ± 0.021	1.11 ± 0.052	1.26 ± 0.065	53.16 ± 0.0.085
		chlorophyll *b*	1.87 ± 0.023	0.75 ± 0.046	1.12 ± 0.051	59.89 ± 0.099
		total chlorophyll	4.24 ± 0.017	1.86 ± 0.053	2.39 ± 0.028	56.24 ± 0.104
		total carotenoids	1.69 ± 0.009	0.86 ± 0.038	0.83 ± 0.024	49.11 ± 0.073
2	*Leucas lavendulifolia*	chlorophyll *a*	1.50 ± 0.014	0.79 ± 0.049	0.71 ± 0.072	47.33 ± 0.096
		chlorophyll *b*	0.87 ± 0. 025	0.39 ± 0.052	0.48 ± 0.038	55.17 ± 0.087
		total chlorophyll	2.37 ± 0.031	1.18 ± 0.063	1.19 ± 0.049	50.21 ± 0.112
		total carotenoids	1.01 ± 0.023	0.51 ± 0.071	0.50 ± 0.054	49.50 ± 0.069

$P<0.01$

Table.9. Variations in the chlorophyll fluorescence parameters induced by pest mites on host medicinal plants

Sl. No.	Species of medicinal plant	Chlorophyll fluorescence parameters of uninfested and infested leaves of medicinal plants									
		F0		Fm		P index		Tfm (mS)		Area (bmS)	
		Un	In	Un	In	Un	In	Un	In	Un	In
1	*Cardiospermum halicacabum*	233 ± 0.071	796 ± 0.124	1277 ± 0.035	1343 ± 0.091	4.278 ± 0.022	0.024 ± 0.215	270.0 ± 0.033	210.0 ± 0.136	25800.0 ± 0.076	5200.0 ± 0.174
2	*Leucas lavendulifolia*	269 ±.0.024	757 ± 0.112	1576 ± 0.047	1332 ± 0.161	4.625 ± 0.175	0.038 ± 0.238	290.0 ± 0.092	270.0 ± 0.126	24600.0± 0.135	6000.0 ± 0.195
3	*Justicia adhatoda*	223 ±.047	657 ± 0.105	1274 ± 0.093	1269 ± 0.146	5.942 ± 0.051	0.012 ± 0.194	270.0 ± 0.067	240.0 ± 0.097	27600.0 ± 0.026	5200.0± 0.209
4	*Biophytum reinwardtii*	236 ±.0.011	674 ± 0.148	1252 ± 0.135	1257 ± 0.168	5.031 ± 0.126	0.026 ± 0.272	280.0 ± 0.084	210.0 ± 0.143	26000.0 ± 0.116	6400.0± 0.162
5	*Bauhinia acuminata*	356 ±.055	456 ± 0.127	1843 ± 0.067	956 ± 0. 129	3.055 ± 0.037	0.116 ± 0.167	240.0 ± 0.143	290.0 ± 0.182	258000.0 ± 0.062	8600.0 ± 0.237
6	*Mentha rotundifolia*	233 ± 0.069	734 ± 0.083	1277 ± 0.058	1441 ± 0.094	4.278 ± 0.119	0.042 ± 0.154	270.0 ± 0.175	240.0 ± 0.231	25800.0 ± 0.081	6400.0 ± 0.212
7	*Vitex negundo*	242 ± 0.073	576 ± 0.117	1445 ± 0.042	1199 ± 0.117	4.480 ± 0.098	0.101 ± 0.185	300.0 ± 0.096	290.0 ± 0.144	23600.0 ± 0.115	6600.0 ± 0.183

F0 = minimum/initial fluorescence; Fm = maximum fluorescence; Un = Uninfested; In = Infested

Table.10. Variations in Fv/Fm values induced by pest mites in the leaves of medicinal plants

Sl. No.	Species of medicinal plant	Species of pest mite	(Fv/Fm) values	
			Uninfested	Infested
1	*Cardiospermum halicacabum*	*Tetranychus neocaledonicus*	0.818 ± 0.021	0.407 ± 0.045
2	*Leucas lavendulifolia*	*T. neocaledonicus*	0.823 ± 0.005	0.432 ± 0.023
3	*Justicia adhatoda*	*Oligonychus biharensis*	0.825 ± 0.019	0.325 ± 0.067
4	*Biophytum reinwardtii*	*O. biharensis*	0.812 ± 0.008	0.464 ± 0. 053
5	*Bauhinia acuminata*	*O. biharensis*	0.807 ± 0.025	0.523 ± 0.062
6	*Mentha rotundifolia*	*Brevipalpus phoenicis*	0.818 ± 0.017	0.491 ± 0.074
7	*Vitex negundo*	*B. phoenicis*	0.833 ± 0.016	0.520 ± 0.025

$P<0.01$

F_0 = minimum/initial fluorescence; Fm = maximum fluorescence, Fv = variable fluorescence (Fm- F_0)

Table.11. Quantitative difference in the biochemical compounds induced by *Tetranychus neocaledonicus* in host medicinal plants

Sl. No.	Biochemical compound	Concentration of compounds in species of medicinal plants							
		Cardiospermum halicacabum				*Leucas lavendulifolia*			
		Un-infested	Infested	Quantitative Increase	Per cent increase	Un-infested	Infested	Quantitative Increase	Per cent increase
1	Proline (µmol/g fresh weight)	1.913 ± 0.012	4.370 ± 0.089	2.457 ± 0.084	128.44 ± 0.057	2.054 ± 0.024	4.401 ± 0.073	2.347 ± 0.068	114.26 ± 0.091
2	Phenol (mg/100g fresh weight)	1.932 ± 0.043	2.557 ± 0.062	0.625 ± 0.073	32.35 ± 0.084	4.317 ± 0.039	5.841 ± 0.098	1.524 ± 0.065	35.30 ± 0.058

$P<0.01$

Table.12. Quantitative difference in photosynthetic pigments (mg/g fresh weight) induced by *Oligonychus biharensis* in host medicinal plants

Sl. No.	Species of medicinal plant	Photosynthetic pigment	Concentration of photosynthetic pigments (mg/g fresh weight) Mean ± SEM			Per cent loss in photosynthetic pigments
			Uninfested	Infested	Quantitative Loss in pigments	
1	*Justicia adhatoda*	chlorophyll *a*	1.82 ± 0.006	0.84 ± 0.046	0.98 ± 0.032	53.85 ± 0.076
		chlorophyll *b*	1.14 ± 0.015	0.45 ± 0.064`	0.69 ± 0.041	60.53 ± 0.102
		total chlorophyll	2.90 ± 0. 025	1.29 ± 0.058	1.61 ± 0.081	55.52 ± 0.097
		total carotenoids	1.31 ± 0.033	0.62 ± 0.071	0.69 ± 0.032	52.67 ± 0.085
2	*Biophytum reinwardtii*	chlorophyll *a*	1.57 ± 0.028	0.80 ± 0.022	0.77 ± 0.047	49.04 ± 0.075
		chlorophyll *b*	1.09 ± 0.019	0.51 ± 0.067	0.58 ± 0.074	53.21 ± 0.096
		total chlorophyll	2.65 ± 0.013	1.31 ± 0.043	1.34 ± 0.029	50.57 ± 0.048
		total carotenoids	1.27 ± 0.011	0.68 ± 0.051	0.59 ± 0.073	46.46 ± 0.085
3	*Bauhinia acuminata*	chlorophyll *a*	3.21 ± 0.008	1.70 ± 0.037	1.51 ± 0.025	47.04 ±0.079
		chlorophyll *b*	1.02 ± 0.015	0.48 ± 0.052	0.54 ± 0.034	52.94 ± 0.068
		total chlorophyll	4.22 ± 0.021	2.18 ± 0.028	2.04 ± 0.053	48.34 ± 0.074
		total carotenoids	1.93 ± 0.013	1.12 ± 0.072	0.81 ± 0.056	41.97 ± 0.067

$P<0.01$

Table.13. Quantitative difference in biochemical compounds induced by *Oligonychus biharensis* in host medicinal plants

Sl. No.	Biochemical compound	Concentration of compounds in species of medicinal plants											
		Justicia adhatoda				*Biophytum reinwarditii*				*Bauhinia accuminata*			
		Un-infested	Infested	Quantitative Increase	Per cent increase	Un-infested	Infested	Quantitative Increase	Per cent increase	Un-infested	Infested	Quantitative Increase	Per cent increase
1	Proline (µmol/g fresh weight)	1.932 ± 0.007	5.549 ± 0.027	3.617± 0.062	187.22 ± 0.051	0.875 ± 0.009	2.169 ± 0.043	1.294 ± 0.025	147.89 ± 0.043	0.679 ± 0.034	1.346 ± 0.092	0.667 ± 0.085	98.23± 0.061*
2	Phenol (mg/100g fresh weight)	8.436 ± 0.041	12.403 ± 0.032	3.967 ± 0.025	47.02 ± 0.046	3.118 ± 0.027	4.309 ± 0.092	1.191 ± 0.087	38.20 ± 0.037	3.417 ± 0.035	4.292 ± 0.079	0.875 ± 0.061	25.61± 0.073**

* $P<0.01$; ** $P<0.02$

Table.14. Quantitative difference in photosynthetic pigments (mg/g fresh weight) induced by *Brevipalpus phoenicis* in host medicinal plants

Sl. No.	Species of medicinal plant	Photosynthetic pigment	Concentration of Photosynthetic pigments (mg/g fresh weight) Mean ± SEM			Per cent loss in photosynthetic pigment
			Uninfested	Infested	Loss in pigment	
1	*Mentha rotundifolia*	chlorophyll *a*	2.34 ± 0.007	1.26 ± 0.080	1.08 ± 0.022	46.15 ± 0.082
		chlorophyll *b*	1.78 ± 0.023	0.79 ± 0.052	0.99 ± 0.034	55.62 ± 0.065
		total chlorophyll	4.11 ± 0.014	2.05 ± .0.061	2.06 ± 0.053	50.12 ± 0.091
		total carotenoids	1.83 ± 0.009	1.01 ± 0.0.0721	0.82 ± 0.062	44.81 ± 0.047
2	*Vitex negundo*	chlorophyll *a*	3.22 ± 0.021	1.93 ± 0.0.051	1.29 ± 0.054	40.06 ± 0.038
		chlorophyll *b*	2.11 ± 0.017	1.16 ± 0.018	0.95 ± 0.071	45.02 ± 0.052
		total chlorophyll	5.32 ± 0.023	3.09 ± 0.041	2.23 ± 0.055	41.92 ± 0.073
		total carotenoids	1.83 ± 0.015	1.12 ± 0.052	0.71 ± 0.072	38.80 ± 0.066

$P<0.01$

Table.15. Quantitative difference in biochemical compounds induced by *Brevipalpus phoenicis* in host medicinal plants

Sl. No.	Biochemical compound	Host plants of *Brevipalpus phoenicis*							
		Mentha rotundifolia				*Vitex negundo*			
		Uninfested	Infested	Amount of Increase	Per cent increase	Uninfested	Infested	Amount of Increase	Per cent increase
1	Proline (µmol/g fresh weight)	1.273 ± 0.025	2.758 ± 0.065	1.485 ± 0.091	116.65±0.058	1.612 ± 0.012	3.019 ± 0.051	1.407 ± 0.025	87.28± 0.064*
2	Phenol (mg/100g fresh weight)	2.915 ± 0.031	3.824 ± 0.052	0.909 ± 0.075	31.18± 0.087	6.813 ± 0.009	8.417 ± 0.032	1.604 ± 0.038	23.54± 0.049**

*P<0.01; ** P<0.02

Table16. **Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Tetranychus neocaledonicus* on *Cardiospermum halicacabum* at different temperature-humidity conditions**

Sl. No.	Type of female	Temperature & Relative humidity	Duration (days)			
			Pre-oviosition period	Oviposition period	Post-oviposition period	Adult longevity
1	Mated	25 ± 2°C & 80 ± 5 % RH	2.14 ± 0.08	9.02 ± 0.15	2.69 ± 0.12	13.85 ± 0.23
		30 ± 2°C & 70 ± 5 % RH	1.71 ± 0.06	7.41 ± 0.09	2.03 ± 0.06	11.15 ± 0.15
		35 ± 2°C & 60 ± 5 % RH	1.14 ± 0.03	7.19 ± 0.14	1.68 ± 0.09	10.01 ± 0.18
2	Unmated	25 ± 2°C & 80 ± 5 % RH	2.01 ± 0.07	9.63 ± 0.08	2.81 ± 0.10	14.45 ± 0.25
		30 ± 2°C & 70 ± 5 % RH	1.62 ± 0.02	8.07 ± 0.10	2.11 ± 0.07	11.80 ± 0.20
		35 ± 2°C & 60 ± 5 % RH	1.09 ± 0.05	7.92 ± 0.13	1.72 ± 0.06	10.73 ± 0.17

Table. 17. The fecundity, egg viability and immature survivorship of *Tetranychus neocaledonicus* on *Cardiospermum halicacabum* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/day	Egg viability (%)	Immature survivorship (%)
			(Mean ± SEM)	Range			
1	Mated	25 ± 2°C & 80 ± 5 % RH	33.76 ± 1.23	28 - 37	3.74 ± 0.12	80.12 ± 2.04	84.53 ± 1.32
		30 ± 2°C & 70 ± 5 % RH	42.63 ± 1.08	36 - 46	5.75 ± 0.09	89.54 ± 1.19	93.67 ± 2.15
		35 ± 2°C & 60 ± 5 % RH	49.71 ± 0.93	42 - 55	6.91 ± 0.04	92.41 ± 1.22	96.72 ± 1.09
2	Unmated	25 ± 2°C & 80 ± 5 % RH	28.42 ± 1.30	25 - 31	2.95 ± 0.11	76. 37 ± 2.13	81.26 ± 2.19
		30 ± 2°C & 70 ± 5 % RH	36.67 ± 1.25	33 - 39	4.54 ± 0.10	83.56 ± 1.87	87.55 ± 1.43
		35 ± 2°C & 60 ± 5 % RH	41.83 ± 1.19	37 – 44	5.28 ± 0.06	85.71 ± 1.32	90.34 ± 1.10

Table. 18. Duration of developmental stages and adults of the sexual progenies of *Tetranychus neocaledonicus* on *Cardiospermum halicacabum* at different temperature-humidity conditions

Sl. No	Life stage	Duration of life stages at different temperature-humidity conditions (days)						Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH		30 ± 2°C & 70 ± 5 % RH		35 ± 2°C & 60 ± 5 % RH		
		Duration	Mean ± SEM	Duration	Mean ± SEM	Duration	Mean ± SEM	
1	Egg	3.82 ± 0.06	3.76 ± 0.08	3.12 ± 0.03	3.11 ± 0.07	3.10 ± 0.02	3.09 ± 0.04	F
		3.75 ± 0.07		3.09 ± 0.05		3.08 ± 0.01		M
2	Larva	2.42 ± 0.02	2.38 ± 0.06	1.98 ± 0.02	1.83 ± 0.06	1.84 ± 0.03	1.73 ± 0.05	F
		2.34 ± 0.04		1.67 ± 0.04		1.62 ± 0.05		M
3	Protochrysalis	1.21 ± 0.05	1.17 ± 0.07	0.84 ± 0.03	0.76 ± 0.08	0.81 ± 0.01	0.75 ± 0.07	F
		1.13 ± 0.02		0.73 ± 0.06		0.72 ± 0.03		M
4	Protonymph	2.52 ± 0.04	2.42 ± 0.05	1.71 ± 0.02	1.45 ± 0.04	1.59 ± 0.05	1.39 ± 0.06	F
		2.32 ± 0.03		1.24 ± 0.03		1.19 ± 0.03		M
5	Deutochrysalis	1.12 ± 0.07	1.11 ± 0.09	0.72 ± 0.07	0.68 ± 0.08	0.69 ± 0.05	0.65 ± 0.08	F
		1.09 ± 0.04		0.64 ± 0.09		0.61 ± 0.04		M
6	Deutonymph	2.82 ± 0.05	2.81 ± 0.08	2.13 ± 0.04	2.04 ± 0.05	2.01 ± 0.02	1.94 ± 0.05	F
		2.79 ± 0.03		1.95 ± 0.03		1.87 ± 0.05		M
7	Teliochrysalis	1.30 ± 0.03	1.28 ± 0.04	0.67 ± 0.05	0.65 ± 0.07	0.64 ± 0.07	0.62 ± 0.08	F
		1.25 ± 0.04		0.62 ± 0.04		0.59 ± 0.06		M
8	Total Immature	15.21 ± 0.13	14.94 ± 0.29	11.17 ± 0.11	10.82 ± 0.24	10.68 ± 0.14	10.18 ± 0.27	F
		14.67 ± 0.18		9.94 ± 0.20		9.68 ± 0.15		M
9	Adult	13.54 ± 0.15	11.92 ± 0.35	11.32 ± 0.23	10.10 ± 0.29	10.19 ± 0.21	9.08 ± 0.30	F
		10.29 ± 0.22		8.87 ± 0.17		7.96 ± 0.15		M

Table. 19. Duration of developmental stages and adults of the parthenogenetic progenies of *Tetranychus neocaledonicus* on *Cardiospermum halicacabum* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	3.52 ± 0.02	3.01 ± 0.04	2.98 ± 0.03	M
2	Larva	2.31 ± 0.06	1.62 ± 0.07	1.59 ± 0.08	M
3	Protochrysalis	1.08 ± 0.05	0.64 ± 0.03	0.61 ± 0.05	M
4	Protonymph	2.21 ± 0.05	1.13 ± 0.06	1.12 ± 0.04	M
5	Deutochrysalis	1.01 ± 0.03	0.62 ± 0.02	0.60 ± 0.06	M
6	Deutonymph	2.64 ± 0.07	1.92 ± 0.04	1.84 ± 0.02	M
7	Teliochrysalis	1.01 ± 0.04	0.60 ± 0.05	0.57 ± 0.08	M
8	Total Immature	13.78 ± 0.23	9.54 ± 0.24	9.31 ± 0.18	M
9	Adult	10.04 ± 0.30	7.98 ± 0.26	7.64 ± 0.21	M

Table. 20. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Tetranychus neocaledonicus* on *Leucas lavendulifolia* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Duration (days)			
			Pre-oviposition period	Oviposition period	Post-oviposition period	Adult Longevity
1	Mated	25 ± 2°C & 80 ± 5 % RH	2.23 ± 0.07	8.67 ± 0.12	2.52 ± 0.05	13.42 ± 0.17
		30 ± 2°C & 70 ± 5 % RH	2.01 ± 0.06	7.35 ± 0.10	2.05 ± 0.11	11.41 ± 0.22
		35 ± 2°C & 60 ± 5 % RH	1.68 ± 0.05	6.87 ± 0.17	1.83 ± 0.06	10.38 ± 0.15
2	Unmated	25 ± 2°C & 80 ± 5 % RH	2.11 ± 0.08	9.01 ± 0.08	2.57 ± 0.15	13.69 ± 0.20
		30 ± 2°C & 70 ± 5 % RH	1.73 ± 0. 05	7.85 ± 0.09	2.14 ± 0.08	11.72 ± 0.13
		35 ± 2°C & 60 ± 5 % RH	1.24 ± 0.06	7.28 ± 0.11	1.91 ± 0.04	10.43 ± 0.18

Table. 21. The fecundity, egg viability and immature survivorship of *Tetranychus neocaledonicus* on *Leucas lavendulifolia* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/ day	Egg viability (%)	Immature survivorship (%)
			(Mean ± SEM)	Range			
1	Mated	25 ± 2°C & 80 ± 5 % RH	26.76 ± 1.23	22 - 29	3.16 ± 0.09	77.32 ± 2.15	80.53 ± 1.25
		30 ± 2°C & 70 ± 5 % RH	35.63 ± 1.08	31 - 40	4.85 ± 0.13	85.34 ± 2.11	88.61 ± 2.03
		35 ± 2°C & 60 ± 5 % RH	39.71 ± 0.93	36 - 42	5.78 ± 0.07	88.56 ± 1.35	91.75 ± 2.11
2	Unmated	25 ± 2°C & 80 ± 5 % RH	22.42 ± 1.30	19 - 24	2.49 ± 0.21	73.87 ± 2.31	78.72 ± 2.87
		30 ± 2°C & 70 ± 5 % RH	32.67 ± 1.25	28 - 35	4.16 ± 0.05	80.76 ± 1.32	84.31 ± 1.09
		35 ± 2°C & 60 ± 5 % RH	37.83 ± 1.19	32 - 39	5.05 ± 0.08	82.81 ± 1.57	86.92 ± 2.26

Table. 22. Duration of developmental stages and adults of the sexual progenies of *Tetranychus neocaledonicus* on *Leucas lavendulifolia* at different temperature-humidity conditions

Sl. No	Life stage	Duration of life stages at different temperature-humidity conditions (days)						Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH		30 ± 2°C & 70 ± 5 % RH		35 ± 2°C & 60 ± 5 % RH		
		Duration	Mean ± SEM	Duration	Mean ± SEM	Duration	Mean ± SEM	
1	Egg	4.8 ± 0.05	4.50 ± 0.06	3.6 ± 0.06	3.55 ± 0.07	3.4 ± 0.07	3.30 ± 0.09	F
		4.2 ± 0.03		3.5 ± 0.04		3.2 ± 0.03		M
2	Larva	3.3 ± 0.04	3.20 ± 0.05	2.6 ± 0.03	2.40 ± 0.05	2.4 ± 0.07	2.25 ± 0.08	F
		3.1 ± 0.02		2.2 ± 0.05		2.1 ± 0.02		M
3	Protochrysalis	1.32 ± 0.03	1.30 ± 0.07	1.10 ± 0.05	1.06 ± 0.10	1.09 ± 0.04	1.05 ± 0.05	F
		1.27 ± 0.06		1.02 ± 0.08		1.01 ± 0.03		M
4	Protonymph	2.58 ± 0.06	2.45 ± 0.09	1.82 ± 0.01	1.70 ± 0.04	1.76 ± 0.02	1.61 ± 0.03	F
		2.31 ± 0.04		1.58 ± 0.03		1.45 ± 0.01		M
5	Deutochrysalis	1.13 ± 0.04	1.11 ± 0.08	0.88 ± 0.03	0.82 ± 0.03	0.82 ± 0.04	0.77 ± 0.06	F
		1.08 ± 0.06		0.76 ± 0.02		0.71 ± 0.03		M
6	Deutonymph	2.94 ± 0.02	2.83 ± 0.05	2.83 ± 0.04	2.76 ± 0.05	2.80 ± 0.02	2.62 ± 0.04	F
		2.71 ± 0.04		2.68 ± 0.02		2.43 ± 0.05		M
7	Teliochrysalis	1.63 ± 0.05	1.48 ± 0.07	1.46 ± 0.04	1.35 ± 0.06	1.32 ± 0.06	1.19 ± 0.10	F
		1.32 ± 0.05		1.24 ± 0.02		1.07 ± 0.05		M
8	Total Immature	17.70 ± 0.16	16.85 ± 0.24	14.29 ± 0.18	13.64 ± 0.35	13.59 ± 0.25	12.78 ± 0.38	F
		15.99 ± 0.11		12.98 ± 0.20		11.97 ± 0.17		M
9	Adult	13.17 ± 0.24	11.62 ± 0.43	11.05 ± 0.27	9.83 ± 0.40	9.98 ± 0.25	8.71 ± 0.41	F
		10.06 ± 0.25		8.61 ± 0.20		7.43 ± 0.19		M

Table. 23. Duration of developmental stages and adults of the parthenogenetic progenies of *Tetranychus neocaledonicus* on *Leucas lavendulifolia* at different temperature-humidity conditions

Sl. No	Life stage	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	4.1 ± 0.04	3.3 ± 0.05	3.00 ± 0.07	M
2	Larva	2.9 ± 0.05	1.9 ± 0.04	1.87 ± 0.05	M
3	Protochrysalis	1.21 ± 0.03	0.96 ± 0.05	0.93 ± 0.03	M
4	Protonymph	2.32 ± 0.05	1.46 ± 0.06	1.32 ± 0.07	M
5	Deutochrysalis	1.04 ± 0.04	0.83 ± 0.07	0.81 ± 0.04	M
6	Deutonymph	2.75 ± 0.02	2.37 ± 0.04	2.16 ± 0.02	M
7	Teliochrysalis	1.29 ± 0.07	0.98 ± 0.03	0.83 ± 0.06	M
8	Total Immature	15.61 ± 0.29	11.80 ± 0.25	10.92 ± 0.24	M
9	Adult	9.47 ± 0.36	8.22 ± 0.29	7.01 ± 0.33	M

Table. 24. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Oligonychus biharensis* on *Justicia adhatoda* at different temperature and humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Duration (days)			
			Pre-oviposition period	Oviposition period	Post-oviposition period	Adult longevity
1	Mated	25 ± 2°C & 80 ± 5 % RH	1.92 ± 0.04	9.17 ± 0.19	1.21 ± 0.06	12.30 ± 0.17
		30 ± 2°C & 70 ± 5 % RH	1.30 ± 0.03	8.03 ± 0.24	1.01 ± 0.03	10.34 ± 0.12
		35 ± 2°C & 60 ± 5 % RH	0.95 ± 0.07	7.42 ± 0.15	0.90 ± 0.07	9.27 ± 0.10
2	Unmated	25 ± 2°C & 80 ± 5 % RH	1.88 ± 0.06	9.61 ± 0.07	1.52 ± 0.04	13.01 ± 0.15
		30 ± 2°C & 70 ± 5 % RH	1.17 ± 0.02	8.64 ± 0.10	1.11 ± 0.05	10.92 ± 0.19
		35 ± 2°C & 60 ± 5 % RH	0.89 ± 0.03	7.95 ± 0.08	0.98 ± 0.08	9.82 ± 0.11

Table. 25. The fecundity, egg viability and immature survivorship of *Oligonychus biharensis* on *Justicia adhatoda* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/day	Egg viability (%)	Immature survivorship (%)
			(Mean ± SEM)	Range			
1	Mated	25 ± 2°C & 80 ± 5 % RH	43.62 ± 2.21	39 - 45	4.76 ± 0.08	78.41 ± 2.04	86.35 ± 2.12
		30 ± 2°C & 70 ± 5 % RH	47.31 ± 3.15	40 - 53	5.89 ± 0.15	85.03 ± 1.87	95.73 ± 3.10
		35 ± 2°C & 60 ± 5 % RH	56.19 ± 2.16	49 - 61	7.57 ± 0.06	89.26 ± 2.35	97.51 ± 2.09
2	Unmated	25 ± 2°C & 80 ± 5 % RH	38.92 ± 1.53	33 - 41	4.05 ± 0.13	74.98 ± 2.67	85.67 ± 2.11
		30 ± 2°C & 70 ± 5 % RH	44.87 ± 2.34	39 - 47	5.19 ± 0.09	81.47 ± 3.14	93.94 ± 1.43
		35 ± 2°C & 60 ± 5 % RH	49.36 ± 1.72	42 - 54	6.21 ± 0.07	85.21 ± 1.28	94.36 ± 1.08

Table. 26. Duration of developmental stages and adults of the sexual progenies of *Oligonychus biharensis* on *Justicia adhatoda* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)						Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH		30 ± 2°C & 70 ± 5 % RH		35 ± 2°C & 60 ± 5 % RH		
		Duration	Mean ± SEM	Duration	Mean ± SEM	Duration	Mean ± SEM	
1	Egg	3.14 ± 0.05	3.11 ± 0.09	2.69 ± 0.06	2.60 ± 0.07	2.47 ± 0.03	2.46 ± 0.06	F
		3.08 ± 0.07		2.51 ± 0.04		2.45 ± 0.05		M
2	Larva	1.13 ± 0.08	1.11 ± 0.08	0.97 ± 0.06	0.96 ± 0.08	0.85 ± 0.07	0.83 ± 0.09	F
		1.09 ± 0.05		0.96 ± 0.04		0.81 ± 0.04		M
3	Protochrysalis	0.95 ± 0.03	0.93 ± 0.05	0.71 ± 0.03	0.69 ± 0.06	0.69 ± 0.07	0.67 ± 0.08	F
		0.91 ± 0.04		0.68 ± 0.06		0.64 ± 0.05		M
4	Protonymph	1.42 ± 0.03	1.31 ± 0.06	0.97 ± 0.02	0.83 ± 0.05	0.82 ± 0.01	0.81 ± 0.04	F
		1.20 ± 0.04		0.93 ± 0.05		0.80 ± 0.04		M
5	Deutochrysalis	0.87 ± 0.05	0.85 ± 0.09	0.62 ± 0.08	0.62 ± 0.11	0.53 ± 0.04	0.52 ± 0.09	F
		0.83 ± 0.06		0.61 ± 0.05		0.51 ± 0.07		M
6	Deutonymph	1.54 ± 0.03	1.53 ± 0.05	1.01 ± 0.03	0.97 ± 0.05	0.91 ± 0.05	0.89 ± 0.10	F
		1.51 ± 0.03		0.93 ± 0.04		0.86 ± 0.08		M
7	Teliochrysalis	0.98 ± 0.04	0.95 ± 0.08	0.81 ± 0.07	0.79± 0.10	0.77 ± 0.08	0.73 ± 0.09	F
		0.92 ± 0.06		0.76 ± 0.05		0.68 ± 0.06		M
8	Total Immature	10.03 ± 0.19	9.79 ± 0.34	7.78 ± 0.13	7.58 ± 0.23	7.04 ± 0.16	6.89 ± 0.37	F
		9.54 ± 0.27		7.38 ± 0.15		6.75 ± 0.24		M
9	Adult	12.46 ± 0.25	11.42 ± 0.42	10.53 ± 0.17	9.63 ± 0.29	9.05 ± 0.12	8.44 ± 0.25	F
		10.38 ± 0.22		8.72 ± 0.15		7.83 ± 0.16		M

Table. 27. Duration of developmental stages and adults of the parthenogenetic progenies of *Oligonychus biharensis* on *Justicia adhatoda* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	3.06 ± 0.07	2.49 ± 0.06	2.44 ± 0.07	M
2	Larva	1.12 ± 0.05	0.93 ± 0.03	0.76 ± 0.06	M
3	Protochrysalis	0.90 ± 0.03	0.61 ± 0.08	0.56 ± 0.05	M
4	Protonymph	1.13 ± 0.04	0.90 ± 0.07	0.79 ± 0.06	M
5	Deutochrysalis	0.82 ± 0.06	0.61 ± 0.05	0.51 ± 0.03	M
6	Deutonymph	1.32 ± 0.03	0.91 ± 0.04	0.82 ± 0.07	M
7	Teliochrysalis	0.89 ± 0.05	0.70 ± 0.09	0.61 ± 0.05	M
8	Total Immature	9.24 ± 0.22	7.15 ± 0.18	6.49 ± 0.31	M
9	Adult	9.13 ± 0.51	7.94 ± 0.28	7.25 ± 0.36	M

Table. 28. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Oligonychus biharensis* on *Biophytum reinwardtii* at different temperature and humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Duration (days)			
			Pre-oviposition period	Oviposition period	Post-oviposition period	Adult longevity
1	Mated	25 ± 2°C & 80 ± 5 % RH	2.02 ± 0.06	9.26 ± 0.13	1.34 ± 0.05	12.62 ± 0.18
		30 ± 2°C & 70 ± 5 % RH	1.48 ± 0.03	8.35 ± 0.09	1.02 ± 0.07	10.85 ± 0.25
		35 ± 2°C & 60 ± 5 % RH	1.06 ± 0.05	7.07 ± 0.10	0.84 ± 0.05	9.97 ± 0.20
2	Unmated	25 ± 2°C & 80 ± 5 % RH	1.83 ± 0.08	9.94 ± 0.15	1.42 ± 0.07	13.19 ± 0.17
		30 ± 2°C & 70 ± 5 % RH	1.25 ± 0.07	8.69 ± 0.07	1.14 ± 0.09	11.08 ± 0.23
		35 ± 2°C & 60 ± 5 % RH	0.98 ± 0.04	8.26 ± 0.12	0.95 ± 0.08	10.19 ± 0.14

Table. 29. The fecundity, egg viability and immature survivorship of *Oligonychus biharensis* on *Biophytum reinwardtii* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/day	Egg viability (%)	Immature survivorship (%)
			(Mean ± SEM)	Range			
1	Mated	25 ± 2°C & 80 ± 5 % RH	38.51 ± 2.40	33 – 41	4.16 ± 0.11	75.32 ± 3.15	82.65 ± 1.12
		30 ± 2°C & 70 ± 5 % RH	44.62 ± 2.27	39 – 47	5.34 ± 0.09	82.16 ± 1.61	89.27 ± 2.09
		35 ± 2°C & 60 ± 5 % RH	51.23 ± 1.65	44 – 56	7.25 ± 0.10	85.24 ± 2.67	92.94 ± 2.16
2	Unmated	25 ± 2°C & 80 ± 5 % RH	35.75 ± 1.23	29 – 37	3.60 ± 0.08	71.65 ± 1.37	79.84 ± 1.53
		30 ± 2°C & 70 ± 5 % RH	41.91 ± 2.16	36 – 45	4.82 ± 0.16	78.39 ± 2.15	85.47 ± 3.15
		35 ± 2°C & 60 ± 5 % RH	47.53 ± 2.32	42 – 50	5.75 ± 0.07	81.93 ± 2.20	89.53 ± 1.28

Table. 30. Duration of developmental stages and adults of the sexual progenies of *Oligonychus biharensis* on *Biophytum reinwardtii* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)						Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH		30 ± 2°C & 70 ± 5 % RH		35 ± 2°C & 60 ± 5 % RH		
		Duration	Mean ± SEM	Duration	Mean ± SEM	Duration	Mean ± SEM	
1	Egg	3.53 ± 0.05	3.4 ± 0.06	2.92 ± 0.07	2.88 ± 0.06	2.74 ± 0.04	2.72 ± 0.09	F
		3.27 ± 0.03		2.83 ± 0.01		2.70 ± 0.06		M
2	Larva	1.21 ± 0.04	1.2 ± 0.07	0.99 ± 0.03	0.99 ± 0.05	0.90 ± 0.05	0.89 ± 0.06	F
		1.19 ± 0.05		0.98 ± 0.04		0.87 ± 0.02		M
3	Protochrysalis	1.29 ± 0.03	1.14 ± 0.05	0.81 ± 0.05	0.80 ± 0.07	0.72 ± 0.07	0.71 ± 0.08	F
		0.98 ± 0.04		0.79 ± 0.02		0.70 ± 0.03		M
4	Protonymph	1.63 ± 0.06	1.53 ± 0.09	1.17 ± 0.02	1.11 ± 0.05	0.95 ± 0.02	0.94 ± 0.04	F
		1.42 ± 0.04		1.05 ± 0.05		0.92 ± 0.03		M
5	Deutochrysalis	0.89 ± 0.05	0.87 ± 0.04	0.65 ± 0.03	0.64 ± 0.06	0.54 ± 0.04	0.53 ± 0.05	F
		0.84 ± 0.01		0.63 ± 0.03		0.52 ± 0.03		M
6	Deutonymph	1.59 ± 0.03	1.57 ± 0.05	1.09 ± 0.06	1.07 ± 0.09	0.99 ± 0.05	0.96 ± 0.09	F
		1.54 ± 0.03		1.04 ± 0.04		0.92 ± 0.07		M
7	Teliochrysalis	0.99 ± 0.04	0.98 ± 0.08	0.85 ± 0.02	0.82 ± 0.04	0.78 ± 0.08	0.73 ± 0.10	F
		0.96 ± 0.06		0.79 ± 0.05		0.68 ± 0.06		M
8	Total Immature	11.13 ± 0.22	10.67 ± 0.36	8.48 ± 0.21	8.30 ± 0.31	7.62 ± 0.23	7.47 ± 0.30	F
		10.20 ± 0.17		8.11 ± 0.19		7.32 ± 0.18		M
9	Adult	12.63 ± 0.28	11.47 ± 0.39	10.79 ± 0.25	9.71 ± 0.34	9.84 ± 0.22	8.77 ± 0.31	F
		10.31 ± 0.20		8.62 ± 0.23		7.69 ± 0.16		M

Table. 31. Duration of developmental stages and adults of the parthenogenetic progenies of *Oligonychus biharensis* on *Biophytum reinwardtii* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	3.25 ± 0.05	2.71 ± 0.06	2.56 ± 0.04	M
2	Larva	1.17 ± 0.06	1.03 ± 0.04	0.86 ± 0.06	M
3	Protochrysalis	0.97 ± 0.04	0.71 ± 0.07	0.67 ± 0.05	M
4	Protonymph	1.23 ± 0.04	0.99 ± 0.05	0.89 ± 0.03	M
5	Deutochrysalis	0.84 ± 0.05	0.62 ± 0.05	0.53 ± 0.07	M
6	Deutonymph	1.49 ± 0.03	0.96 ± 0.06	0.88 ± 0.02	M
7	Teliochrysalis	0.91 ± 0.02	0.73 ± 0.06	0.65 ± 0.05	M
8	Total Immature	9.86 ± 0.27	7.75 ± 0.29	7.04 ± 0.31	M
9	Adult	10.08 ± 0.31	8.27 ± 0.35	7.43 ± 0.28	M

Table. 32. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Oligonychus biharensis* on *Bauhinia acuminata* at different temperature and humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Duration (days)			
			Pre-oviosition period	Oviposition period	Post-oviposition period	Adult longevity
1	Mated	25 ± 2°C & 80 ± 5 % RH	1.94 ± 0.08	8.03 ± 0.17	1.31 ± 0.09	11.28 ± 0.23
		30 ± 2°C & 70 ± 5 % RH	1.33 ± 0.05	7.12 ± 0.08	1.06 ± 0.05	9.51 ± 0.19
		35 ± 2°C & 60 ± 5 % RH	0.96 ± 0.07	6.22 ± 0.14	0.91 ± 0.03	8.09 ± 0.17
2	Unmated	25 ± 2°C & 80 ± 5 % RH	1.91 ± 0.6	8.36 ± 0.20	1.52 ± 0.07	11.79 ± 0.21
		30 ± 2°C & 70 ± 5 % RH	1.18 ± 0.04	7.43 ± 0.15	1.05 ± 0.08	9.66 ± 0.16
		35 ± 2°C & 60 ± 5 % RH	0.87 ± 0.02	6.32 ± 0.12	0.98 ± 0.05	8.17 ± 0.18

Table. 33. The fecundity, egg viability and immature survivorship of *Oligonychus biharensis* on *Bauhinia acuminata* at different temperature-humidity conditions

Sl. No.	Type of female	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/ day	Egg viability (%)	Immature survivorship (%)
			(Mean ± SEM)	Range			
1	Mated	25 ± 2°C & 80 ± 5 % RH	31.43 ± 1.21	27 - 36	3.91 ± 0.17	73.25 ± 2.18	79.53 ± 1.87
		30 ± 2°C & 70 ± 5 % RH	37.86 ± 2.14	33 - 40	5.32 ± 0.09	79.47 ± 1.35	84.37 ± 2.15
		35 ± 2°C & 60 ± 5 % RH	42.58 ± 1.09	37 - 45	6.85 ± 0.11	83.24 ± 2.16	87.42 ± 1.49
2	Unmated	25 ± 2°C & 80 ± 5 % RH	27.26 ± 1.35	22 - 31	3.26 ± 0.20	69.08 ± 3.05	74.15 ± 2.34
		30 ± 2°C & 70 ± 5 % RH	32.55 ± 2.16	28 - 34	4.38 ± 0.07	76.43 ± 1.76	81.62 ± 2.07
		35 ± 2°C & 60 ± 5 % RH	35.64 ± 2.11	32 - 38	5.64 ± 0.08	79.06 ± 1.31	83.17 ± 1.12

Table. 34. Duration of developmental stages and adults of the sexual progenies of *Oligonychus biharensis* on *Bauhinia acuminata* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)						Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH		30 ± 2°C & 70 ± 5 % RH		35 ± 2°C & 60 ± 5 % RH		
		Duration	Mean ± SEM	Duration	Mean ± SEM	Duration	Mean ± SEM	
1	Egg	3.87 ± 0.05	3.78 ± 0.06	2.95 ± 0.02	2.89 ± 0.03	2.71 ± 0.02	2.67 ± 0.03	F
		3.68 ± 0.03		2.84 ± 0.01		2.63 ± 0.01		M
2	Larva	1.84 ± 0.04	1.71 ± 0.05	1.23 ± 0.03	1.21 ± 0.04	1.08 ± 0.05	1.02 ± 0.07	F
		1.57 ± 0.02		1.19 ± 0.02		0.96 ± 0.04		M
3	Protochrysalis	1.37 ± 0.03	1.23 ± 0.03	0.92 ± 0.04	0.91 ± 0.05	0.83 ± 0.03	0.82 ± 0.06	F
		1.09 ± 0.01		0.89 ± 0.02		0.80 ± 0.05		M
4	Protonymph	1.98 ± 0.03	1.86 ± 0.05	1.29 ± 0.05	1.23 ± 0.08	1.09 ± 0.02	1.04 ± 0.04	F
		1.73 ± 0.04		1.16 ± 0.05		0.98 ± 0.03		M
5	Deutochrysalis	1.12 ± 0.05	1.05 ± 0.04	0.76 ± 0.03	0.74 ± 0.03	0.65 ± 0.04	0.63 ± 0.05	F
		0.97 ± 0.01		0.71 ± 0.01		0.61 ± 0.02		M
6	Deutonymph	1.77 ± 0.03	1.73 ± 0.03	1.27 ± 0.03	1.21 ± 0.06	1.09 ± 0.05	1.05 ± 0.08	F
		1.68 ± 0.02		1.15 ± 0.04		1.01 ± 0.04		M
7	Teliochrysalis	1. 09± 0.04	1.08 ± 0.07	0.98 ± 0.02	0.95 ± 0.05	0.87 ± 0.02	0.84 ± 0.05	F
		1.07 ± 0.05		0.92 ± 0.04		0.81 ± 0.06		M
8	Total Immature	13.04 ± 0.27	12.42 ± 0.31	9.40 ± 0.23	9.13 ± 0.37	8.32 ± 0.25	8.06 ± 0.35	F
		11.79 ± 0.19		8.86 ± 0.20		7.80 ± 0.18		M
9	Adult	11.03 ± 0.29	10.30 ± 0.46	9.43 ± 0.24	8.41 ± 0.33	8.01 ± 0.15	7.28 ± 0.32	F
		9.56 ± 0.21		7.39 ± 0.19		6.54 ± 0.23		M

Table. 35. Duration of developmental stages and adults of the parthenogenetic progenies of *Oligonychus biharensis* on *Bauhinia acuminata* at different temperature-humidity conditions

Sl. No.	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	3.49 ± 0.05	2.76 ± 0.04	2.55 ± 0.04	M
2	Larva	1.39 ± 0.03	1.05 ± 0.03	0.95 ± 0.02	M
3	Protochrysalis	1.04 ± 0.04	0.93 ± 0.07	0.74 ± 0.06	M
4	Protonymph	1.49 ± 0.04	1.08 ± 0.05	0.93 ± 0.03	M
5	Deutochrysalis	0.97 ± 0.05	0.76 ± 0.08	0.67 ± 0.07	M
6	Deutonymph	1.67 ± 0.03	1.09 ± 0.03	0.98 ± 0.05	M
7	Teliochrysalis	1.03 ± 0.06	0.94 ± 0.05	0.81 ± 0.03	M
8	Total Immature	11.08 ± 0.29	8.61 ± 0.36	7.62 ± 0.28	M
9	Adult	8.29 ± 0.35	6.53 ± 0.41	5.73 ± 0.37	M

Table. 36. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Brevipalpus phoenicis* on *Mentha rotundifolia* at different temperature-humidity conditions

Sl. No.	Temperature & Relative humidity	Duration (days)			
		Pre-oviosition period	Oviposition period	Post-oviposition period	Adult longevity
1	25 ± 2°C & 80 ± 5 % RH	4.37 ± 0.31	18.23 ± 0.42	4.03 ± 0.27	26.63 ± 0.52
2	30 ± 2°C & 70 ± 5 % RH	3.42 ± 0.25	17.32 ± 0.30	3.18 ± 0.21	23.92 ± 0.61
3	35 ± 2°C & 60 ± 5 % RH	3.26 ± 0.18	16.49 ± 0.23	3.11 ± 0.15	22.86 ± 0.43

Table. 37. The fecundity, egg viability and immature survivorship of *Brevipalpus phoenicis* on *Mentha rotundifolia* at different temperature-humidity conditions

Sl. No.	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/day	Egg viability (%)	Immature survivorship (%)
		(Mean ± SEM)	Range			
1	25 ± 2°C & 80 ± 5 % RH	29.82 ± 1.23	25 - 32	1.64 ± 0.07	82.74 ± 1.86	84.26 ± 1.53
2	30 ± 2°C & 70 ± 5 % RH	35.61 ± 1.15	31 - 37	2.06 ± 0.05	87.11 ± 2.03	90.11 ± 1.47
3	35 ± 2°C & 60 ± 5 % RH	31.74 ± 0.89	27 - 34	1.93 ± 0.04	88.82 ± 1.37	89.61 ± 1.25

Table. 38. Duration of development of immature stages (egg-adult) of *Brevipalpus phoenicis* on *Mentha rotundifolia* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	6.09 ± 0.31	5.17 ± 0.15	5.24 ± 0.21	F
2	Larva	4.15 ± 0.25	3.21 ± 0.23	3.30 ± 0.19	F
3	Protochrysalis	2.26 ± 0.12	2.14 ± 0.16	2.27 ± 0.23	F
4	Protonymph	3.27 ± 0.28	3.06 ± 0.15	3.11 ± 0.21	F
5	Deutochrysalis	2.93 ± 0.19	2.24 ± 0.20	2.32 ± 0.17	F
6	Deutonymph	4.16 ± 0.22	3.86 ± 0.13	3.89 ± 0.20	F
7	Teliochrysalis	2.53 ± 0.32	2.19 ± 0.24	2.32 ± 0.16	F
8	Total Immature	25.39 ± 0.54	21.87 ± 0.49	22.45 ± 0.34	F

Table. 39. Duration of pre-oviposition, oviposition, post-oviposition and adult longevity of *Brevipalpus phoenicis* on *Vitex negundo* at different temperature-humidity conditions

Sl. No.	Temperature & Relative humidity	Duration (days)			
		Pre-oviosition period	Oviposition period	Post-oviposition period	Adult longevity
1	25 ± 2°C & 80 ± 5 % RH	6.02 ± 0.27	15.36 ± 0.35	3.61 ± 0.31	24.99 ± 0.70
2	30 ± 2°C & 70 ± 5 % RH	5.16 ± 0.32	14.39 ± 0.29	3.24 ± 0.19	22.79 ± 0.41
3	35 ± 2°C & 60 ± 5 % RH	4.73 ± 0.20	13.87 ± 0.37	2.90 ± 0.24	21.50 ± 0.39

Table. 40. The fecundity, egg viability and immature survivorship of *Brevipalpus phoenicis* on *Vitex negundo* at different temperature-humidity conditions

Sl. No.	Temperature & Relative humidity	Fecundity (number of eggs/female)		Number of eggs/female/day	Egg viability (%)	Immature survivorship (%)
		(Mean ± SEM)	Range			
1	25 ± 2°C & 80 ± 5 % RH	23.41 ± 1.05	20 - 25	1.52 ± 0.08	76.37 ± 2.31	79.54 ± 1.73
2	30 ± 2°C & 70 ± 5 % RH	28.62 ± 0.91	24 - 32	1.99 ± 0.06	81.15 ± 1.47	84.72 ± 1.62
3	35 ± 2°C & 60 ± 5 % RH	25.14 ± 0.42	21 - 29	1.81 ± 0.05	79.21 ± 1.64	83.14 ± 1.35

Table. 41. Duration of development of immature stages (egg-adult) of *Brevipalpus phoenicis* on *Vitex negundo* at different temperature-humidity conditions

Sl. No	Life stages	Duration of life stages at different temperature-humidity conditions (days)			Female (F)/Male (M) progenies
		25 ± 2°C & 80 ± 5 % RH	30 ± 2°C & 70 ± 5 % RH	35 ± 2°C & 60 ± 5 % RH	
1	Egg	7.27 ± 0.23	6.38 ± 0.19	6.43 ± 0.31	F
2	Larva	4.76 ± 0.18	4.13 ± 0.27	4.11 ± 0.15	F
3	Protochrysalis	2.43 ± 0.31	2.24 ± 0.22	2.37 ± 0.34	F
4	Protonymph	3.52 ± 0.24	3.21 ± 0.16	3.29 ± 0.27	F
5	Deutochrysalis	3.11 ± 0.30	2.43 ± 0.18	2.47 ± 0.21	F
6	Deutonymph	4.52 ± 0.35	3.94 ± 0.26	4.23 ± 0.17	F
7	Teliochrysalis	2.61 ± 0.27	2.26 ± 0.19	2.45 ± 0.13	F
8	Total Immature	28.22 ± 0.62	24.59 ± 0.46	25.36 ± 0.50	F

Table. 42. Species of mite predators present on medicinal plants surveyed

Sl. No.	Species of mite predators	Family	Host plants
1.	*Amblyseius largoensis* (Muma), 1955	Phytoseiidae	*Justicia adhatoda*, *Datura metel*, *Cardiospermum halicacabum*, *Leucas lavendulifolia**, *Acalypha indica**, *Moringa oliefera*, *Crotalaria retusa*, *Desmodium gangeticum*, *Helianthus annus*, *Mussaenda frondosa**, *Phyllanthus amarus*, *Ricinus communis*, *Sesamum indicum*, *Sida rhombifolia*, *Emilia sonchifolia*, *Cassia fistula*, *Clitoria ternatea*, *Thottea siliquosa*, *Oxails corniculata* & *Inula racemosa**
2.	*A. channabasavannai* Gupta and Daniel, 1978	Phytoseiidae	*Biophytum reinwardtii**, *Clerodendron infortunatum*, *Boerhaavia diffusa*, *E. sonchifolia**, *Mentha rotundifolia*, *C. ternatea*, *M. frondosa*, *A. indica*, *Aerva lanata*, *Strychnos nux-vomica* & *Vernonia cinera*
3.	*A. indirae* Gupta, 1985	Phytoseiidae	*J. adhatoda*, *P. nigrum*, *Andrographis paniculata**, *Ecobolium viride**, *B. reinwardtii** & *Chromoleana odorata*
4.	*A. herbicolus* (Chant)		*R. communis* & *Leucas aspera*
5.	*Neoseiulus longispinosus* (Evans, 1952)	Phytoseiidae	*M. oliefera*, *R. communis*, *Carica papya*, *J. adhatoda*, *Nageia wallichiana*, *C. halicacabum**, *L. lavendulifolia**, *A. indica*, *H. annus*, *M. frondosa*, *Cyathula prostrata*, *Datura metel*, *M. rotundifolia* & *Gliricidia sepium**
6.	*A. paraaearialis* Muma, 1967	Phytoseiidae	*Eucalyptus globules**, *Ficus bengalansis* & *Elaecarpus recurvatus*
7.	*Paraphytoseius multidentatus* (Swirski and Shechter), 1961	Phytoseiidae	*Indigofera tinctoria**, *Hibiscus aculeatus**, *A. moschatus*, *Adenanthera pavonina*, *E. sonchifolia* & *Lantana camara**
8.	*P. orientalis* (Narayanan, Kaur & Ghai)	Phytoseiidae	*J. adhatoda*, *P. nigrum* & *C. prostrate*
9.	*A. aerialis* (Muma), 1955	Phytoseiidae	*Zingiber officinale*, *T. chebula*, *Citrus limon*, *V. trifolia*, *Rosa centifolia*, *Plumbago indica* & *Malus sylvestris*
10.	*A. adhatodae* Muma, 1967	Phytoseiidae	*R. indica*, *Psidium guajava*, *L. lavendulifolia**, *T. chebula** & *Nageia wallichiana*
11.	*Euseius sacchari* Ghai and Menon, 1967	Phytoseiidae	*Evolvulus alsinoides*, *R. communis*, *P. emblica**, *A. indica*, *Azadiracta indica* & *Clerodendrum infortunatum**
12.	*E. coccineae* Gupta, 1975	Phytoseiidae	*I. tinctoria*, *E. recurvatus**, *Annona squamosa*, *Gymnema sylvestre** & *C. inerme*

13.	*E. ovalis* (Evans)	Phytoseiidae	*G. sepium*, *Woodfordia fruticosa*, *Plectranthus amboinicus**, *Scoparia dulcis**, *M. sylvestris*, *P. reticulatus*, *Justicia adhatoda*, *D. metel*, *C. halicacabum**, *Ipomoea mauritiana**, *B. variegata* , *C. paniculatum*, *A. indica**, *Moringa oliefera*, *Vitis vinifera*, *L. lavendulifolia**, *A. esculentus*, *Bacopa monnieri* & *C. ternatea*
14.	*E. alstoniae* Gupta, 1975	Phytoseiidae	*L. aspera*, *S. rhombifolia*, *J. gendarussa*, C. *paniculatum*, *Ecobolium viride** & *Premna corymbosa**
15.	*E. rhododendronis,* Gupta, 1970	Phytoseiidae	*Z. officinale*, *Curcuma aromatica* & *I. balsamina**
16.	*E. finlandicus* (Oudemans, 1915)		*H. annus*, *M. frondosa* & *Datura metel*,
17.	*Cunaxa myabunderensis* Gupta & Ghosh, 1980	Cunaxidae	*V. negundo**, *O. sanctum**, *O. gratissimum* & *L. inermis**
18.	*Bdelloides* sp.	Bdellidae	*B. acuminata*, *L. lavendulifolia*, *O. sanctum*, *O. gratissimum*, & *V. negundo*
19.	*Agistemus* sp.	Stigmaeidae	*Artabotrys zeylanicus** & *Dalbergia lanceolaria*
20.	*Cheyletus malaccensis* Oudemans, 1903	Cheyletidae	*V. negundo*, *J. adhatoda* & *Aegle marmelos**

* New record

Table. 43. Species of insect predators present on medicinal plants surveyed

Sl. No.	Species of insect predators	Family	Host plant
1	*Feltiella acarisuga* (Vallot, 1872)	Cecidomyiidae	*C. halicacabum**, *Rosa centifolia*, *A. esculentus*, *Scoparia dulcis**, *H. rosa-sinensis*, *Vitis vinifera*, C. *ternatea**, *A. indica**, *Leucas aspera**, *L. lavendulifolia**, *R. communis* & *Helianthus annus*
2	*Scolothrips asura* Ramakrishna & Margabandhu, 1931	Thripidae	*Bauhinia accuminata**, *Malus sylvestris**, *Biophytum reinwardtii**, *Clerodendrum infortunatum*, *Withania somnifera*, *Citrus limon*, *F. religiosa*, *J. adhatoda** & *Oxails corniculata*
3	*S. longicornis* Priesner, 1926	Thripidae	*C. halicacabum**, *L. lavendulifolia*, *A. indica*, *R. communis**, *Justicia adhatoda*, *Emilia sonchifolia** & *Thottea siliquosa**
4	*Stethorus punctillum* Wiese, 1981	Coccinellidae	*R. communis*, *Datura metel*, *Boerhaavia diffusa*, *Emilia sonchifolia**, *Clerodendron infortunatum*, *M. frondosa*, *Clitoria ternatea**, *A. indica**, *Aerva lanata*, *Strychnos nux-vomica*, *Vernonia cinera*, *S. rhombifolia**, *Rosa centifolia* & *D. motorium**
5	*S. gilvifrons* (Mulsant, 1850)	Coccinellidae	*A. indica*, *Helianthus annus*, *H. rosa-sinensis**, *A. esculentus* & *Carica papya*

* New record

Table. 44. Predatory potential of natural enemies on selected species of pest mites

Sl.No.	Species of Insect/mite predator selected	Life stages of the predator selected	Species of Pest mite offered as test prey	Per day consumption of predator on life stages of pest mites (Mean ± SE)					
				Egg		Nymph		Adult	
				offered	consumed	offered	consumed	offered	consumed
1	*Feltiella acarisuga*	Larva	*Tetranychus neocaledonicus*	50	43.07 ± 2.04	50	35.19 ± 2.13	50	23. 27 ± 2.17*
2	*Amblyseius largoensis*	Adult female	*T. neocaledonicus*	50	27.48 ± 1.92	50	18.79 ± 2.05	50	10.47 ± 1.08**
3	*Scolothrips asura*	Larva	*Oligonychus biharensis*	50	39.61 ± 1.32	50	27.15 ± 1.16	50	21. 27 ± 2.13*
4	*Euseius ovalis*	Adult female	*O. biharensis*	50	21.92 ± 1.09	50	14.79 ± 2.05	50	8.47 ± 2.08**
5	*Cunaxa myabunderensis*	Adult female	*Brevipalpus phoenicis*	30	26.03 ± 2.02	30	23.61 ± 1.57	30	17.19 ± 2.17*
6	*C. myabunderensis*	Nymph	*B. phoenicis*	30	19.14 ± 1.83	30	14.61 ± 2.04	30	11.61 ± 2.13*
7	*A. largoensis*	Adult female	*B. phoenicis*	30	14.32 ± 2.07	30	9.92 ± 1.09	30	6.73 ± 1.24**

* P<0.01; ** P<0.02

Table. 45. Acaricidal activity of *Glyricidia sepium* leaf extract on the species of pest mites studied

Sl. No.	Concentration (%) of the plant extract tested	Per cent mortality of pest mites (Mean ± SEM) at different exposure periods					
		Tetranychus neocaledonicus			*Oligonychus biharensis*		
		24 h	48 h	72 h	24 h	48 h	72 h
1	2.5	10.34 ± 1.21	13.24 ± 2.25	15.47 ± 2.10	7.25 ± 1.17	10.41 ± 2.19	11.21 ± 2.05
2	5.0	50.21 ± 1.92	53.29 ± 1.78	56.33 ± 1.97	41.04 ± 2.31	42.54 ± 1.94	43.61 ± 2.23
3	10.0	81.83 ± 1.16	85.83 ± 2.03	89.31 ± 2.15	72.52 ± 1.24	73.98 ± 2. 24	77.37 ± 1.98

$P<0.01$

Table. 46. Acaricidal activity of *Chromolaena odorata* leaf extract on the species of pest mites studied

Sl. No.	Concentration (%) of the plant extract	Per cent mortality of pest mites (Mean ± SEM) at different exposure periods					
		Tetranychus neocaledonicus			*Oligonychus biharensis*		
		24 h	48 h	72 h	24 h	48 h	72 h
1	2.5	9.15 ± 0.93	10.78 ± 1.93	11.25 ± 2.13	6.13 ± 1.20	7.72 ± 1.20	8.43 ± 2.17
2	5.0	47.23 ± 1.25	48.56 ± 2.17	50.73 ± 2.09	36.16 ± 2.08	37.16 ± 1.37.	39.27 ± 1.90
3	10.0	74. 16 ± 1.05	76. 58 ± 1.15	77. 29 ± 2.03	61.71 ± 1.21	63.42± 2.41	64.03 ± 2.09

$P<0.02$