STUDIES ON MITES ASSOCIATED WITH TEA PLANTATIONS

IN NORTH KERALA

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the faculty of science, University of Calicut
For the Award of the Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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CERTIFICATE

This is to certify that the thesis titled "**STUDIES ON MITES ASSOCIATED WITH TEA PLANTATIONS IN NORTH KERALA"** is an authentic record of the work carried out by **Jayakrishnan.T.V.** under my supervision and guidance in partial fulfillment of the requirements of the Degree of Doctor of Philosophy in Zoology in the Division of Acarology of this Department and that no part thereof has been presented before for any other degree or diploma.

C.U Campus
27.01. 2016

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DECLARATION

I do hereby declare that this thesis titled "**STUDIES ON MITES ASSOCIATED WITH TEA PLANTATIONS IN NORTH KERALA"** is an authentic record of the 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 has been submitted before for the award of any other Degree or Diploma.

Calicut University Campus,
Date: 27/01/2016 **Jayakrishnan.T.V.**

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CONTENTS

LIST OF PLATES INCLUDED

22) Postembryonic developmental stages of *B.phoenicis*

23) Duration (in days) of pre-oviposition, oviposition, post- oviposition periods of *B. phoenicis* on Tea at different temperature - humidity conditions

24) Fecundity of *B.phoenicis* on *C. sinensis* at different temperature humidity conditions.

25) Duration (in days) of development of *B.phoenicis* on *C. sinensis* at different temperature humidity conditions

26) Comparative histogram showing duration of life stages of *B.phoenicis* under different temperature-humidity conditions on Tea

27) Morphological description of Larva of *B.phoenicis*

28) Morphological description of Protonymph of *B.phoenicis*

29) Morphological description of Deutonymph of *B.phoenicis*

30) Morphological description of female of *B.phoenicis*

31) Duration (in days) of pre-oviposition, oviposition, post- oviposition periods of *A.theae* on Tea at different temperature - humidity conditions

32) Fecundity of *A.theae* on *C. sinensis* at different temperature humidity conditions.

33) Duration (in days) of development of *A.theae* on *C. sinensis* at at different temperature humidity conditions

34) Comparative histogram showing duration of life stages of *A.theae* under different temperature-humidity conditions on Tea

35) Postembryonic developmental stages of *A.theae*

36) Morphological description of Nymphal stages of *A.theae*

37) Morphological description of Adult male & Female of *A.theae*

38) Plants selected for the preparation of Aqueous extracts

39) Glass Atomizer

40) a) Ovicidal activity of aqueous plant extracts on *O. coffeae* under laboratory condition

b) Acaricidal activity of aqueous plant extracts on adult *O. coffeae* under laboratory conditions

41) Predatory mites recovered along with *O.coffeae*

42) Rate of predation of different life stages of *A.largoensis* on *O.coffeae*

LIST OF TABLES

21) Fecundity of *B.Phoenicis* on *C.sinensis* at 25± 2ºC & 80 ± 5% RH

22) Fecundity of *B.Phoenicis* on *C.sinensis* at 30 ± 2ºC & 70 ± 5% RH

23) Fecundity of *B.Phoenicis* on *C.sinensis* at 35 ± 2ºC & 60 ± 5% RH

24) Duration (in days) of development of *B.Phoenicis* on *C.sinensis* at 25± 2ºC & 80 ± 5% RH

25) Duration (in days) of development of *B.Phoenicis* on *C.sinensis* at 30 ± 2ºC & 70 ± 5% RH

26) Duration (in days) of development of *B.Phoenicis* on *C.sinensis* at 35 ± 2ºC & 60 ± 5% RH

27) Duration (in days) of pre-oviposition, oviposition and post-oviposition of *A.theae* on *C.sinensis* at different temperature-humidity conditions

28) Fecundity of *A.theae* on *C.sinensis* at25± 2ºC & 80 ± 5% RH

29) Fecundity of *A.theae* on *C.sinensis* at30 ± 2ºC & 70 ± 5% RH

30) Fecundity of *A.theae* on *C.sinensis* at 35 ± 2ºC & 60 ± 5% RH

31) Duration (in days) of development of *A.theae* on *C.sinensis* at 25± 2ºC & 80 ± 5% RH

32) Duration (in days) of development of *A.theae* on *C.sinensis* at 30 ± 2ºC & 70 ± 5% RH

33) Duration (in days) of development of *A.theae* on *C.sinensis* at 35 ± 2ºC & 60 ±5% RH

34) Ovicidal activity of aqueous plant extracts on eggs of *O. coffeae* under laboratory condition.

35) Acaricidal activity of aqueous plant extracts on adult *O. coffeae* under laboratory conditions.

36) Rate of Predation by *A.largoensis* on *O.coffeae* under different Prey-predator ratios

37) Rate of Predation by *A.herbicolus* on *O.coffeae* under different Prey-predator ratios

38) Rate of predation by different life stages of *A.largoensis* on different stages of *O. coffeae* in 24 hours at a temperature of 30 ± 2ºC and 70 ± 2% RH.

39) Percentage of predation by different stages of *A. largoensis* on different stages of *O. coffeae* in 24 hours at a temperature of 30 ± 2ºC and 70 ± 2% RH

PART I
INCIDENCE AND SEASONAL ABUNDANCE OF TEA MITES

INTRODUCTION

Tea is one of the most popular beverages all over the world owing to its distinct aroma, flavor and health benefits. It is a heterogeneous plant with many overlapping morphological, biochemical and physiological attributes. It is a perennial plant which belongs to the family *Camelliaceae* and all the cultivated tea plants belong to two distinct species viz. *Camellia sinensis* (L.) O. Kuntze, the short leaved "China" plants and *C. assamica* (Masters) Wight, the broad leaved "Assam" cultivar. The "Cambod" variety, a subspecies of the latter, is classified as *C. assamica* ssp. *Lasiocalyx* Wight (Wight, 1959). "China", "Assam", "Cambod" 'jats' and a large number of their hybrids are cultivated commercially in majority of the tea plantations. Many wild species of *Camellia* have also contributed to the present day hybrid population of cultivated tea plants. Tea prefers a warm humid climate, well distributed rainfall and long sunshine days. Under natural conditions, this plant grows to a small tree but brought into a bush form by pruning at regular intervals for the convenience of plucking. It is mainly grown in Asia followed by Africa and to a very small extent in Europe, Australia and South America. India is the second largest producer of tea in the world.

Tea plays a major role in the economy of several underdeveloped and developing nations in Asia and Africa. In India, this crop is grown in more than 500,000 ha, of which about 97,600 ha is cultivated by 123,000 small

growers. Besides them, there are large companies and proprietary holdings owning large areas of tea plantations. The Indian tea industry directly employs more than a million people, of which 50% are women (Hudson *et.al*. 2002).The industry generates income and livelihood for more than 10 million people in this country. The tea gardens situated in the rural areas contribute significantly to the social, educational and economic development of the people of these regions. The tea ecosystem, situated close to the forest ecosystem has a predominant role in the maintenance of terrestrial ecology by providing extensive land cover and preventing soil erosion. In India most of the tea plantations are situated in the North Eastern and southern region of the country. Tea plantations in south India are spread over the slopes of Western Ghats of Wayanad, Central Travancore, High Ranges, Nilgiris, Anamallais and Chikmangalur of Karnataka (Plate.1).

Similar to any other plantation crop, tea plants also are subjected to the attack of more than 300 species of animals, the most important of which are insects, mites and nematodes. Since tea is a perennial crop and grown as monoculture, the tea ecosystem provides a stable, favorable environment and unbroken food supply to the pests. Each tea growing country has its own distinctive pests though many species have been recorded from more than one zoogeographical area. Crop loss in tea due to pests, diseases and weeds varies between 15 and 20 percent. The magnitude of losses is found to be higher today in view of the increased production and productivity. In south India,

mite infestation causes severe damage to tea plantation and thereby causes considerable loss to our economy. A severe outbreak of red spider mites happened in 2005 in the Nilgiri district of Tamilnadu caused severe loss to planters in turn leading to significant economic damage. Reports have come from Kerala also about the destruction caused by different groups of mites on tea. In many instances, lack of information about the correct identity of mites, their biology and ecology caused serious consequences to tea planters.

Among the arthropod pests associated with tea plantations, mites constitute an important group of organisms belonging to the class Arachnida of the phylum Arthropoda. Mites together with ticks constitute the subclass Acari and the study centered on Acari constitutes the distinct discipline, the so called Acarology. In the 20th century, Acarology has gained considerable momentum throughout the world on account of the role played by Acari either in the beneficial or injurious levels in various fields of human fascination such as agriculture, floriculture, horticulture, animal husbandry, forestry, forensic science, medical and veterinary fields and so on. Because of their microscopic size and cryptic behaviour, mites usually escape the attention of man and the damage symptoms induced by many of the phytophagous mites are assessed solely on the basis of host response. In terms of habits, mites represent a heterogeneous group enjoying phytophagous, predatory, parasitic, scavenging and commensalistic modes of life. The major plant feeding groups of mites generally belong to the families

Tetranychidae, Tenuipalpidae, Eriophyidae, and Tarsonemidae which are considered to be of economic importance due to the various types of injuries caused by them leading to substantial yield loss. Apart from these, a few groups of oribatid mites which are known to colonize a variety of forest and garden plants also exhibit phytophagous habit. Plants also support a considerably good number of predatory mites coming under the families Phytoseiidae, Ascidae, Bdellidae, Cheyletidae, Cunaxidae, Stigmaeidae, Trombididae etc. which play an important role in checking the population of pest mites under field conditions.

Phytophagous mites cause several types of direct damages like loss of chlorophyll, appearance of striplings or bronzing of foliage, formation of galls and erineal patches and stunting of growth, thereby causing a number of deformities and reduction of yield. Besides these direct damages, many species are known to act as vectors of pathogenic plant viruses causing more potential loss to growers. During the last few decades, indiscriminate use of chlorinated hydrocarbons against general pests, resulted in massive destruction of their natural enemies. In addition, the implementation of improved cultivation practices and changed environmental conditions together played significant roles in the rapid buildup of mite populations to exceed the economic threshold levels and thereby assigning the status of pests in varying levels.

Considering the increasing need of tea as a popular beverage among all sectors of people and the varying levels of everlasting pest problems experienced in the tea plantations of North Kerala, the present study was proposed with a view to undertake detailed survey on the mites, both of the phytophagous and predatory category and to study the distribution pattern, seasonal abundance, the effect of climatic conditions on the population density of pest mites and also to elucidate the damage potential of the most injurious species of local importance through qualitative and quantitative measures. The study was also extended to locate some natural enemies like the predatory phytoseiid mites which have promising potential to exert significant regulation of selected pest mite population under laboratory conditions. Simultaneously, initiates have also been made during the present study, to develop some biopesticide formulations comprised of plant extracts in different concentrations against selected pest mite species.

REVIEW OF LITERATURE

Tea mites being a less explored and poorly known group currently includes only very few references and hence in the present review attention has been focussed to incorporate the research work carried out on phytophagous mites infesting on all types of host plants including the tea plant.

Peal (1868) made the first record of phytophagous mites in India when he discovered the tea mites in Assam and called it as red-spider. Wood Mason (1884) conducted further studies on this mite and described it as *Tetranychus bioculatus* which formed the first published reference on Indian plant mite of agricultural significance. According to Das (1960) the major factors influencing the abundance of RSM were nature and time of pruning and skiffing, degree of cleaning at pruning, defoliation, height of plucking, abandoned tea and seed trees, kinds or 'Jats' of tea, and type of manuring. Rimando (1962) provided information on two species of spider mites viz. *T. fijiensis* and *T. neocaledonicus* from coconut foliage in Philippines. A detailed account on the mites of the families, Tenuipalpidae and Tetranychidae associated with citrus in South East Asia was provided by Manson (1963). Osakaba (1965) carried out studies on the seasonal fluctuation and population density of the tea spider mite, *T. kanzawai* and revealed that heavy rain and wind results in its high mortality in Japan. Gupta *et al*. (1971) made a study

on the phytophagous and predatory mite fauna of Punjab and Himachal Pradesh. Nageshchandra and ChannaBasavanna (1976a) prepared a list of the host plants of *B. phoenicis.* The same authors (1976b) made faunistic studies of the false spider mites of India. Banerjee (1979) reported that leaf temperature and light penetration within tea bushes could influence the distribution of *O. coffeae* and the species preferred to colonise the middle zone of the bush (30 cm below the plucking surface)

Lal and Mukharji (1980) recorded the seasonal history of *Eotetranychus orientalis* and *E. uncatus*. They observed that high temperature with low humidity and sunny days was favourable for *E. orientalis*, while moderate temperature with moderate to high humidity favoured the development of *E. uncatus*.

The population density of the pink tea mite, *Acaphylla theae* would attain the peak level during late May, and then was found to fluctuate in June- August, showing an increase again to reach the peak level in late October, as evidenced through the studies of Muraleedharan and Chandrasekharan (1981). Observation on the seasonal incidence of *T. ludeni* on brinjal was made by Puttaswamy and ChannaBasavanna (1981a). They observed that heavy rain washed off the active stages of the mite and increase in population was related with periods of less rainfall, lower RH and higher mean temperature. An ecological study of the influence of temperature,

relative humidity and rainfall on the population of spider mite species like *E. orientalis, T. neocaledonicus* and *T. cinnabarinus* on cassava was carried out by Lal (1982) and observed a significant correlation between population increase and relative humidity and non-significant correlation between population size and temperature. Salmon (1983) conducted studies on the influence of host plants and temperature on the population build-up of *E. orientalis.* Dhooria and Butani (1983) recorded highest population of *E. orientalis* on orange during the period from May to September and negligible population during December to March. They also observed a positive correlation between mite population and high temperature. Boyne and Hain (1983) studied the effect of constant temperature, relative humidity and rainfall on the development of *O. ununguis* on Fraser fir seedlings and observed best response of the mite to temperatures averaging to 26ºC and to relative humidity levels approaching 50 to 60%. Sharma and Kushwaha (1984) studied the varietal preference of *T. neocaledonicus* on 4 varieties of brinjal in Rajasthan and observed high incidence of the mite on Black beauty variety. Mikwaila (1985) reported that in Malawi, South East Africa, the population of RSM reached in peak level during mid-November and the peak population persisted till the onset of monsoon. Murega and Khaemba (1985) studied the effect of infestation by red spider mites on cotton. The authors expressed severity of damage in terms of decline in vegetative growth, number and surface area of leaves, seed development and yield of the plant.

Holtzer *et al.* (1988) gave information on the direct and indirect effects of microenvironment on population dynamics of tetranychid mites. Shanks and Doss (1989) studied the seasonal variation in the population density of the two spotted spider mite on strawberry.

Goodwin (1990) studied the seasonal abundance and control measures of spider mites infesting strawberries in coastal New South Wales. Bali (1993) conducted preliminary studies on the demography of the Pacific spider mite, *T. pacificus*. Studies on the relationship of the population of *Schizotetranychus cajani* with different parameters like temperature and relative humidity were made by Karmakar *et al.* (1994) and the authors recorded maximum mite population at 26.95ºC and 49.55% RH. Salazar *et al.* (1998) conducted biological observations on the two spotted spider mite, *T. urticae* infesting raspberry crop and found that the population of this mite was highest in February. Saikia *et al.* (1999) investigated the biology of *O. coffeae* on tea and revealed that the mite could breed throughout the year and its life cycle was shorter, during April and May. Haq (1999a) studied the occurrence and outbreak of the coconut mite, *Aceria guerreronis* in Kerala and he further (1999 b) gave information on the distribution of this mite in peninsular India and adjacent islands. Selvasundaram and Muraleedharan (2003) reported that in South India the incidence of RSM was the period of high during January to May and it was low during June to December. The population density was highest during April/May and it was lowest during the wet, rainy months of July to October.

Sangita and Bhardwaj (2004) conducted observations on the population build up of *P. ulmi* and suggested that an increase in mite population could be attained by a subsequent increase in temperature and relative humidity to 20.85 - 22.85°C and 72.8 - 90.4 % RH respectively. Karmakar and Saha (2005) studied the population dynamics of *B. phoenicis* on the invasive plant, *Mikania micrantha* in relation to weather parameters and observed significant positive correlations between mite population and minimum temperature and minimum relative humidity. Girisha and Nandihalli (2009) studied the seasonal abundance and varietal reaction of the coconut mite, *A. guerreronis* during 2004-2005 in Dharwad area and observed that the mite population occurred throughout the year with variations during different seasons of the year. The mite population was high during the months of April and May. Ahmed and Aslam (2011) documented the adverse effect of persistent rainfall on the population density of *O.coffeae* in Bangladesh. In Sri Lanka, the outbreaks of *O.coffeae* occurred during dry weather, i.e. May–September and January-April period as reported by Amarasena *et al*.(2011)

Haque *et al.* (2011) studied the seasonal abundance of spider mite *T.urticae* on vegetables and ornamental plants in Rajshahi, Bangladesh, during August, 2010 to January 2011 and observed that the increase in mite population was directly related with the increase in temperature.

Nasareen and Ramani (2015) assessed the impact of seasonal changes on the population density of the gall mite, *A. doctersi* with in the leaf galls of *Cinnamomum verum* during the period from January, 2012 to December,

2012. The authors found a positive correlation between temperature and population density of the mite whereas rainfall showed a negative correlation with mite population size. The same authors (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. They also depicted negative correlation between number of mites and rain fall and positive correlation of the same with relative humidity. While conducting studies on the seasonal incidence of the red spider mite, *O. coffeae* infesting tea in Assam, Mazid *et al*. (2015) recorded highest population of the mite in the second fortnight of June and lowest mite population was observed in December. With the onset of rainfall, the mite population was found to show a sudden decline and in winter months, the population was minimum. The authors could establish a moderate positive correlation with humidity and maximum temperature and significant positive correlation with minimum temperature and rainfall. Results of the surveys conducted by Srikumar *et al.* (2015) in tea plantations of Anamallais, Tamilnadu revealed the record of *Persea americana* as a new host plant of *O. coffeae.*

MATERIALS AND METHODS

Sampling localities

In par with the objectives of the proposed research work, field sampling was carried out from sites distributed over tea plantations of the Wayanad district of Kerala. Wayanad is located in the north east of Kerala state. It is set high on the Western Ghats with altitudes ranging from 700 to 2100 m. The geographical location of Wayanad is 11. 27' to 15. 58' N latitude and 75.47' to 70.27' E longitude. It boarders with the Kozhikode, Malappuram and Kannur districts in Kerala, Nilgiri district in Tamilnadu and Coorg, Mysore and Chamarajanagar districts of Karnataka. The average rainfall in the district is 2322 mm. The mean maximum and minimum temperature for the last 5 years were 29^0 C and 18^0 C respectively. This place experiences a high relative humidity during the south-west monsoon. The flora of Wayanad are characteristic of the Western Ghats and the plantation crops are grown in the cool climate. Tea is grown as an industry in large estates.

The sampling localities included in the present investigation were

1. Mananthavadi:

It is located 28 km north-east of the district headquarters, Kalpetta, 80 km east of Thalassery and 92 km north-east of Kozhikode.

2.Periya:

It is located 32 km towards north from district headquarters, Kalpetta and 8 km from Mananthavady.

3. Vythiri:

It is located 60 km east of Kozhikode and 18 km south-west of district headquarters, Kalpetta.

4. Chundale:

Chundale is located in Kalpetta, the district headquarters of Wayanad.

5. Meppadi:

It is located 14 km south-west of Kalpetta and 80 km east of Kozhikode.

The tea plantations located in the above mentioned sites (Plate 2) were visited frequently to record the incidence of mites and also for collection of the different groups of mites. Live specimens representing the different species of mites in all stages of development were collected during the study period by examining the infested leaves and leaflets of tea plants grown in the various localities. Data on the climatic parameters of the sampling sites were well documented at the time of sampling.

Sampling of mites

Aerial parts of the tea plants, especially the leaves and leaflets showing signs of mite infestation were collected with the help of a scissors and transferred to polythene bags, loosely tied with rubber band, labelled and transported to the laboratory for examination. Within the laboratory, the collected leaf samples were examined under a Stemi DV4 stereozoom microscope and the live mites were directly picked up with the help of a moistened camel hair brush. The mites thus picked up were either transferred to 70% alcohol for further processing or to fresh leaves for biological studies.

For the study of seasonal abundance of major pest mites identified, an experimental area consisting of 1000 unpruned tea bushes were selected. This block was further subdivided in to 5 sub blocks consisting of 200 bushes each. Ten leaves were randomly sampled from each block at monthly interval from January to December, 2011. The collected leaves were transferred to polythene bags and were brought to the laboratory. Adult and immature stages of mites were counted under the stereozoom microscope at 10x magnification and data was recorded. The correlation coefficients were worked out between the average number of mites recorded and the corresponding monthly mean weather parameters viz., temperature, relative humidity and rainfall.

OBSERVATIONS

FIELD SURVEY

Results of field survey carried out during the present study enabled to record the presence of different groups of phytophagous mites and predatory mites associated with the tea plantations of North Kerala. Apart from mites, a number of insect groups also were present in the tea plantations surveyed. The recovered mites on identification were found to belong to the families Tetranychidae, Tenuipalpidae, Eriophyidae, Tarsonemidae and phytoseiidae. Of these, the former three families represented exclusively phytophagous mites showing heavy infestation in tea plantations while and phtoseiidae comprised of predatory mites. The phytophagous mites collected during the study were identified as *Oligonychus coffeae* Neitner, *Brevipalpus phoenicis* Geijskes, *Acaphylla theae* Watt, *Calacarus carinatus* Green, *Polyphagotarsonemus latus* Banks and the predatory mites were of the genus *Amblyseius viz. A.largoensis* (Muma), *A. herbicolus* (Chant), *A.channabasavannai* Gupta and Daniel and *Neoseiulus longispinosus* (Evans). Of the phytophagous mites recoverd, *O.coffeae, B.phoenicis, A. theae and C.carinatus* were found distributed in all the collection sites screened during the study while incidence of *P. latus* was scanty and detected only in Mananthavadi and Periya sites. Of all the phytophagous mites,

O.coffeae was recognized as the most widely distributed species in the tea plantations of North Kerala and which was recognized to induce severe damage to the tea plants.

Of the above phytophagous species, *O.coffeae, A.theae and B.phoenicis* were considered for detailed studies on seasonal abundance and distribution pattern owing to their large population size observed during the present study. For this, regular sampling of the above three species was carried out for a period of January 2011 to December 2011 follwing the method described earlier.

Seasonal distribution of *O.coffeae,* the Red Spider mite (RSM)

Results of field study showed that the number of mites started to increase from the month of February. Mite population continued to increase gradually with the increase in atmospheric temperature from February to May. As shown in table 1 & Plate 4, the maximum population of mites could be observed in the month of May, reaching a population size of 74.6 ± 4.1 mites per leaf. Then the mite population was found to decline in June and showed further reduction in July and August, with the commencement of monsoon. As the rainfall got reduced, the mite was found to regain its population density from September onwards, and reached to a moderate size of 32.4 ± 1.4 per leaf in October. With the decrease in environmental temperature, the mite population again experienced a decline as the

temperature got decreased and very low numbers could be noted on tea leaves during the months of November and December. The mean number of RSM recorded per leaf was 16.6 ± 0.8 and 11.1 ± 0.1 respectively for the months of November and December. On statistical analysis a significant and positive relationship (r = 0.65) was observed between mite population and minimum temperature whereas, relationships with other meteorological parameters were found to be non-significant.

Seasonal distribution of *B. phoenicis*

During the field survey, *B. phoenics* was found to occur on tea leaves throughout the year. The population of the mite varied significantly on different months of the year (Table 2 & Plate 4). The mite showed peak population density during the months of April and May recording a mean number of 14.7 ± 1.6 and 16.1 ± 2.4 respectively per tea leaf. At the onset of the South-West monsoon, from June to August 2011, the mite population was found to decline and the number of mites on tea leaf was scanty. A moderate population density of the mite was observed during all the remaining months.

The results of the studies on population distribution of mite upon statistical analysis enabled to establish a significant positive correlation between mite population and maximum temperature (r = 0.86) and a strong negative correlation (r = -0.65) between population density and rainfall. All the other meteorological parameters were found to be non-significant.

Seasonal distribution of *A.theae*

Incidence of *A.theae* on tea was recorded throughout the year and its population was found to fluctuate in accordance with the seasonal factors. During the month of January 2011, the population of *A.theae* on tea plants was scanty (8.4 ± 0.2 mites per leaf) and subsequently, the population size got increased from the month of February (Table 3 & Plate 4). Resembling the former two species mentioned earlier, *A.thea* also attained a peak population size (45.6 ± 3.2) in the month of May when the atmospheric temperature almost reached to 29.4 ^{o}C. Thereafter, the mite population dwindled, reaching a minimum level during the monsoon period. The population size of the mite was moderate during the month of September and started to decline in the subsequent months of November and December. Statistical analysis of the results of population studies of the mite disclosed a significant positive correlation (r = 0.84) between mite population and maximum temperature whereas a significant negative correlation was observed between mite population density and minimum RH (r = - 0.64) and rainfall (r = - 0.71).

PART II
FEEDING AND BREEDING BIOLOGY OF MITES INFESTING TEA

INTRODUCTION

Tea plants host diverse types of arthropod pests, of which insects and mites have been assigned as the major group. In almost all tea plantations of south India, mites have been recognized to cause considerable damage to the foliage, quite often imparting a grazed appearance to tea bushes. Among the mite pests, the major groups which threaten the tea plantations of South India have been categorized under two superfamilies viz. Tetranychoidea and Eriophyoidea. In the former group, two closely related but distinct families viz. the Tetranychidae and the Tenuipalpidae, are of major concern to tea plantations of North Kerala. In the latter group, members of the family Eriophyidae are known to damage the young bushes in tea plantations.

Members of Tetranychidae of the order Prostigmata are commonly called as Spider mites. They are the most important mites attacking plants. Many of the spider mite species are polyphagous and include some of the major pests of economic plants. These mites are commonly called as spider mites because of their ability to spin silk to form the webbing for the anchorage of eggs, protection or pheromonal transfer. These silk strands, produced from a pair of glands near the mouth, help in the dispersal from infested to non-infested leaves. Extensive silk webbing may form a shield which protects the mites from pesticide sprays. Life history of tetranychids includes different stages viz., egg, a six-legged larva, two eight-legged

nymphs (protonymph and deutonymph) and three quiescent stages in between, before transforming into an eight-legged adult. Under ideal conditions, they can complete their development from egg to adult in a short time and there may be many overlapping generations in a single season. Development from egg to adult often takes one to two weeks or more, depending on mite species, host plants, temperature, humidity and other environmental factors.

Members of the family Tenuipalpidae are commonly known as ‘false spider mites’ and belong to the superfamily tetranychoidea in the order Prostigmata. Tenuipalpid mites are not true spider mites as they do not produce silk webbing on plants. They are also called as ‘flat mites’ because most of the species are dorsoventrally flattened. Apart from the direct damage caused by feeding, many species are known to serve as vectors, transmitting various phytopathogenic plant viruses. The life cycle of the false spider mites is similar to that of spider mites consisting of egg, larva, protonymph, deutonymph and adult stages. The duration of developmental time differs among different species, but is longer than that in spider mites. Parthenogenesis is common in this group and they often have a very high female to male sex ratio.

Eriophyid mites, the commonly called gall mites or blister mites belong to the family Eriophyidae of the order Prostigmata.They are fusiform

or worm-like and invisible to the naked eye, but induce diverse forms of visible plant abnormalities such as galls, leaf blisters and rusts. Most of the species are highly host specific and many species are limited to plant species within a single genus, with few exceptions. Unlike the mites of other groups, eriophyids are characterized by the possession of two pairs of legs, in all stages of development. Both pairs of legs terminate in a feather-like empodium and are without true claws. The life cycle passes through the egg, nymph and adult stages. Development is temperature-dependent and life cycle is completed in about a week around 25°C. The life cycle may be more complex due to the presence of an overwintering 'deutogyne' female in temperate regions.

The present study includes an investigation on the feeding and breeding attributes of three very common species of mite pests of tea viz., the red spider mite, *O.coffeae*, the flat mite of the family Tenuipalpidae, *B.phoenicis* and the tea rust mite of the family eriophyidae, *A. theae* under different temperature-humidity parameters to supplement data on the optimum conditions for the population buildup of these species. The temperature-humidity parameters selected were 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH.

Further, the extent of damage induced by these species of mites were also assessed through the estimation of loss in chlorophyll content in the mite

infested leaves. Biotic stress developed by the tea plant in response to mite infestation was also worked out by estimating the elevation in the levels of phenol and proline content in tea leaves.

REVIEW OF LITERATURE

The present review was organized, mainly concentrating on the developmental strategies of mites causing damage to crop plants along with their feeding impact on respective hosts.

Feeding biology of plant mites:

Studies conducted by Wight and Bora (1960) revealed that infestation by *O.coffeae* on tea was negatively associated with the phloem index for the frequency of calcium-oxalate crystals in the petiole. Jeppson et *al*. (1975) provided information on the polyphagous habit of the red spider mite, *O. coffeae* on various crops like coffee, rubber, indigo, grape, cashew etc. and they recorded that the nature of feeding of the species resembled that of the other tetranychids by making punctures on the leaf epidermis with its chelicerae. Oomen (1982) observed that *B. phoenicis* on tea would assemble in cracks, pits, crevices, or other protected sites on the leaves, especially at the midrib and other veins and would feed on the underside of the leaves, on petioles and non-lignified areas of twigs. The author also reported that this mite would move to young leaves or upper leaf surfaces when its population got increased. Kiefer *et al*. (1982) provided a consolidated account on the various types of host abnormalities brought about by the feeding activity of eriophyid mites in North America. Plourde *et al.* (1983) studied the feeding

effect of *P. ulmi* on apple leaves and observed significant reduction in chlorophyll content. Meena and Sadana (1983) conducted studies on the quantitative changes in chlorophyll content in the leaves of *Coleus* due to the feeding activity of the tenuipalpid mite, *B.obovatus* and recorded 75.94% and 51.78% chlorophyll loss in heavily and moderately infested leaves respectively. Smitley and Kennedy (1988) analysed the mechanism of aerial dispersal of *T. urticae* and recorded the effect of weather conditions on the process. A summarized account on the damage caused by eriophyid mites to plants of North East India was furnished by Ghosh *et al.* (1989). Öncel *et al*. (1996) reported proline as a universal osmolyte accumulated in response to several stresses and which would have utility in plant defense reactions.

Chakraborty *et al*. (2002) studied the biochemical response of tea plants exposed to biotic stress due to blister blight infection caused by *Exobasidium vexans* and evaluated the levels of proteins, proline and phenols. The authors accounted a marked increase in the levels of proline and phenols in the infested leaves in comparison with the healthy leaves. A review on the feeding injury and economic importance of four species of the genus *Brevipalpus* viz. *B. californicus*, *B. phoenicis*, *B. Obovatus* and *B. Lewisi* was made by Childers *et al*. (2003). Gotoh *et al.* (2004) evaluated the damage potential of *T. pueraricola* on kidney bean. Khattab and Khattab (2005) collected galled and un-galled *Eucalyptus* leaves to study the different changes resulted from the biotic stress challenged with insect feeding and

observed an increase in free proline content in the galled leaves than that of healthy leaves, indicating the biogenic stress experienced by the plant. The ovicidal effect of essential oils of *Lantana camara* at a concentration of 272.27 µg / mL against *T. urticae* was proved by Badawy (2006).

Khattab (2007) studied the defense mechanism of cabbage plant against the phloem sucking aphid, *Brevicoryne brassicae* and observed an increased level of free proline content in the infested cabbage leaves as compared to the control ones. Sangeetha and Ramani (2007) recorded significant loss in chlorophyll content in the leaves of *M. oleifera* owing to infestation by *T. neocaledonicus.* Alvarado *et al.* (2008) studied the effects of gall induction on leaf phenolic compounds and their indirect effects on the subsequent attack of folivorous insects in *Achatocarpus gracilis*, *Guettarda elliptica*, *Cordiaalliodora*, *Ruprechtia fusca and Guapira macrocarpa* and found that the concentration of phenols was greater in galled leaves than in ungalled leaves of all the plants except *G. macrocarpa*. Hazarika *et al*. (2009) reported that nymphs and adults of the red spider mite while feeding would lacerate the cells, creating tiny characteristic reddish brown marks on the upper surface of mature leaves of tea. Hundred per cent mortality with pongal oil at 1% and 3% concentration was reported against the two spotted spider mite, *T. urticae* by Pavela (2009).

Sangeetha and Ramani (2011) assessed the damage induced by the spider mite, *O.biharensis* on the detached leaves of *M. esculenta* in the laboratory at 30 ± 2°C and 70 ± 5%RH and per cent loss in chlorophyll '*a*' and '*b*' contents recorded were 86.40 ± 1.6 % and 81.03 ±1.2 % respectively. Increase in total phenol content of infested plants was recorded as 11.67 ± 0.17 mg phenol/gm plant material. Jayasinghe and Mallik (2011) studied the relationship between infestation of *T.urticae* and yield loss in tomato*, Lycopersicon esculentum* and found middle stage of the crop was the most critical period for mite infestation contributing to more than 50% of total yield loss due to leaf defoliation and reduction of chlorophyll content of the leaves. Sheela and Ramani (2012) observed infestation of *B. phoenicis* on *H. rosasinensis* causing twisting, crinkling and distortion of leaves. Prabheena and Ramani (2013) studied the feeding activity of *B.phoenicis* on the leaves of *Ocimum gratissimum* and found that chlorophyll *a* and *b* content of heavily infested leaves showed a drastic reduction ranging from 82.7% to 90.1% and from 86.6% to 88.5% respectively. Rehman *et al*. (2013) evaluated the infestation levels of the aphid, *Lipaphis erysimi* in some cultivars of mustard. The phloem sap directly consumed by aphids caused water stress in the plant tissues which resulted in the accumulation of proline which would act as water-stress adjuster in plants. Lee *et al*. (2014) reported the presence of *A.theae* on tea in Korea which induced leaf rust. The mite was found as a vagrant on the lower leaf surface and lived under floral bud scales.

Nasareen and Ramani (2014) quantified the chlorophyll loss due to infestation by the gall mite, *A. pongamiae on P.pinnata.*by making a comparative assessment of chlorophyll content of the normal and galled leaves. The percent loss due to mite infestation ranged from 47.36% to 94% for chlorophyll 'a' and 26.35% to 89.9% for chlorophyll 'b'. Maritim *et al*. (2015) conducted studies to determine the physiological and biochemical responses of 8 tea cultivars to water-deficit stress and observed an increased accumulation of leaf proline and suggested that its concentration could be used as a marker for water stress in tea.

Breeding biology of plant mites:

Ewing (1914) conducted studies on the biology of spider mites and identified the importance of webbing as a substratum for the attachment of eggs and quiescent individuals. Boyce and Korsmier (1941) studied the biology of the citrus bud mite, *A. sheldoni* which completed its development with in 7 days under laboratory conditions at 24^{o}C. Kiefer (1942) observed the phenomenon of deuterogyny in eriophyid mites where there was alternation of generations with two types of females, the protogynes and deutogynes. Manglitz and Cory (1953) studied the biology of *B. australis* and recorded the durations of each of the developmental stages as 8.6, 6.2 and 7 days for larva, protonymph and deutonymph respectively at 21-30^{o}C. Biological studies on *T. macdanieli* were made by Nielsen (1958) in Utah. He

also recorded that *Amblyseius fallacies* could effectively check the population outbreak of *T. macdanieli* in the field in Ontario. Boudreaux (1958) studied the effect of relative humidity on egg-laying, hatching and further development of spider mites. Das (1959) conducted studies on the developmental biology and bionomics of *O. coffeae* on tea. The author observed that this mite was characterized by a high reproductive capacity and could reach upto high population levels in a brief time, causing significant economic damage.

Srivastava and Mathur (1962) conducted biological studies on the red spider mite, *T. cinnabarinus* and observed that the mite completed its development with an average of 14.3 days on castor. The longevity of the adult male and female was observed to be 1-4 and 8-14 days, respectively. Boudreaux (1963) established the occurrence of arrhenotokous parthenogenesis in *Panonychus* and *Tetranychus*. Helle and Bollard (1967) made karyokinetic analysis of *T. horridus* and identified the incidence of thelytokous parthenogenesis. Das and Das (1967) studied the effect of temperature and humidity on the development of the red spider mite, *O. coffeae* and reported that the optimum condition essential for hatching was within a temperature range of 20°-30°C and R.H. range of 49-94%. Putman (1970) carried out studies on the breeding biology of *P. ulmi*, and observed that mating sequences and sex ratio of the species varied with respect to seasonal changes. Gupta *et al.* (1974) made observations on the rate of

development, longevity and fecundity of *O. indicus* on 3 host plants *viz*. sorghum, maize and sugar cane at 5 constant temperatures like 25° C, 27° C, 30° C, 32.5° and 35°C. It was observed that maize was the favourite host and 30°C was the most suitable temperature. Penman and Cone (1974) studied the mating behaviour of the two spotted spider mite and examined the role of web, tactile stimuli and female sex pheromones in attracting males to the quiescent female deutonymphs.

Lal (1977) carried out studies on the biology of *E. orientalis* on 2 host plants, *viz. Bauhinia variegata* and *Rauwolfia serpentine* under 2 different temperatures of 28.64°C and 23.61°C. Longer duration of development was observed at lower temperature in both cases. Maity and Chakrabarti (1978) studied the effect of temperature and relative humidity on the development of *P. citri* on *Carica papaya* at 23.6 ±1°C and 64.5% RH, 26.7 ±1°C and 51.5% RH and 30.6 ±1°C and 48.7% RH and observed 30.6 ±1°C and 48.7% RH as the most favourable combination. The authors noted an increase in the duration of incubation period with decrease in temperature. Easterbrook (1979) traced the biology of *A. schlechtendali* and observed a negative correlation between temperature and life cycle duration. Ferro and Chapman (1979) studied the effect of temperature and humidity conditions on the hatching of eggs in the two spotted spider mite and they observed that high humidity and temperature inhibited the process. A comparative study made by Saito (1979) on the duration of life cycles of three species of tetranychids viz.,

O. ununguis,T. urticae and *P. citri* revealed that *T. urticae* had a higher fecundity level and shorter duration of development.

Puttaswamy and ChannaBasavanna (1980) studied the influence of temperature and relative humidity on the oviposition and development of *T. ludeni* on French beans and recorded optimum conditions for the development between 32 ± 1ºC and 35 ± 1ºC and 65 ± 3% and 75 ± 3% RH. Ray and Rai (1981) studied the biology of *T. neocaledonicus* on okra and observed that pre-oviposition period lasted for twelve hours and eggs were laid singly on both surfaces of leaves. Puttaswamy and ChannaBasavanna(1981b) conducted observations on the influence of six host plants on the development, fecundity and longevity of *T. ludeni* and reported maximum fecundity on okra (149.40 eggs) and French bean (148.90 eggs), shortest developmental time for the species on brinjal (9.24 days) and highest longevity on South French bean (21.08 days) and American cucurbit (26.91 days). The same authors (1981c) studied the influence of 3 species of *Amaranthus viz. A. tricolor, A. spinosus,* and *A. viridis* on the biology of *T. neocaledonicus* at temperatures ranging from 23°-26°C and R.H. of 74 – 81% and observed longer duration of development on *A. tricolor* (11.81 days), higher longevity (27.69 days) and fecundity (147.42 eggs) on *A. viridis.* A study on the influence of host plants on the reproductive biology of *T. neocaledonicus* was made by Puttaswamy and ChannaBasavanna (1982). Dhooria (1982) conducted studies on the ovipositional preference, host range and seasonal incidence of *E. orientalis* on

45 plants and recorded high oviposition along the mid rib region and dorsal surface of leaf lamina in all hosts. Carey and Bradley (1982) carried out studies on the life histories of *T. pacificus,T. urticae* and *T. turkestani* at 5 constant temperatures ranging from 15.5° to 29.4°C on cotton and constructed life tables from the survivorship and fecundity data collected. The average developmental time ranged from 6.1 to 6.7 days at 29.4°C and 25.8 to 29 days at 15.5°C for all the 3 species. Mallik and ChannaBasavanna (1983) conducted studies on the biology *T. ludeni* on French bean. The durations of egg, larva, protonymph and deutonymphal periods were 106 h, 32.5 h, 34.5 h and 49 h respectively.

Dhooria (1985) studied the development of *E. orientalis* on 4 host plants and observed that the mean durations of larval and nymphal stages of the species were higher on the upper surface of young leaves in all the host plants. Young *et al.* (1986) examined the role of female tetranychid mites in the regulation of sex ratio among the progenies. Pande and Sharma (1986) studied the biology of *T. neocaledonicus* on cucurbits at 5 different temperatures and observed that the mite did not survive at a temperature beyond 37^{o}C. Ali and Sarkar (1987) studied the development of *T. bioculatus* and observed that duration from egg to adult was 15 days and longevity of adult female and male averaged to 20.7 and 18.3 days respectively. Sadana and Kumari (1987) traced the rate of development of *B. phoenicis* on seedless guava at three humidity- temperature parameters viz. 20, 25 & 30±1^{0}C and

50,70 and 90% RH and they observed 25^0C in combination with 70% RH as the most suitable condition for the rapid development of the species. Chiavegato (1988) carried out studies on the biology of *P. citri* on the fruits and leaves of lemon and found that the species preferred leaves than fruits for its development. Naidu and ChannaBasavanna (1989) studied the breeding biology and seasonal population fluctuations of *Eriophyes cymbopogonis* infesting *Cymbopogon winterianus* and showed that it took 5.6 days to complete development at 28±1ºC. Manjunatha and Puttaswamy (1989) studied the biology of *T. neocaledonicus* on French bean crop under green house condition and found that the males and females of this species completed their life cycle in 10.19 ± 0.84 and 10.44 ± 0.97 days respectively. Sirsikar and Nagabhushanam (1989) studied the biology of *O. tylus* and found that the mite required 9.90 ± 0.45 days for the completion of its development. Mallikarjunappa and Nageshchandra (1989) studied the biology of *E. hicoriae* on guava. Dhooria and Sagar (1989) made a comparative study on the biology of *T. cinnabarinus* on 4 different varieties of Japanese mint. They noted the durations of pre-oviposition (1-3 days), ovi-position (2-17 days) and post-oviposition periods (0-6 days) of the species. Thirugnanasuntharan (1990) conducted studies on the population dynamics of *O.coffeae* on tea under laboratory conditions and recorded a mean value of 17.6 days for the completion of its life cycle.

Results of biological studies carried out by Rosero *et al.* (1990) on *T. cinnabarinus* showed that the species completed its development in144 hours. Neelu Nangia *et al.* (1990) made observations on the biology and control aspects of *O. mangiferus* on *Terminalia* species. Childers *et al.* (1991) conducted studies on the biology of *E. banksi* on grape fruit leaves at different temperatures. Das and Gupta (1991) performed developmental studies on the citrus mite, *E. orientalis* under field conditions in West Bengal. Manjunatha *et al.* (1991) observed that the longevity of *T. neocaledonicus* differed from plant to plant. Fujibayashi and Sekita (1993) described the development and induction of diapause in the Kanzawa spider mite, *T. kanzawai.* The effect of plant quality on the life history parameters of *T. urticae* was studied by Wilson (1994). Pringle *et al.* (1994) made studies on the developmental biology of the carmine and green forms of *T. urticae*. Aponte and Mc Murtry (1997) investigated the biology of *O. perseae* at different temperatures (15º, 20º, 25º and 30ºC) and found that the reproduction rate was highest at 25ºC. Bonato and Gutierrez (1999) investigated the longevity and fecundity of inseminated and uninseminated females of *T. neocaledonicus, T. lambi, T. fijiensis* and *T. marianae* and found that the uninseminated females laid fewer eggs but lived longer than the inseminated females. Saha *et al.* (1999) studied the biology of the red spider mite, O. *coffeae* at 26ºC and 71.6% RH and 33.2ºC and 79.85% RH. The duration of life cycle was shorter (8.88 ±0.60 days) with higher fecundity at 33.2ºC and 79.85% RH and it was longest

(13.23 ±0.61 days) with lowest fecundity at 26ºC and 71.60% RH. Nandagopal and Gedia (1999) carried out studies on the biology of the white spider mite, *T. hypogaea*, a pest of groundnut. Ramaraju *et al.* (1999) carried out works on the management and control of the coconut eriophyid mite, *A. guerreronis* in Tamil Nadu.

Gotoh and Nagata (2001) conducted studies on the developmental and reproductive traits of *O. coffeae* collected from tea on Okinawa Island. The threshold temperature for development was found to be 10ºC and a marked decline in the developmental time with rise in temperature was observed. Sakunwarin *et al.* (2003) traced the biology of the cassava mite, *T. truncatus* and observed that the species could develop and reproduce within a wide range of temperatures. Temperatures ranging from 24ºC-31ºC appeared as the most favourable for the development and survival of the species. The durations of immature stages were observed to decline with rising temperature up to 32.5ºC. The authors suggested a temperature range of 28 - 31 ºC to be optimal for the development of the mite. Gotoh *et al.* (2003) studied the life history parameters of *P. mori, P. bambusicola, P. ulmi, P. thelytokus, P.citri,* and *P. osmanthi* at 25ºC. Golpayegani *et al.* (2004) made a detailed investigation on the biology of *A. viennensis* on black cherry, *Prunus serotina* at 23 ±1ºC and 75 ±5% RH and they reported that the mite took 11.93 and 16.18 days respectively for the development of males and females. Kasap (2004) investigated the developmental duration and reproduction rate of *T.*

urticae on 5 different apple cultivars at 25ºC and 65 ±10% RH. Chen *et al.* (2005) studied the bionomics of *O. biharensis* on 4 different cultivars of litchi and found that Baitangying litchi was the most suitable host plant for the mite.

The durations of different developmental stages of *T. neocaledonicus* on a mangrove plant, *Rhizophora mucronata* at 30ºC were recorded by Ghoshal *et al.* (2006) and the authors reported 3.33 ± 0.23, 3.25 ± 0.22, 3.8 ± 0.17 and 3.6 ± 0.15 days respectively for egg, larva, protonymph and deutonymph of the species. Teodoro and Reis (2006) provided information on the reproductive performance of *B. phoenicis* on coffee and citrus. Haque *et al.* (2007) investigated the duration of development of the red spider mite, *O. coffeae* infesting rose and recorded shortest duration of 5.3 ± 0.16 days at 30.28 ºC and 70% RH and longest duration of 12.91 ± 0.21 days at 19.8 ºC and 75.41% RH. Sangeetha and Ramani (2007 b) evaluated the fecundity of *T. neocaledonicus* on *M. oleifera.* They reported that the mite deposited 26.7 ± 0.63 eggs within a mean oviposition period of 6 days at 25ºC and 80% RH. The same authors (2008) conducted studies on the embryonic development of *T. neocaledonicus* infesting *M. oleifera* through *in situ* examination of eggs during the days of incubation and provided data on the events involved. Rodrigues and Machado (2009) studied the development of eggs of *B.phoenicis* and observed the formation of a globular structure at the equatorial region, probably involved in respiration. Gotoh and Nagata (2009) conducted studies on the development and reproduction of *O.coffeae* on tea

and reported that the developmental time declined as temperatures increased from 15-32°C. Prabheena and Ramani (2010) conducted biological studies on *B. phoenicis* infesting the medicinal shrub, *Ocimum gratissimum* and observed that the mite populations comprised entirely of female individuals and the mode of reproduction was parthenogenesis alone. Total duration of development of the species at 30^0 C and 65% RH was recorded as 22.8 days. Sheela and Haq (2010) studied the breeding biology of *A.vitifoliae* infesting *Hibiscus vitifolius* and recorded the durations of developmental stages. The development was completed in 13 – 16 days. Abou-Awad *et al*.(2011) studied the influence of temperature and relative humidity on the rate of development, fecundity and life table parameters of *O.mangiferus* and observed that the optimal condition for the development of this species was a combination of 15–31ºC and 65–75% RH. Chakrabotry *et al.* (2015) studied the effect of temperature on tea spider mite, *O. coffeae* and observed that the period of different developmental stages was longer in the colder months. A shorter duration of 6.90 ± 0.09 days was recorded during the month of June whereas in February it took 14.47±0.25 days to complete the life cycle. They observed an increase in the developmental rate with the increase in temperature. Dutta (2015) studied the seasonal impact on the biology of *O.coffeae* in Assam during the seasons April-May, June-July and Aug-Sep and recorded a shorter duration of development (10.97 days) during June-July.

MATERIALS AND METHODS

Laboratory culturing of mites

Laboratory culturing was carried out for making observations on the biology of the mite species under study, recording the impact of temperature and relative humidity parameters and for understanding their various life activities. Live cultures of different stages of selected species of mites were maintained in the laboratory on fresh tea leaves, collected from the tea plantations at an interval of 3 - 4 days or at the time of need. Each culture set consisted of 2-4 leaves, kept in petridishes lined with moist cotton pads and were treated as experimental sets. Stock cultures of the mites were also maintained in the laboratory in the same manner so as to ensure continuous supply of life stages.

Biological studies

Assessment of feeding damage:

Damage potential of selected mite species viz. *O.coffeae, B. phoenicis* and *A. theae* on tea plants was estimated quantitatively by estimating the chlorophyll, phenolic and proline contents of experimental and control leaves. Fully expanded upper 2 or 3 leaves showing damage symptoms induced by individual mite species were collected from 4 plants per plot for extraction.

Uninfested leaves of same age group were taken as control. The eggs, life stages, moulting skin and faecal matter of the mites were removed from the infested leaves through careful examination under a stereozoom microscope.

a) **Estimation of Chlorophyll loss**

Estimation of the amount of chlorophyll pigments was done based on the protocol advocated by Arnon (1949). Fresh leaves of control as well as experimental plants were collected for analysis, washed with water and blotted between sheets of filter paper. For the estimation of chlorophyll, chilled 80% acetone was used as the extraction medium. Precautions were taken to avoid exposure of the extract to light. Fresh leaf sample (0.1g) was weighed in an electronic balance (Sartorius, Germany). It was then crushed with the help of mortar and pestle in 20 ml of 80% acetone (v/v) (Merck, India). Then the homogenate was centrifuged at 5,000 rpm for 10 minutes in a cooling centrifuge at 4^{o} C (Sigma, Germany). The supernatant was collected in a polypropylene tube (Tarsons, India). The residue was again washed with 80% acetone and centrifuged again. The procedure was repeated till the pellet became colour less. The final volume of the pooled supernatant was noted. The absorbance was read at 663 nm and 645 nm against the solvent blank (80% acetone) using a UV visible spectrophotometer (Systronics, India). The amount of chlorophyll present in the extract was calculated using the following formulae adopted from Arnon (1949), Manuela *et al.*, (2012),

Molazem *et al.,* (2010) and Khaleghi *et al.*, (2012). The concentration of chlorophyll pigments was expressed in mg/g fresh weight of the leaf tissue.

$$\text{Chlorophyll a (mg/g)} = \frac{[12.7x(A66\ \ ) - 2.69x(A645)]xV}{(1000\ xW)}$$

$$\text{Chlorophyll b (mg/g)} = \frac{[22.9x(A645) - 4.68x(A663)]x\ V}{(1000x\ W)}$$

$$\text{Chlorophyll total (mg/g)} = \frac{[20.2x(A645) + 8.02x(A663)]x\ V}{(1000\ xW)}$$

Where, W is the fresh weight of the leaf sample used and V is the total volume of the sample solution.

b) **Estimation of total phenolic content**

The alterations in the levels of total phenolic content of tea leaves owing to mite infestation were estimated using the Folin-Ciocalteu reagent (Singleton and Rossi Jr., 1965; Osawa and Namiki, 1981; Gaxiola *et al*., 2001). 0.1 g of leaf samples were weighed separately (Sartorius, Germany), homogenized in 80% aqueous ethanol (Merck, India) at room temperature and crushed using a clean mortar and pestle. It was then centrifuged in a refrigerated centrifuge (Sigma, Germany) at 4°C at a speed of 10,000 rpm for 20 minutes and the supernatant was collected. The residue was re-extracted twice with 80% ethanol and supernatants were pooled, put in to evaporating dishes and evaporated to dryness at room temperature. Residue was re-dissolved in 5 ml of distilled water. Hundred microliter of this extract was

diluted to 3 ml with water and 0.5 ml of freshly prepared Folin-Ciocalteu reagent (Merck, India) was added. After 3 minutes, 2 ml of 20% of sodium carbonate (w/v) (Himedia, India) was added and the contents were mixed well. The colour was developed and absorbance was measured at 650 nm in a spectrometer (Thermo Scientific, USA) after 60 minutes using catechol as standard. The results were expressed as mg catechol/g of fresh weight of the material.

c) **Estimation of proline content**

Estimation of proline content was made according to the procedure adopted by Bates *et al.,* 1973. Purified proline (Himedia, India) was used to standardize the procedure for quantifying sample values. Acid-ninhydrin was prepared by warming 1.25g ninhydrin (Himedia, India) in 30 ml glacial acetic acid (Merck) and 20 ml 6M phosphoric acid (Merck, India), with agitation, until getting dissolved. The reagent was stored at 4°C to remain stable for 24 hours. Approximately 0.5g of leaf sample was ground in a mortar with liquid nitrogen; homogenized in 10ml of 3% aqueous sulfosalicylic acid (w/v) (Himedia, India) and the homogenate was filtered using Whatman #2 filter paper. 2ml of the filtrate was allowed to react with 2 ml each of acid-ninhydrin and glacial acetic acid (Merck, India) in a test tube, incubated for 1 hour at 100°C in a boiling water bath and the reaction was terminated in an ice bath. To the reaction mixture 4.0 ml of toluene (Merk,India) was added

and stirred well for 15-20 seconds. The chromophore containing toluene was aspirated from the aqueous phase, warmed to room temperature and the absorbance was read spectrophotometrically (Thermo Scientific, USA) at 520 nm using toluene as blank. The proline concentration was determined from a standard graph and calculated in µg/g weight of fresh leaf samples (Bagdi and Shaw, 2013).

Breeding biology

Postembryonic development

Stock cultures of the live specimens of selected species of mites were maintained in the laboratory to facilitate studies on breeding biology. Successful rearing and maintenance of sufficient stock cultures of the pest mites in the laboratory were carried out following leaf flotation technique. For this, leaf discs (2cm x 2cm) were excised from tea plants and kept in petri dishes lined with moistened cotton pads. Mites were transferred carefully to the leaf discs with the help of moistened camel hair brush. The cotton pads were made wet with water whenever necessary to maintain the vigour of leaves. When the leaves showed symptoms of decay, mites were transferred to fresh leaf discs. For studying sexual development, newly moulted females were introduced on to the leaf discs along with adult males and durations of pre-oviposition periods were recorded. The males were removed soon after the females laid the first set of eggs. Studies on parthenogenetic development

were made after isolating the female deutonymph and closely observing the subsequent development. The eggs laid by individual female were considered for subsequent studies on life cycle. The number of eggs laid by the mated and virgin females were recorded separately at regular intervals. The old leaf discs, which contained the eggs, were placed on freshly prepared leaf discs. Eggs were kept on the same until adult emergence occurred. Mites on each leaf disc were observed daily from egg to adult stage. The developmental duration of each stage was assessed separately for males and females. Oviposition periods of females were calculated from the time of deposition of first egg to the time of deposition of last egg. Post - oviposition periods were calculated from the time the last egg was deposited to the time of death of the female. During the period of the present study, a combination of 3 different temperature – humidity parameters were selected for assessing their impact on life cycle of the selected species of mites viz. *O.coffeae, B. phoenicis* and *A. theae*. The selected temperature – humidity parameters were 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH . For each temperature – humidity set up, 5 sets of cultures were maintained and repeated three times in an incubator, containing saturated salt solution to maintain constant RH. Preparation of the various saturated salt solutions used for the study has been discussed subsequently.

Regular observation was made on each culture set at 6 hours intervals under 32 x magnification of a stereozoom microscope. Data on various

biological parameters like mating, oviposition and incubation, hatching and moulting were recorded. Durations of larval, nymphal and quiescent stages, and total duration of F_1 generation were also recorded. Data collected on the above lines of study were tabulated and presented. Values were expressed as Mean ± SEM (Standard Error of Mean). Relevant photographs were also taken and presented.

Preparation of saturated salt solutions to maintain constant RH

To understand the effect of relative humidity on the post-embryonic development of the tea mites, saturated salt solutions were prepared by dissolving salts to saturation in boiling water. The solution was partially cooled and more salt was added. After the solution was cooled completely, more salt was added and the mixture was allowed to stand for about 2 weeks to ensure saturation. Temperature was made constant for each saturated salt solution in order to ensure constant relative humidity (Winston and Bates, 1960). The solution mixture containing equal volumes of saturated solution of LiCl and Mg $(NO_3)_2$ was used to set the relative humidity 60 ± 5% at 35 ± 2°C. Relative humidity 70 ± 5 % at 30 ± 2°C was set using the solution mixture containing equal volume of saturated solutions of NaCl and KCl. Saturated solution of NaCl was used to maintain the relative humidity 80 ± 5% at 25 ± 2°C.

Morphological studies of developmental stages

In order to study the morphological characters of the larval, nymphal and adult stages of the three species of mites selected for detailed developmental studies, specimens of the various life stages were preserved in 70% alcohol and were dehydrated by passing through 80%, 90% and absolute alcohol and cleared in a mixture of lactic acid and absolute alcohol (1:1 ratio). The cleared specimens were slide mounted in a drop of Hoyer's medium and kept overnight in an oven set at 45-50^{o}C until the desired clarity of specimen was obtained. Morphological details of the various developmental stages viz. the larva, protonymph, deutonymph and adults (male and female) were drawn using a Camera Lucida attached to a Meopta Research microscope. Measurements of the various life stages were made using stage and ocular micrometers.

4. Preparation of mounting medium

Hoyer's medium

Plant mites were best mounted in Hoyer's medium. It was prepared by mixing known quantities of the following ingredients, as given below.

Gum Arabic – 100 g

Distilled water – 50 ml

Chloral hydrate – 200 g

Glycerine – 30 ml

Gum Arabic crystals were crushed and soaked in distilled water and kept overnight. Dissolved the crystals by stirring with a glass rod. To this, chloral hydrate and glycerine were added and mixed well. The mixture was filtered through 2 folds of fine glass wool and used for mounting.

OBSERVATIONS

FEEDING BIOLOGY

Qualitative assessment of damage induced by *O.coffeae*

Results of microscopic observation on the damaged leaves of *C.sinensis* collected from different sampling localities helped to understand the details of the nature and degree of infestation induced by *O.coffeae*. It was observed that *O.coffeae* showed a marked preference to the upper surface of mature leaves, especially to the midrib and the marginal areas. In severe cases of infestation, younger leaves were also found damaged by the mite. The middle zone of the bush (about 30 cm below the plucking surface) was found preferred by the mite. In addition to the life stages of the species, the leaf surface was found characterized by the presence of intense webbing by the mites. The presence of moulting skin, egg cases, faecal pellets and the webbing accelerated the accumulation of dust particles on the leaf surface. Infested leaves collected from the field disclosed the presence of a large number of reddish brown spots due to the feeding activity of the mite. While feeding, the various life stages of the mite punctured the epidermal layer of the leaf with their chelicerae and sucked out the cell contents. Each feeding event was found to result in the development of minute characteristic reddish brown marks on the upper surface of mature leaves, which turned to red in

severe cases. The feeding punctures were often found coalesced to form bronzy areas. Heavy infestation caused acute chlorosis of the leaves, forming necrotic areas on the lamina. (Plate 5)

Quantitative assessment of damage induced by *O.coffeae*

Results of quantitative studies clearly established that infestation by *O.coffeae* on tea could induce drastic changes in various biochemical parameters.

a) Estimation of Chlorophyll

For rating the damage caused to the tea plant owing to infestation by *O.coffeae*, comparative estimation of chlorophyll content of the mite infested and uninfested (control) tea leaves was performed. Results of quantitative studies on the amounts of chlorophyll 'a' and 'b' pigments present in the experimental and control leaves have been presented (Table 4 & plate 6). A noticeable reduction was observed in the chlorophyll content of infested leaves due to heavy feeding by the mite. As shown in the table, the mean amounts of chlorophyll 'a' in the uninfested and infested leaf samples recorded during the study were 0.91 ± 0.01 and 0.35 ± 0.01 mg/gm tissue respectively. This showed that the mite infested leaf samples had a loss of 61.14 ± 0.57 % of chlorophyll 'a' pigment when compared to the uninfested leaves of tea. The mean amounts of chlorophyll 'b' recorded in the uninfested and infested leaves were 0.38 ± 0.01 and 0.20 ± 0.01 mg/gm tissue

respectively which showed a loss of 46.81 ± 2.89 % chlorophyll 'b' owing to infestation by the red spider mite (RSM). The total chlorophyll content recorded for uninfested and infested tea leaves were 1.29 ± 0.02 and 0.55 ± 0.01 mg /gram tissue respectively showing a decline of 57.36 ± 0.75 % due to the infestation of *O.coffeae*. Upon statistical analysis, both the data were found significant ($p < 0.01$).

b) Estimation of Phenolics

The phenolic content of the tea leaves infested by *O. coffeae* showed an increase when compared to the uninfested samples. The uninfested and mite infested tea leaves showed 55.35 ± 1.88 and 94.59 ± 1.97 mg of phenol/gram tissue respectively (Table 5 & Plate 7). The per cent increase in phenol content due to *O.coffeae* infestation was recorded as 71.82 ± 3.6 %.

c) Estimation of Proline

The amount of proline in the tea leaves also showed an increase as a result of infestation by *O.coffeae*. (Table 6 & Plate 7). The uninfested and infested tea leaves contained 0.47 ± 0.02 and 0.87 ± 0.02 mg of proline /gram tissue respectively. An increase of 87.0 ± 6.79 % in proline content was recorded due to the infestation of *O.coffeae*.

Qualitative assessment of damage induced by *Acaphylla theae*

During the initial stages of infestation by this mite, upward curling and discolouration of leaves was observed in the tea plantation. In severe cases of infestation, leaves became leathery and assumed brown colour. Adults, larvae and eggs were mostly found on the under surface of young leaves. However, in cases of severe infestation, the upper surfaces of tea leaves also showed symptoms of infestation, though the mite density was comparatively less than that of lower surface. At times, leaf petioles and tender stems of tea plants were also invaded by this mite. Most of the mites were present on the leaves located at the top of the bushes. The number of mites was comparatively lesser on the leaves of bottom branches. All active life stages were found voraciously sucking the leaf sap, especially from the lower surface. The feeding activity was prolonged for 1-2 minutes at each feeding spot. Premature abscission of leaves was also noticed in the case of heavy infestation.

Quantitative assessment of damage induced by *A.theae*

The extent of damage induced by *A.theae* was estimated quantitatively and the results are presented below.

a) Estimation of Chlorophyll

In order to quantify the degree of damage caused by the feeding activity of *A.theae* on tea, chlorophyll content of the infested leaves was estimated and compared with that of uninfested leaves. As depicted in table 7 & Plate 8, the mean amounts of chlorophyll 'a' in the uninfested and mite infested leaf samples recorded during the study were 0.87 ± 0.01 and 0.67 ± 0.01mg/gm tissue respectively. This showed that the mite infested leaf samples had a loss of 23.24 ± 0.82 % of chlorophyll 'a' pigment when compared to the uninfested leaves of tea. The amount of chlorophyll 'b' recorded in the case of uninfested and mite infested tea leaves were 0.31 ± 0.02 and 0.23 ± 0.00 mg/gm tissue respectively which showed a loss of 25.34 ± 2.53% owing to infestation by *A.theae*. The total chlorophyll content present in the uninfested and mite infested leaves were 1.19 ± 0.01 and 0.90 ± 0.01mg/gm tissue respectively. The per cent loss in total chlorophyll content was recorded as 23.89 ± 0.83.

The data were proved to be significant ($p < 0.01$) when analysed statistically.

b) Estimation of Proline

The amount of proline showed an increase in mite infested leaves during the present study. The mean concentration of proline in uninfested and mite infested leaf samples of *A.theae* were recorded as 0.45 ± 0.02 and 0.64 ±

0.02 mg/gm of leaf sample respectively (Table 9 & Plate 9). This showed that *A.theae* infestation caused an increase in proline production in the leaves of *C.sinensis*. The per cent of increase in proline content could be recorded as 41.85 ± 3.08.

c) Estimation of Phenolics

Resembling the proline production, the phenolic content also was found enhanced owing to infestation by *A.theae.* As presented in table 8, the mean concentration of phenolics in the uninfested leaf sample was 44.91 ± 1.48 mg/gm tissue while that of the infested leaves was 60.33 ± 1.47 mg /gm tissue. The per cent increase in phenol content recorded during the present study due to infestation by *A.theae* was 34.95 ± 2.99.

Qualitative assessment of damage induced by *B. phoenicis*

The flat mite, *B. phoenicis* was found to infest the lower surface of the mature leaves of *C.sinensis*, both in field and laboratory conditions. The mite was found to exhibit a specific preference to inhabit leaves of plants grown in shaded areas. The feeding activity of this mite was found to induce discolouration of leaves. Symptoms of infestation were mainly visible on either side of the midrib which gradually got extended to the entire leaf lamina. All life stages of the species displayed voracious feeding activity by sucking the leaf sap. The epidermal cells of the leaves were found punctured by the various instars of the species, with the help of their cheliceral stylets.

Initial symptoms of damage were recognized by the appearance of various chlorotic spots which on progressive feeding by mites, gradually turned to brown patches. Severe infestation by this species was found to result in defoliation of bushes.

Quantitative assessment of damage induced by *B. phoenicis*

Apart from cellular damage, the feeding activity of *B.phoenicis* was found to alter the different biochemical parameters studied.

a) **Estimation of Chlorophyll**

The chlorophyll contents of mite infested and uninfested leaves of *C.sinensis* were estimated in order to quantify the severity of infestation by *B.phoenicis*. The values have been tabulated and presented in Table 10 & Plate 10. The percent loss in chlorophyll 'a' and 'b' pigments were recorded to be 12.84 ± 0.66 % and 23.07 ± 1.89 % respectively. The total chlorophyll content present in the uninfested and mite infested leaves were 1.14 ± 0.02 and 0.96 ± 0.01 mg/gm tissue respectively. The per cent loss in total chlorophyll content due to infestation by *B.phoenicis* was recorded as 15.73 ± 0. 53.

The results when statistically analysed proved to be significant. ($P < 0.01$).

b) **Estimation of Proline**

Feeding by *B.phoenicis* was found to stimulate the production of proline in the leaves of *C.sinensis*. The amount of proline in the mite infested leaves was averaged to 0.59 ± 0.02 mg/gm (Table 12 & Plate 11) whereas the uninfested leaves presented a lower quantity of proline which could be recorded as 0.44 ±0.02 mg/gm tissue. Per cent increase in proline recorded during the study owing to *B.phoenicis* infestation was estimated as 35.45 ± 2.02.

c) **Estimation of Phenolics**

The concentration of phenolics was also found elevated due to mite infestation. Leaf samples infested by *B.phoenicis* revealed a mean quantity of 65.79 ± 2.26 mg of phenol/gm leaf tissue when compared to unifested leaves which contained 54.64 ±2.09 mg of phenol/gm tissue (Table 11 & Plate 11).The per cent elevation of phenol due to *B.phoenicis* was estimated as 20.65±1.39.

BREEDING BIOLOGY

Postembryonic development of *O. coffeae*

Oviposition

Adult females were found depositing eggs on the upper surface of tea leaf along the mid-rib and veins. Ovipositing females constructed silken web across the midrib and major lateral veins prior to the deposition of the eggs. (Plate 16, Fig 1). Eggs were deposited in close proximity and usually found in colonies. The eggs were spherical, smooth, with a slight depression on the exposed top side. A short hair-like process was found arising from the upper pole. The eggs were red in colour and shining. It changed to light orange colour before hatching. The pre-oviposition period i.e., the period preceding the beginning of oviposition activity, was recorded to be 1.15 ± 0.08 days at 25 ± 2ºC & 80 ± 5% RH, 0.6 ± 0.06 days at 30 ± 2ºC & 70 ± 5% RH and 0.53 ± 0.03 days at 35 ± 2ºC & 60 ± 5% RH (Table 13 & Plate 12). The oviposition periods observed were 8.1 ± 0.23 days, 7.4± 0.16 days and 6.6 ± 0.16 days for the temperature-humidity conditions viz. 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH (Table 13). The post-oviposition periods for the above three temperature-humidity combinations were 1.55 ± 0.16 days, 0.75 ± 0.07 days and 0.6 ± 0.07 days respectively (Table 13 & Plate 12). During post - oviposition period, the adult female became inactive and lethargic and feeding activity was minimal. The post-oviposition period was followed by the death of the individuals. Number of eggs laid by a gravid female of *O.coffeae* during its life time was minimum during the 1st and 2nd days of oviposition. However, gradual increase was observed from the 3rd day onwards until it reached its peak level on the 4th or

5th day of oviposition. It started declining from the 5th or 6th day onwards, reaching a minimum at the end of oviposition period. For selected temperature-humidity combinations viz. 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH, the fecundity recorded was 25.0± 1.09 (Mated - 27.0 ± 0.87 & Virgin – 22.6 ± 1.29), 29.2 ± 1.44 (Mated - 32.6 ± 1.63 & Virgin – 25.8 ± 0.97) and 37.9 ±1.14 (Mated - 40.8 ± 0.86 & Virgin - 35.0 ± 0.95) respectively. (Table 14, 15 and 16 & Plate 13). The duration of development of *O.coffeae* on *C.sinensis* was 13.23 ± 0.14 days, 12.23 ± 0.14 days and 11.98 ± 0.14 days at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C &70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH respectively (Tables 17 - 19 & Plate 14-15).

Hatching

Hatching process was initiated by formation of a narrow slit and the separation of the egg case by the movements of the emerging larva. The mouth parts and the first pair of legs projected out of the egg case in the beginning which was followed by the emergence of the last two pairs of legs. Shortly after hatching, the larva moved away in search of food. The remnant egg shell was white and transparent (Plate 16 , Figs. 2). The hatching process took 5 - 6 minutes to complete with no major changes at different temperature-humidity conditions provided.

Duration of developmental stages

Incubation period

Incubation period was shortest (4.78 ± 0.07 days) at 35 ± 2ºC & 60 ± 5% RH and longest (6.15 ± 0.14 days) at 25 ± 2ºC & 80 ± 5% RH. At 30 ± 2ºC & 70 ± 5% RH, the incubation period was 5.48 ± 0.13 days.

Larval period

The newly emerged larva (Plate 16 Fig 3) was round and possessed 3 pairs of legs. At the time of hatching it was yellow in colour which subsequently changed to pale orange. The idiosoma later showed a greenish appearance with the intake of plant sap. The active larval life lasted for 1.8 ± 0.07 day, 1.73 ± 0.08 day and 2.08 ± 0.04 day at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively. The larva of *O. coffeae* passed through the 1st quiescent phase and consequently moulted into the protonymph.

Protonymphal period

The protonymph (Plate 16 Fig. 5) possessed four pairs of legs. The body was oval, the anterior pairs of legs were pale crimson, while the posterior pairs were deep reddish brown. Protonymphs passed through a resting stage or the so called 2nd quiescent phase before moulting into the deutonymph. The duration of active protonymphal period was shorter at 30 ±

2ºC & 70 ± 5% RH extending for 1.6 ± 0.04 day and longer at 25 ± 2ºC & 80 ± 5% RH being 1.93 ± 0.05 days. At 35 ± 2ºC & 60 ± 5% RH, the duration was 1.75 ± 0.08 days.

Deutonymphal period

Deutonymph was similar to the protonymph in appearance except in their larger size. At the deutonymphal stage, the sexes could be differentiated. The females were slightly bigger and had the hysterosoma rounded at the posterior end whereas the hysterosoma of the males were tapering posteriorly (Plate 16 Fig. 5). The respective durations of deutonymphal period were 1.68 ± 0.08 days, 1.75 ± 0.06 days and 1.7 ± 0.10 days respectively at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH .

Quiescent Periods

A period of zero activity or quiescence could be observed in the life cycle of *O.coffeae* at the end of active period of each developing stage. During this period, the individual stopped feeding and other noticeable life activities became sluggish and entered into an inactive stage called quiescent phase. During quiescence, the individuals withdrew their legs beneath the hysterosoma and were ovoid in shape (Plate 16, Fig. 4). Before moulting, the cuticle became transparent in nature. In the life history of *O.coffeae*, three quiescent phases, known as the first, second and third quiescence were observed, at the end of larval, protonymphal and deutonymphal stages

respectively. The period of quiescence did not show much variation at different temperature-humidity conditions. All the quiescent phases took around 0.5 day for their completion

Moulting

Moulting was observed at the end of each quiescent phase of the larva, protonymph and deutonymph. Increased size of the body was observed at the beginning of moulting. In the next step, a horizontal slit was formed at the mid dorsal region between the second and third pairs of legs. This slit further progressed to either sides and eventually met ventrally. The backward thrust exerted by the individual caused the widening of the split and emergence of the posterior part of the body. This was followed by the backward crawling of the individual which resulted in the detachment of gnathosoma and legs from the moulting skin. The entire process was completed in about 8-10 minutes with no significant change in duration at different temperature-humidity conditions. Moulting skin, covering the first two pairs of legs was found unbroken whereas the posterior part was found split up into pieces after the emergence of the nymph (Plate 16, Fig 3).

Adult Stages

The adult male (Plate 16, Fig. 7) differed from the female in size and shape of the body. The female (Plate 16, Fig 8) was nearly elliptical or oval with broadly rounded hysterosoma at its posterior end. The legs and

propodosoma were bright crimson, whereas the abdomen was dark purplish brown. The male was smaller, and had a slimmer body with posteriorly tapering hysterosoma. The legs, particularly the first pair, were longer than those of the female. Male possessed almost same body color as that of female except at the tip of its abdomen which was crimson in colour. The tip of the aedeagus was bent to the ventral surface at right angles.

Mating

Mating occurred soon after moulting of the female deutonymph. In the laboratory cultures, males emerged comparatively earlier than the females and were found wandering about in search of female deutonymphs in quiescence. As soon as a male encountered a female deutonymph ready for moulting, the male rested close to the female, with its forelegs extending over the dorsum of the latter. In most of the observations, mating occurred even before the completion of the moulting of the female deutonymph. During copulation, the male crept beneath the female hysterosoma. Posterior end of the male hysterosoma was then held in a curved position, protruding the aedeagus upwards to the genital opening of the female. Mating lasted for about 2 minutes. At the end of mating, the male withdrew the aedeagus and moved backwards. A male was found inseminating an average of 8-10 females during its lifetime. Similarly a single female admitted many males in succession.

Parthenogenesis versus Sexual development

O.coffeae reproduced both sexually and by parthenogenesis. The sequence of events involved in the post-embryonic development was alike in both types of reproduction. However, in the case of parthenogenetic development, all the progeny consisted of males while in the sexual reproduction both males and females were produced in a sex ratio of 1:10. A slight difference was noticed in the durations of the different developmental stages in both the types of reproduction. The durations recorded at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH were 13.23 ± 0.14 days (Sexual - 13.39 ± 0.16 days & Parthenogenesis - 12.83 ± 0.08 days), 12.23 ± 0.14 days (Sexual - 12.42 ± 0.12 days & Parthenogenesis - 11.94 ± 0.26 days) and 11.98 ± 0.14 days (Sexual - 12.25 ± 0.06 days & Parthenogenesis - 11.56 ± 0.21 days). Parthenogenetic development took lesser time than the sexual development at all the temperature - humidity combinations studied.

Morphological description of life stages of *Oligonychus coffeae*

Egg

Measurements

Diameter 125 – 132 µm

Freshly laid eggs were spherical and reddish-orange in colour. The colour changed to golden brown and then dark brown before hatching. Red eye spots were visible through the translucent egg case few hours prior to hatching.

Larva (Plate 17)

Measurements

Length: 192 – 222 μm

Width : 148 – 162 μm

Dorsal region

More or less rounded in shape with transparent integument; anteriorly protruding rostrum; peritremes distally curved; 10 pairs of dorsal setae, smooth and pointed.

Ventral region

Setae MV_1 and MV_2 present; indistinct genital area; anal region with 2 pairs of anal and 1 pair of para-anal setae; anal and para- anal setae small and pointed; integument ornamented with irregular striations giving a wavy appearance; 3 pairs of legs.

Protonymph (Plate, 18)

Measurements

Length: 266 – 296 µm

Width : 177 – 192 µm

Dorsal region

Striations present; rostrum protruding; peritremes distally curved; stylets parallelly running forwards; 12 pairs of dorsal setae, all long and thin.

Ventral region

Medioventral setae MV_1 and MV_2 present; genital area indistinct; 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, 19)

Measurements:

Length: 355 – 399 µm

Width: 251– 281 µm

Dorsal region

Integumental striations transverse with slight variations; rostrum long and stout; peritremes directed backwards and curved into a small hook; setae P_1 , P_2 and P_3 smooth and pointed; hysterosomal seta D_5 added anew; all hysterosomal setae long and pointed.

Ventral region

Seta *MV3* added anew; anal area distinct and clearly developed; both anal and genital area with irregular striations; genital setae slightly anterior to genital opening ; 2 pairs of anal setae and 1 pair of para-anal setae present.

Adult female (Plate, 20)

Measurements

Length: 577 – 621 μm

Width: 384 – 414 μm

Dorsal region

Gnathosoma protruding anteriorly; backwardly directed peritremes curved into a pair of hook like structures distally; anterior margin of propodosoma more or less arched, setae *P1* ,*P2* and *P3* short and thin; dorsum with transverse conspicuous striations; seta *D5* short and thin; all other hysterosomal setae elongated and pointed.

Ventral region

Three pairs of medio-ventral setae *MV1, MV2* and *MV3* present; genital seta anteriorly positioned to genital opening, genital opening encircled by diverging striations; 2 pairs of anal and 1 pair of para-anal setae present.

Adult Male (Plate,21)

Measurements

Length: 384 – 414µm

Width: 236 – 266µm

Slender elongated body with long legs; Aedeagus bent at right angle to shaft.

Postembryonic development of *B. phoenicis*

Oviposition

The entire population of *B. phoenicis* was found to comprise females and they generally preferred the lower surface of leaves for egg laying. In rare cases, when the population density of the mite was high, eggs were laid on the upper surface of the leaf also. During oviposition, the female laid single eggs by slightly lowering its hysterosoma. The eggs appeared in clusters, as several eggs were laid side by side. The eggs were sticky and were found attached to leaf until hatching. Newly laid eggs were red in colour, elliptical and slightly broadened at one end. Several egg clusters could be observed on the leaf surface, usually in the cracks and cervices.

The pre-oviposition period of *B. phoenicis* was recorded to be 4.1 ± 0.38 days at 25 ± 2°C & 80 ± 5% RH, 3.4 ± 0.31 days at 30 ± 2°C & 70 ± 5% RH and 3.8 ± 0.29 days at 35 ± 2°C & 60 ± 5% RH. The oviposition period was recorded to be 16.7 ± 0.45 days at 25 ± 2°C & 80 ± 5% RH, 16.6 ± 0.4

days at 30 ± 2ºC & 70 ± 5% RH and 15.7 ± 0.67 days at 35 ± 2ºC & 60 ± 5% RH. After oviposition period, the mites were found inactive with minimum feeding activity. The post ovipostion periods of *B. phoenicis* at different temperature and humidity conditions were 2.8± 0.25 days at 25 ± 2ºC & 80 ± 5% RH, 2.6 ± 0.22 days at 30 ± 2ºC & 70 ± 5% RH and 2.7 ± 0.26 days at 35 ± 2ºC & 60 ± 5% RH. The number of eggs laid by the females ranged from 17 – 25 at 25 ± 2ºC & 80 ± 5% RH, 25 - 31 at 30 ± 2ºC & 70 ± 5% RH and 20 - 27 at 35 ± 2ºC & 60 ± 5% RH. During the oviposition period, the females laid highest number of eggs on the 7th or 8th day. The adult longevity of *B. phoenicis* recorded at different temperature and humidity conditions were 23.56 ±0.56 days at 25± 2ºC & 80 ± 5% RH, 22.6 ± 0.31 days at 30 ± 2ºC & 70 ± 5% RH and 22.6 ± 0.66 days at 35 ± 2ºC & 60 ± 5% RH. (Tables 20-23 & Plates 22- 24)

Hatching

Initiation of hatching was marked by the appearance of a semicircular slit at the apical pole of egg. Then the slit continued to either sides followed by the movement of larva inside the egg shell. As the slit got widened, the emerging larva protruded its first pair of legs followed by the swift movement of propodosoma which helped it to come out. The process of hatching was completed within 15 - 20 minutes. (Plate 22, Fig 3)

Duration of Developmental Stages

Incubation period

Duration of incubation showed variation with respect to altered temperature-humidity conditions. Incubation period was shortest (9.0 ± 0.26 days) at 30 ± 2ºC & 70 ± 5% RH and longest (10.4± 0.4 days) at 25 ± 2ºC & 80 ± 5% RH. At 35 ± 2ºC & 60 ± 5% RH, the incubation period was 9.35 ± 0.24 days.

Larval Period

Larvae were small, six legged and bright orange-red in colour when newly emerged which turned to opaque orange. (Plate 22 Fig 4). As the larva began to feed, it developed black and orange patches on the body. The active larval stage extended for 4.3 ± 0.23 days at 25 ± 2ºC & 80 ± 5% RH, 3.95 ± 0.14 days at 30 ± 2ºC & 70 ± 5% RH and 3.65 ± 0.22 days at 35 ± 2ºC & 60 ± 5% RH. At the end of active period, the feeding activity of the larva got declined and became lethargic.

Nymphal stages

Protonymph

Protonymphs looked like larvae generally, but larger than the larvae and characterized by the presence of 4 pairs of legs (Plate 22, Fig 5). The integument appeared to be transparent with orange and black patches. With

continuous feeding activity, the colour of the protonymph became more intense.The protonymphal period lasted for 4.25 ± 0.23 days at 25 ± 2ºC & 80 ± 5% RH, 3.9 ± 2.2 days at 30 ± 2ºC & 70 ± 5% RH and 3.85 ± 0.24 days at 35 ± 2ºC & 60 ± 5% RH. At the end of the active stage, the feeding activity of the protonymph got decreased and it entered in to the second quiescent phase.

Deutonymph

In appearance, the newly emerged deutonymph was similar to the protonymph, except being slightly larger (Plate 22, Fig 2). The active feeding period of deutonymph lasted for 5.35± 0.18 days at 25 ± 2ºC & 80 ± 5% RH, 4.8 ± 0.2days at 30 ± 2ºC & 70 ± 5% RH and 5.05 ± 0.14days at 35 ± 2ºC & 60 ± 5% RH. At the end of this active period, deutonymph became lethargic and entered into third quiescence.

Adult

Female

The body of the adult female appeared elliptical, flat and light reddish or orange spot (Plate 22, Fig. 8). The newly emerged female remained motionless for some time and slowly started movement and started feeding on leaf sap. As feeding progressed its body colour gradually changed to blackish red.

Quiescent periods

At the end of each active of development, an inactive quiescent phase was observed. During the development of *B.phoenicis*, three quiescent phases were observed viz. Ist, 2nd and 3rd quiescent stages, each at the end of the larval, protonymphal and deutonymphal stages respectively (Plate 22, Fig 7). During quiescent phase, the instar stopped feeding, became lethargic and immovable. Upon quiescence, the instar assumed a characteristic posture, with its stylets penetrated into the plant tissue and legs stretched outward. The durations of 1st quiescent phase were recorded as 2.1 ± 0.13 days at 25 ± 2^{o}C & 80 ± 5% RH 1.8 ± 0.08 days at 30 ± 2^{o}C & 70 ± 5% RH and 2.15 ± 0.15 days at 35 ± 2^{o}C & 60 ± 5% RH. It took 3.1 ± 0.18 , 2.45 ± 0.17 and 2.85 ± 0.18 for the completion of 2nd quiescent phase at 25 ± 2^{o}C & 80 ± 5% RH, 30 ± 2^{o}C & 70 ± 5% RH , 35 ± 2^{o}C & 60 ± 5% RH respectively. The 3rd quiescent stage lasted for 2.2 ± 0.11 days at 25 ± 2^{o}C & 80 ± 5% RH, 1.9 ± 0.15 days at 30 ±2^{o}C & 70 ± 5% RH and 2.25 ± 0.08 days at 35 ± 2^{o}C & 60 ± 5% RH.

Moulting

At the end of each phase of quiescence, the individual emerged out into the next instar by the process of moulting. This process was lasted for 15-20 minutes. During moulting, the outer cuticle became silvery white in colour and a horizontal slit appeared at the mid dorsal region of the body. The slit

further extended to both sides and met ventrally. The backward thrust exerted by the emerging individual helped to widen the slit which further aided in the emergence of anterior part of the body.

Breeding pattern

In both laboratory and field conditions, the entire population of *B.phoenicis* was composed of only females. The mode of reproduction was exclusively parthenogenesis, leading to the formation of only female progenies.

Duration of life cycle

The mean duration of development of *B. phoenicis* from egg to adult were recorded as 31.45 ± 0.26 days at 25 ± 2ºC & 80 ± 5% RH, 27.8 ± 0.37 days at 30 ± 2ºC & 70 ± 5% RH and 29.15± 0.33 days at 35 ± 2ºC & 60 ± 5% RH. (Tables 24-26 & Plates 25 - 26)

Morphological description of life stages of *Brevipalpus phoenicis*

Egg

Measurements:

Width: 71 - 73 µm

Length: 98- 102µm

Freshly laid eggs were elliptical and bright orange – red in colour. The colour gradually changed to dull red and a shiny coating appeared on the egg. Eye spots of the larva could be visible through the egg case, a few hours prior to hatching.

Larva (Plate, 27)

Measurements:

Length: 142 - 146 µm

Width: 84 - 88 µm

Dorsal region

Almost rounded in shape, transparent; body with fine striations having variations at different regions; rostrum round and anteriorly protruding; stylets short and protruding beyond the rostral apex; 3 pairs of propodosomal 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; $f3$, h_1 large and lanceolate; c_1, d_1, e_1 smooth.

Ventral region

Striations present; 3 pairs of ventral setae present, *1a, 3a* and *4a, 1a* larger than the other two; indistinct genital area; 2 pairs of pseudoanal setae present; 3 pairs of legs.

Protonymph (Plate, 28)

Measurements:

Length:183 - 186 µm

Width:111 -116 µm

Dorsal region

Striations present; narrow and protruding rostrum; stylets long, parallel, running forward, extending far beyond the anterior margin of the rostrum; pedipalp 4 segmented; propodosoma broader posteriorly; 3 pairs of propodosomal setae, v_2, sc_1,sc_2; 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 large, lanceolate.

Ventral region

3 pairs of ventral setae; 1 pair of aggenital setae; two pairs of smooth pseudo anal setae, ps_1 and ps_2; anal area well demarcated by well-developed anal plates; 4 pairs of legs.

Deutonymph (Plate, 29)

Measurements:

Length: 261- 265 µm

Width: 139-146 µm

Dorsal region

Entire body surface reticulated; rostrum stout and broad; stylets discernible; anterior region of propodosoma more or less arched; dorsal setae larger than setae of ventral side; 9 pairs of dorsal opisthosomal setae (as mentioned in protonymph)

Ventral region

1 pair of aggenital setae, ag_1; genital plate developed with one pair of genital setae g_1; anal plate well developed; 2 pairs of smooth pseudo anal setae $ps_1$and ps_2 present.

Adult Female (Plate, 30)

Measurements: Length:293-299 µm

Width:163 – 167 µm

Dorsal region

Rostral shield well developed; stylets basally originating; pedipalp stout and four segmented; striations clearly marked; ornamentation ranges from smooth to reticulate; verrucose, aerolate and colliculate; 9 pairs of dorsal opisthosomal setae, f_3 , h_2, and h_1 small and smooth.

Ventral region

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

Postembryonic development of *A.theae*

Oviposition

Adult females exhibited a general preference to the lower surface of the leaf lamina, both in the field and laboratory conditions. Eggs deposited were solitary. Occasionally they were observed in groups of 2, 3, 5 etc. They were seen closely adhered to the leaf surface by some sticky substance. Eggs were shiny and globular. The pre-oviposition period was recorded as 1.81 ± 0.08 days at 25 ± 2ºC & 80 ± 5% RH , 1.69 ± 0.08 days at 30 ± 2ºC & 70 ± 5% RH and 1.94 ± 0.04 days at 35 ± 2ºC & 60 ± 5% RH .The oviposition periods observed were 7.63 ± 0.26 days, 6.88 ± 0.23 days and 7.88 ± 0. 35 days for the temperature-humidity conditions viz., 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH . The post-oviposition periods for the above three temperature-humidity combinations were 2.44 ± 0.88 days, 2.13 ± 0.23 days and 2.38 ± 0.18 days respectively. During the post - oviposition period, the adult female became inactive and its feeding activity

was minimal and this was followed by the death of the individuals. The number of eggs laid by a gravid female of *A.theae* during its life time reached its peak level on the 3rd and 4th days of oviposition. The rate of oviposition showed a decrease from the 5th or 6th day onwards and reached the minimum at the end of the oviposition period. For temperature-humidity conditions of 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH, the fecundity recorded was 17.9 ± 0.46, 20.5 ± 0.34 and 20.7 ± 1.01 respectively. (Table, 27 – 30 & Plate, 31-32).

Hatching

A few hours prior to hatching, the egg assumed a milky colouration and a small cone like projection appeared at one pole of the egg, which resulted in the stretching of the chorion. Subsequently a longitudinal slit appeared at the protruded area through which the gnathosoma and legs of the first nymph came out. The vigorous movements of the legs and body resulted in the complete extrusion of the first nymph from the egg case. The hatching process was completed in 10 – 15 minutes and no major changes could be observed under the different temperature-humidity conditions tested. Shortly after hatching, the nymph moved away in search of food. The remnant of egg case was white and transparent.

Duration of developmental stages

(Table 31- 33 & Plate 33-34)

Incubation period

The incubation period was found to be of the shortest duration (1.63 ± 0.06 days) at 30 ± 2ºC & 70 ± 5% RH and of the longest duration (2.33 ± 0.07 days) at 25 ± 2ºC & 80 ± 5% RH. At 35 ± 2ºC & 60 ± 5% RH, the incubation period was recorded as 2.2 ± 0.07 days

Nymphal stages

Results of developmental studies disclosed that *A.theae* had two active nymphal stages viz. the first nymph and the second nymph. The transformation from the first nymph to the second nymph was marked by a moulting process which in turn was preceded by the occurrence of the first quiescent phase or nymphochrysalis. The active period of the second nymph was terminated by the initiation of the second quiescent phase or imagochrysalis which through a second moulting emerged in to the adult form.

First nymph

The newly emerged first nymph was very small, sluggish, vermiform and pale white in colour. It started feeding immediately after hatching. The duration of first nymphal period was shorter at 30 ± 2ºC & 70 ± 5% RH extending for 1.6 ± 0.04 days and longer at 25 ± 2ºC & 80 ± 5% RH being

2.08 ± 0.05 days. At 35 ± 2ºC & 60 ± 5% RH, the duration was 1.63 ± 0.06 days (Plate 35 Fig. 7). The first nymph subsequently ceased its feeding activity and entered in to a brief first quiescent or nymphochrysalis stage.

Second nymph

The second nymph was elongated, vermiform and pale yellow in colour. It was larger in size and more active than the first nymph (Plate 35, Fig.8). The duration of the second nymphal period could be recorded as 2.38 ± 0.04 days, 2.1 ± 0.04days and 2.33 ± 0.07 days respectively at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH . At the end of this active period, the second nymph entered in to an inactive or quiescent period for a short interval.

Quiescent Periods

A period of zero activity could be observed in the life cycle of *A.theae* at the end of the first and second nymphal stages. During this period, the individual stopped feeding and other noticeable life activities, became sluggish and entered into an inactive stage called the quiescent phase. The first and second second quiescent phases were termed as the nymphochrysalis and imagochrysalis respectively (Plate 35 Fig.7). The period of quiescence did not show much variation at different temperature-humidity conditions. All the quiescent phases took around 0.75 day for their completion.

Moulting

Moulting was observed at the end of each quiescent phase. Just before moulting, the quiescent stage became turgid and swollen in appearance. The movement of the succeeding active instar could be observed clearly. During moulting, a posterior emergence was noticed. The entire process was completed in about 20-30 minutes with no significant changes in duration at different temperature-humidity conditions. The moulting skin appeared to be wrinkled.

Adult Stages

The adult mites were larger in size when compared to the nymphal stages. They were fusiform, blunt anteriorly and orange in colour. No deuterogyny was observed. Males were observed to be smaller than the females. They were found actively feeding on the lower surface of leaves. Adult longevity was recorded as 11.88 ± 0.34, 10.69 ± 0.36 and 12.19 ± 0.37 at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH.

Morphological description of life stages of *A.theae*

Egg

Measurements

Diameter: 30 – 33 µm

Eggs, Minute, transparent, smooth and spherical. Before hatching, eggs became more transparent and movements of the first were nymph were visible through the egg case.

First nymph (Plate 36, Fig.1)

Measurements

Length: 54 – 59 µm

Width: 18 – 23 µm

The newly emerged first nymph appeared transparent and no microtubercles could be observed; the number of annulations ranges from 22 – 25 on dorsal side and 34 – 37 on ventral side; two setae detected on coxa 1 (c_1 and c_2) and on second coxa only one seta (c_3) noted; genital area and shield lacking; on the tarsus feather claw bears more than 4 rays; all leg segments free; dorsal seta, lateral seta and caudal seta present;ventral setae v_1, v_2, v_3 present.

Second nymph (Plate 36, Fig 2)

Measurements

Length : 72 – 81 µm

Width : 24 - 29 µm

Larger than the first nymph; number of annulations ranges from 26-28 without microtubercles; ventral annuli 44-48; dorsal seta directed backwards; microtubercles scattered on some of the rings of abdomen; genital area and shield entirely lacking; two setae detected on coxa 1 (c_1 and c_2) and on second coxa only one seta (c_3) noted; dorsal seta, lateral seta and caudal seta present; ventral setae v_1, v_2, v_3 present; on the tarsus feather claw bears more than 4 rays; all leg segments free.

Adult Female (Plate 37, Fig. 2)

Measurements

Length :130 - 155 µm

Width : 56 -61 µm

Prodorsal shield with centro-longitudinal ridge made by segmented median line and admedian lines; frontal lobe indented, projecting over gnathosoma; opisthosoma with mid-dorsal ridge; dorsal annuli 27-29, without microtubercles; ventral annuli 53-58,microtubercles small, beadlike ; female genital cover flap with numerous broken longitudinal lines and granules basally and 4-5 irregular longitudinal lines apically; dorsal seta,

lateral seta and dorsal seta present; ventral setae v_1, v_2, v_3 present; on the tarsus feather claw bears more than 4 rays; all leg segments free.

Adult male

(Plate,37 Fig. 1)

Measurements

Length :110 - 131 µm

Width: 54 -60 µm

Male is comparatively shorter than the female. It resembles female in all structural details except the genitalia.

PART III
BIOCONTROL OF TEA RSM, *Oligonychus coffeae*

INTRODUCTION

Field and laboratory studies during the present work revealed that *O.coffeae* is the most serious mite pest of tea causing severe damage to plantations of Wayanad district as compared to the other mite species which were subjected to detailed biological studies.

The current control measures practiced against the red spider mite, *O.coffeae* on tea plants rely heavily on the application of various synthetic acaricides such as dicofol, propargite, ethion, endosulphan, fenazaquin, dimethoate, profenophos and phosalone (Gurusubramanian *et al.* 2008). The indiscriminate use of these chemicals has given rise to a number of ecological backlashes comprising resurgence of primary pests, destruction of natural enemies, outbreak of secondary pests, development of resistance, undesirable residues on made tea and consequent health hazards, environmental contamination and increased costs of application (Muraleedharan *et al.* 1988) which would cause a serious drain on the economy of developing countries. In the recent years, this has become a major concern to the tea industry as the importing countries are imposing stringent restrictions for acceptability of the made tea because of pesticide residues (Gurusubramanian *et al*., 2008). These problems have necessitated the search for effective and alternative biodegradable insecticides.

Control measures using plant products were considered as an ecofriendly as well as safer pest management tactic even before the introduction of chemical pesticides. The re-evaluation and use of traditional pesticides of plant origin that farmers have been using over several decades offer a clue to local sourcing of pest control strategies. Plant extracts in crude form often consists of a complex mixture of active compounds. When compared to the use of individual constituents, use of complex mixtures as pesticides have advantages as natural mixtures may act synergistically and they may show greater overall bioactivity. In addition to this, pest resistance is much less likely to develop with mixtures (Berenbaum *et al*. 1991). These reasons support the use of chemically unrefined crude plant extracts containing mixtures of bioactive plant compounds rather than the use of pure individual compounds. Moreover, the former will be simpler and cheaper to prepare if the plant materials are locally available. India has a vast number of herbal plants with medicinal and pesticide properties, which can be used for the production of biopesticides in pest management in an economic and ecofriendly way.

Hence in the present study, an attempt was made to explore the potential and possibility of using the aqueous plant extracts of some commonly available and ecofriendly botanicals for the management of the red spider mite, *O.coffeae* by analyzing the ovicidal and acaricidal activities of extracts of selected plants under laboratory conditions.

Integrated Pest Management (IPM) approaches, create opportunities for increased inclusion of biologically based pest management tools such as parasitoids and predators, semiochemicals, phytochemicals and microbials. IPM gives much stress in the implementation of biological control of pests using their natural enemies. Since a minimum prey density is usually required to support a permanent predatory population, biological control is most suited to pest species with a relatively high economic injury level.

Predatory mites constitute a highly significant group owing to their potential in controlling the insect and mite pest populations below the economic injury level. There is enough evidence that the members of mite families like Phytoseiidae, Ascidae, Cheyletidae, Bdellidae, Cunaxidae, Stigmaeidae, Tydeidae, Anystidae, Erythraeidae and Tarsonemidae are potential predators that can control the mite pests infesting various crops considerably. Among the predatory mites, species of Phytoseiidae are potentially important in the control of phytophagous mites of the families Tetranychidae, Eriophyidae, Tenuipalpidae, and Tarsonemidae.

In the present study, the feeding potential of phytoseiid predators has been evaluated for the control of the population density of the Red Spider Mite, under laboratory conditions.

REVIEW OF LITERATURE

The present review was organized, mainly concentrating on the studies related with the ecofriendly control strategies of pests causing damage to crop plants with special reference to tea plants.

Biological control of plant mites:

Mathen *et al.* (1968) reported that the parasitic mite, *Pyemotes ventricosus* could be used as an effective biocontrol agent of the notorious coconut pest, the so called back headed caterpillar, *Opisina arenosella.* The predatory potential of the phytoseiid species, *Amblyseius finlandicus* on the tetranychid species infesting citrus in Punjab was reported by Gupta *et al.* (1971). Kropezynska (1973) carried out studies on the feeding potential of four species of phytoseiid mites viz. *T. pyri, T. potentillae, Phytoseius macropilis* and *A. finlandicus* on different species of prey mites. Prasad (1973) elucidated the role of *P. macropilis* in controlling the spider mite populations in Hawaii and found a decline in the size of the pest population with an increase in the predator population. Mallik and Channabasavanna (1976) identified *A. longispinosus* as a potential predator of spider mites and they suggested that it can be utilized for controlling the spider mite pest, *T. ludeni*.

Puttaswamy and ChannaBasavanna (1979) reported *T. tetranychivorus* as a potential biocontrol agent of *T. ludeni* in India. Hall *et al,* (1980) made a comprehensive survey on the biological control agents of the coconut mite, *A. guerroronis.* Dhooria (1980) recorded that the nymphs and adults of *A. alstoniae* could predate on all stages of *E. orientalis* with a preference to larvae and protonymphs. The feeding preference of *P. persimilis* to individual stages of the two spotted spider mite, T. *urticae* in the German Federal Republic was assessed by Ohnesorge (1981). Krishnamoorthy (1982) conducted studies on the influence of temperature on the development, survival and fecundity of the predatory mite, *A. tetranychivorus* feeding on *T. urticae.* Yousef *et al.* (1982) examined the effect of two prey species, *T. urticae* and *Tenuipalpus granati* on the biology of *A. gossypii* and *Agistemus exsertus* in Egypt. Based on laboratory studies, Boyne and Hain (1983b) showed that the phytoseiid predator, *N. fallacis* could be used as a biological control agent of the spruce spider mite infesting the fraser fir seedlings.

Results of ecological studies made by Ezulike and Odebiyi (1984) on *A. fustis,* a predator of *O. gossypii* infesting cassava in Nigeria disclosed that the nymphs and adults of the predator could feed on all stages of the tetranychid prey under laboratory conditions.

Sharma and Sadana (1987) conducted studies on the effect of predator - prey density on the prey consumption and daily rates of egg production in *A.*

finlandicus when fed on *E. orientalis.* Hayes and McArdle (1987) suggested the possibility of utilizing *T.pyri*, as an integrated control agent against *P. ulmi.* Hariyappa and Kulkarni (1988) studied the biology of *A. longispinosus,* a predator of *P. latus* at 23-27^{0}C and 65-70% RH. The mean durations of the egg, larval, protnymphal and deutonymphal stages were 46.45, 14.10, 2.78 and 22.71 hours respectively in males and the respective durations in females were 45.67, 14.27, 23.18, 24.41 hours. Neelu Nangia and ChannaBasavanna (1989) carried out studies on the feeding potential of *A. tetranychivorus* on selected tetranychid and tenuipalpid mites. Sharma and Sadana (1989) studied the development of *A. finlandicus* on *E. orientalis* and the results of their studies revealed that when fed on females, the species required a minimum period of 7.8 days and when fed on prey larvae, it took a maximum of 9.6 days for the completion of development. Jose *et al*. (1989) observed that a single individual of *A. alstoniae,* during its life time, could consume an average of 191.30 eggs, 76 larvae, 2.60 nymphs and 46.24 adults of *T. macfarlanei*. Clements and Harmsen (1990) studied the prey-stage preferences and prey capturing behavior of the Stigmaeid and Phytoseiid predators and their potential in biological control of mite pests.

Rasmy *et al.* (1990) studied the influence of predation by phytoseiid mites, *viz. Phytoseiulus finitimus, P.persimilis* and *A. gossypii* on the development, reproduction and mortality of *T. urticae.* Spicciarelli *et al.* (1992) observed a rapid decrease in the two spotted spider mite population

when the phytoseiid mites were released on to the mite infested leaves. Castagnoli *et al.* (1995) reported *N. californicus* as one of the most effective phytoseiid predator which could be used for the control of spider mite population on many agricultural crops and fruit orchards. Momen (1996) reported that the oviposition and prey consumption rates of the predatory mite species depended on the number of prey mites available. The functional and numerical responses of *N. californicus* to eggs and protonymphs of *T. urticae* under laboratory conditions were studied by Castagnoli and Simoni (1999). Lester *et al*. (1999) studied the potential of *A.fallacis* in the biological control of tetranychid mites *viz*. *P. ulmi* and *T. urticae* in an Ontario peach orchard.

The potential of *A. cucumeris* as a biocontrol agent against *S. nanjingensis* was assessed by Zhang *et al.* (2000). Manjunatha *et al*. (2001) evaluated the feeding preference of *A. ovalis* to different stages of *Petrobialatus*. Abhilash and Sudharma (2002) conducted studies on the biology and predatory potential of *A. longispinosus* on the pest mite, *T. ludeni.* The mean durations of egg, larva, protonymph and deutonymph observed were 3 ± 0.35, 0.88 ± 0.13, 1.43 ± 0.18 and 1.55 ± 0.14 days respectively. Opit *et al.* in USA (2004) evaluated the predatory potential of *P. persimilis* on *T. urticae* by releasing the predator in 1:6, 1:4 and 1:2 predator: prey ratio. Studies carried out by Lahiri *et al*. (2005) disclosed the abundance of predatory mites on the medicinal plants of Kolkata. Thakur and

Dinabandhu (2005) reported that *N. longispinosus* could feed on *Tetranychus* species infesting on apple and fig trees.

Messelink *et al.* (2006) studied the potential of 10 species of phytoseiid predators for control of *F. occidentalis* infesting green house cucumber in Netherlands. They identified *T. limonicus* as the best predator of *F. occidentalis.* Fraulo and Liburd (2007) in Florida conducted green house and field experiments to determine the efficacy of *N. californicus* for controlling *T. urticae* in strawberries. Arthurs *et al.* (2009) in USA evaluated the predatory potential of *A. swirskii* and N. *cuccumeris* on *S. dorsalis* and concluded that *A. swirskii* was more effective than *N. cucumeris*. Oliveira *et al*. (2009) studied the feeding potential of the predatory mite, *P. macropilis* on the two-spotted spider mite, *T.urticae* on strawberry plants under greenhouse conditions.

Ahn *et al.* (2010) studied the functional responses of *N. californicus* to *T. urticae* on strawberry leaves in Korea. They observed that as the temperature got increased, the predator took less time to consume the prey eggs and nymphs. Perumalsamy *et al*. (2010) conducted studies on the biology and predatory efficiency of *Stethorus gilvifrons* on *O.coffeae* and found that adult female consumed an average of 205 eggs, 92.2 larvae, 81.8 nymphs and 52.4 adult mites per day. Gonzáles-Zamora *et al*. (2011) reported *S. longicornis* as a potential predator of E. *orientalis.* They also found that it

showed voracious feeding on different life stages of the pest mite and reduced the pest population. Carrillo and Pena (2012) evaluated the predator preferences of *A.largoensis* 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 it consumed 45 eggs per day. Sarwar *et al*. (2012) proved the successful use of the phytoseiid predator, *N. pseudolongispinosus* for biological control programmes against spider mites.

Fiedler (2012) conducted studies on the interaction between beneficial organisms in controlling the spider mite, *T. urticae* and found that the predatory mites *A.swirskii* and *P.persimilis* showed a high efficacy when used together to control *T.urticae* (86% mortality). When predators were used separately, they were less effective against the pest (about 63% mortality). Rahman *et al.* (2012) evaluated the predatory potential, prey stage preference and optimum predator–prey ratio of *N. longispinosus* on *O. coffeae* and found that predator–prey ratios of 1:33 and 1:50 were effective in laboratory conditions and 1:25 was effective under green house conditions. Liyaudheen *et al*. (2014) studied the feeding potential of *E. ovalis* on *T. macfarlanei,* a major spider mite pest inducing considerable damage and yield loss to the vegetable crop, okra in Kerala. Sanchit and Shukla (2016) studied the feeding potential of the phytoseiid predator, *A. longispinosus* against the spider mite,

T. urticae and the results of their studies revealed that the larva, protonymph, deutonymph, and the adult male and female of *A. longispinosus* showed more preference to the eggs followed by mixed stages and adult stages of prey mite.

Formulation and Application of biopesticides

Use of biopesticides as an alternative pest control strategy has gained increasing attention in the current scenario owing to the various ecological, environmental and health hazards experienced by man owing to the overzealous and indiscriminate use of different types of pesticides against crop pests. Being a consumable commodity, heavy reliance on chemical pesticides for plant protection is not advisable in tea plantation as it would lead to serious health hazards. Apart from these, application of chemical pesticides would also lead to the development of resistance in target organisms and intensify the pest problems further. All these would necessitate the implementation and relying of alternative practices of pest control, one of which being the safer mode of application of plant extracts.

Cranham and Helle (1985) who observed that spider mites developed pesticide resistance very quickly and completed numerous generations annually when exposed to high frequency of pesticide spray applications. The need for adopting biological control measures was stressed by Van Lenteren and Woets (1988) in order to reduce the application of synthetic pesticides as well as to avoid residual problems associated with the application of synthetic

pesticides in tea. The indiscriminate and excessive use of pesticides causes destruction of natural enemies of pests and other non-target organisms, pesticide resistance in pests, pesticide residues in crop and health hazards to consumers (Muraleedharan, 1995).

Goncalves *et al.* (2001) studied the effect of aqueous extracts of clove, neem and chinaberry on survival of eggs, larvae, nymphs and adult females of the cassava green mite, *Mononychellus tanajoa.* The results of their study revealed that neem extracts at concentrations higher than 2.5% could be used for the control of *M. tanajoa.* Sarmah *et al*. (2009) evaluated the acaricidal activity of aqueous extracts of four species of plants viz. *Polygonum hydropiper*, *Xanthium strumarium*, *Acorus calamus* and *Clerodendron infortunatum* in different concentrations against *O.coffeae* under both laboratory and field conditions. The authors recorded strong ovicidal action with *X. strumarium* (87.09%) and A. *calamus* (70.62%) where as least action in *P. hydropiper* (30.86%) and *C. infortunatum* (20.58%). Application of *C. infortunatum* extract caused maximum adult mortality. Vinayaka and Kekuda (2010) elucidated the insecticidal efficacy of different concentrations of methanol extract of fruits and leaves of *C. frutescens* against the larvae of *Aedes aegypti*. Preliminary phytochemical analysis conducted by the same authors showed the presence of tannins, alkaloids, steroids and glycosides in both extracts. Roobakkumar *et al.* (2010) assessed the bioefficacy, ovicidal action and ovipositional deterrence of aqueous extracts of neem kernel,

pongam kernel and garlic in the laboratory against *O.coffeae* and observed that neem kernel aqueous extract could induce more than 90% mortality. Muzemu *et al*. (2011) evaluated the extracts of *Lippia javanica* leaf powder and *Solanum delagoense* ripe fruit pulp for pesticidal effects against rape aphids and tomato red spider mites as alternatives to conventional pesticides. Oni (2011) proved the insecticidal properties of fruit and seed powders of *Capsicum frutescens* and *C. annum* in the laboratory against stored products pests like *Callosobruchus maculatus* and *Sitophilus zeamais.* Roy *et al*. (2011a) tested the acaricidal and ovicidal activities of *Clerodendrum viscosum* extracts against *O.coffeae*. The aqueous solvent extracts of *C. viscosum* showed 40–90% mortality of *O. coffeae,* while 67–92 % mortality was recorded with petroleum ether extract, 50–80% with acetone extract and 43–87% mortality with methanol extract. The same authors (2011b) studied the acaricidal, anti-ovipositional and ovicidal activities of different solvent extracts prepared from the leaves and succulent stems of *Polygonum hydropiper* against *O. coffeae*.

Soumya and Bindu (2012) evaluated the antifungal potential of aqueous leaf and fruit extracts of *C.frutescens* against four major fungal strains associated with groundnut storage and suggested that groundnuts treated with *C. frutescens* fruit extracts were capable of preventing fungal infection. Vasanthakumar *et al*. (2012) elucidated the acaricidal activity of aqueous plant extracts of *Vitex negundo*, G*liricidia maculata, Wedelia*

chinensis, *Morinda tinctoria* and *P. glabra* against the red spider mite, *O.coffeae* in the laboratory and observed that the aqueous extracts of *P. glabra and M. tinctoria* had the maximum ovicidal action, ovipositional deterrence and adult mortality. The acaricidal properties of aqueous seed extract of *Melia azedarach* in different concentrations like 1%, 2%, 4%, 6%, 8% and 10% were evaluated by Roy and Mukhopadyay (2012) against *O. coffeae* in the laboratory. The authors observed significant reduction in the viability of eggs and also observed a reduction in adult emergence and increased duration of total developmental period. Syahputra *et al*. (2013) evaluated the acaricidal activity of 30 tropical plant extracts against the citrus rust mite, *Phyllocoptruta oleivora* and the citrus red mite, *P. citri.* Aqueous seed extract of *Jatropha curcas* exhibited the strong acaricidal activity against *P. oleivora* with LC50 of 0.8%, followed by the aqueous seed extract of *Mimusops elengi* and *Pometia pinnata* with LC50 of 1.06% and 1.29%, respectively. Radhakrishnan and Prabhakaran (2014) studied the efficacy of aqueous extracts of commonly available weeds found in tea plantations against *O.coffeae* under laboratory condition. The aqueous extracts of *Allamanda catharitica* and *Conyza bonariensis* showed 100.0 % and 80.0 % adult mortality respectively in 5% concentration after 96 hours of observation. Studies conducted by Thambi and Cherian (2015) revealed that leaf extracts of *Strychnos nux-vomica* in ethyl acetate solvent was highly toxic against adults of stored pest like *Sitophilus oryzae*. Mamun *et al.* (2015) evaluated the

toxicity of plant extracts of some locally available indigenous plants viz., *Azadirachta indica, Lantana camara, Datura metel, P. hydropiper*, *Xanthium strumarium* and *Swietenia mahagoni* at different concentrations against the red spider mite, *O. coffeae* under both laboratory and field conditions in Bangladesh and the results revealed that aqueous extract of *X. strumarium* showed the highest average mortality (89.66%) of red spider mite at 10% concentration followed by *S. Mahagoni* (86.21%), 72 hours after the treatment. Acaricidal effect of different solvent extracts of *Parthenium hysterophorus* against *O. coffeae* was evaluated by Mech *et al.*(2015) and they revealed that methanol extracts showed highest adult mortality (97.25%) at 1% concentration at 24 h of observation followed by chloroform ether (65.03%) and petroleum ether extracts (47.43%).

MATERIALS AND METHODS

Biocontrol of Pest mites

Considering the severity of damage induced by *O. coffeae* to tea leaves when compared to the other two species, *B. phoenicis* and *A. theae* as evidenced through the present study, attempts were made to develop proper formulations of biopesticides for application against *O. coffeae* under laboratory conditions. Additionally, studies were also made to elucidate the feeding potential of selected predatory mites on *O.coffeae*.

Formulation and Laboratory application of Biopesticides in the laboratory conditions

Three plant species showing insecticidal properties were selected for the preparation of biopesticides, as given below:

1. Gliricidia sepium (Jacq.)

G.sepium, is a medium sized leguminous tree belonging to the family Fabaceae. The tree is used in many tropical and sub-tropical countries for various purposes such as live fencing, fodder, coffee shade, firewood and green manure. It is also used for its medicinal and insect repellent properties. It can grow from 10 to 12 meters high. The bark is smooth and its colour can range from a whitish grey to deep red-brown. It has composite leaves that can

be 30 cm long. Each leaf is composed of leaflets that are about 2 to 7 cm long and 1 to 3 cm wide. The flowers are located on the end of branches that have no leaves. These flowers have a bright pink to lilac colour that is tinged with white. The fruit is a pod which is about 10 to 15 cm in length. It is green when unripe and becomes yellow-brown when it reaches maturity. The pod produces 4 to 10 round brown seeds. (Plate 38, Fig. 2)

2. ***Strychnos nux-vomica*** L.

S. nux-vomica is a medium sized deciduous tree, native to India and Southeast Asia. It belongs to the family Loganiaceae. The wood is dense, hard white, and close-grained. The branches are irregular and are covered with a smooth ashen bark. The young shoots are a deep green colour with a shiny coat. Leaves are simple, opposite, ovate or broadly elliptic and 7–15 × 4–10 cm in size. They have a shiny coat and are smooth on both sides. The flowers are small with a pale green colour with a funnel shape. The fruits are about the size of a large apple with a smooth and hard shell which when ripened is a mild shade orange in colour. The flesh of the fruit is soft and white with a jelly-like pulp containing seeds covered with a soft woolly substance. It is a major source of the highly poisonous, bitter alkaloids, strychnine and brucine. (Plate 38, Fig. 3)

3. Capsicum frutescens L.

C.frutescens is a species of chilli pepper belonging to the family Solanaceae. It is an annual or short-lived perennial plant. Leaves are ovate-lanceolate and 3–10 × 1.5–6 cm in size. Flowers are white with a greenish white or greenish yellow corolla, and are either insect or self-pollinated. The plants' berries typically grow erect and fusiform in shape. They are usually very small and pungent, growing 10–20 millimetres long and 3–7 millimetres in diameter. Fruits are red or white when ripe and contain many seeds. (Plate 38, Fig 1)

Preparation of aqueous plant extracts

Leaves of *G. sepium, S. nux-vomica* and fruits and seeds of *C. frutescens* were collected locally. Each plant material was dried under shade and powdered by using electric grinder and passed through a 20 mesh sieve and kept in a polyethylene bag. 150 g of each powdered plant material were taken into a conical flask of 1 litre capacity and 500 ml of distilled water was added to it and shaken for 8 hours in a mechanical shaker and then kept it for 24 hours. The extract was separated using fine muslin cloth and then filtered. The filtrate was collected in a 1 litre capacity conical flask and volume was made up to 500 ml. This was considered as the stock solution. Required concentrations (5.0, 10.0 and 15.0 %) were prepared from the stock solution.

Assessment of ovicidal / acaricidal activity aqueous plant extracts

For the assessment of ovicidal properties of the extracts, gravid females of *O.coffeae* were introduced on to leaf discs placed on moistened cotton pads in petri dishes and kept overnight for oviposition. After 18 hours, the introduced mites were removed with the help of a fine brush. The eggs laid on tea leaves were counted under a stereomicroscope as pre-treatment count. 150 eggs were considered for each ovicidal treatment of the plant extract and observed for five times (30 eggs/observation). All the other eggs were removed cautiously by using a fine needle. After counting, the eggs were subjected to spraying of different concentrations of aqueous plant extracts such as 5.0, 10.0 and 15% (w/v) using a glass atomizer (Plate 39). The control eggs were segregated in the above manner and treated with water. Hatchability of eggs without any treatment was also noted. Hatchability was determined for both experimental and control batches of eggs for a period of 12 days after oviposition. Those eggs that did not hatch after this period were regarded as non-viable (Sarmah *et al*.,1999). Per cent reduction in hatchability was calculated based on the following formula:

$$\text{Egg mortality (\%)} = \left(\frac{\text{No. unhatched eggs/treatment}}{\text{Total No. of eggs/treatment}} \times 100\right)$$

For laboratory evaluation of plant extracts, 30 healthy adult females of the red spider mite, *O. coffeae* (24 hours old) were released on to fresh tea leaf disc kept in petri dish lined with moistened cotton. Aqueous plant extracts in different concentrations were sprayed on the leaf surface. The number of live red spider mites was counted at 24, 48 and 72 hours after treatment with the plant extracts. Each treatment was replicated five times.

Evaluation of Feeding Potential of Phytoseiid Mites

Feeding preference of individual stages of a phytoseiid predatory mite *A. largoensis* to the different stages of *O.coffeae* was tested under laboratory conditions. Several culture sets were maintained in the laboratory as described above at 30 ± 2ºC & 70 ± 5% RH. The experiment was initiated by setting five culture sets containing leaf discs with different stages of the prey. The culture sets were arranged in such a way that each leaf disc harboured 25 individuals of respective prey mites. In the case of eggs it was 50/ leaf disc. Different stages of predator viz. male, female, larva, protonymph and deutonymph were released on to each culture set containing different stages of prey mites. Observation on feeding activity as well as feeding preference of immature and adult stages of each predator species was made. Average number of prey consumed in 24 hour was recorded. Data obtained on the above parameters were tabulated and presented through appropriate

figures/graphs. Data obtained on feeding potential were also subjected to statistical analysis using ANOVA.

Interaction of *O.coffeae* and predatory phytoseiids viz. *A.largoensis, A.herbicolus* was also studied at different prey - predator ratios viz., 2:1, 5:1 and 10:1. The culture sets were prepared in such a way that each leaf disc harboured 20 adult individuals of *O.coffeae*. Proportionate numbers of predatory mites were released to each culture set. Number of days taken by predatory mites for the complete consumption or killing of the prey was recorded. The results were statistically analysed.

OBSERVATIONS

Effects of Aqueous plant extracts on *O.coffeae*

Ovicidal activity of aqueous plant extracts

The results of studies on the biocidal activity of aqueous extracts of selected plants on the eggs of *O.coffeae* are presented in Table No 34 Plate 40a. As shown in the table highest mortality of eggs could be registered for the extracts of *C.frutescens* and *S. nux-vomica* at higher concentrations (10.0%), inducing mortality rates of 82.66 and 72.67 % respectively. The lowest rate of egg mortality (40.67 %) was recorded for the extract of *G.sepium.* On application of extracts of *C.frutescens* and *S. nux-vomica* in lower concentration (5 %), the egg mortality rate was found lowered to 60.67 % and 56.67% respectively. A still reduced rate of egg mortlity rate (28.67%) was observed with the extract of *G.sepium* when applied in lower concentration (5%). When the plant extract concentration was further lowered to 2.5%, the rate of ovicidal activity also got decreased for all selected plants, accounting to 42 and 29.33% respectively for *C. frutescens* and *S. nux-vomica* and 19.33 % *for G.sepium.*

Acaricidal activity of plant extracts on adult mites

Different concentrations (2.5, 5.0 and 10.0%) of aqueous extracts of *C. frutescens*, *S. nux-vomica* and *G.sepium* were tested to evaluate their toxic effect at 24, 48 and 72 hours against adult red spider mites under laboratory conditions and the results obtained have been summarized in Table 35 and Plate 40 b. In all cases of treatment, mortality showed a linear trend i.e., increasing with increase in the concentration of biopesticides.

As shown in the table, the maximum acaricidal activity was observed with the aqueous extracts of *C. frutescens* when applied in lower concentration (2.5 %). The per cent mortality of adult mites after 24, 48 and 72 hours of application of the extract of *C. frutescens* could be recorded as 30, 32.67 and 37.33 respectively while the extract of *G.sepium* showed lowest activity, inducing only 14% mortality after 24 hours of treatment. There were no marked changes in the levels of toxicity between 24 and 72 hours. The per cent mortality caused by the extract of *S. nux-vomica* in 2.5 % concentration after 24 and 48 hours could be recorded as 17.33 and 19.66 respectively. There was no significant change in the mortality rate between 48 and 72 hours.

The extracts of *C. frutescens* and *S. nux-vomica* when applied in 5% concentration induced more or less similar acaricidal activity. The observed rate of mortality after 24 hours of treatment was 46 and 44.67 % respectively

for *C. frutescens* and *S. nux-vomica* and which was found to increase to reach 67.3 and 62 % after 72 hours of treatment.

Treatment with higher concentrations (10.0%) of aqueous extracts of *C.frutescens*, *S. nux-vomica* and *G.sepium* could manifest death rates of 84, 74.67 and 58.67 % adult mites respectively after 24 hours. A gradual increase in the rate of mortality was observed during the time elapsed. The percent of mortality recorded at 72 hours after treatment of extracts was 94.67, 83.87 and 77.33 for *C.frutescens*, *S. nux-vomica* and *G.sepium* respectively.

Feeding potential of predatory mites on *O.coffeae*

Of the various species of predatory mites recovered during the survey, 2 species of the genus *Amblyseius* viz. *A. largoensis*, and *A. herbicolus* showed high population density, wide distribution trend and voracious feeding habits. These species were always found in constant association with the major pest mite species, *O.coffeae* infesting tea which encouraged to undertake further studies.

The two species of predatory mites, *A. largoensis* and *A. herbicolus* selected for the present study, proved their efficacy as predators of *O.coffeae* (Plate 41). During the feeding process, the predator was found grasping the prey with its second pair of legs. The first pair of legs were found held over the prey. The predator then bent its gnathosoma until its longitudinal axis was perpendicular to the prey's body and began to cut the cuticle. Once the body cuticle of the prey got penetrated, the movement of the body fluid of the prey into the gut of the predator was clearly visible .The coloured body fluid of the

prey could be clearly seen through the transparent body of the predator. The mode of feeding of the various life stages of the predators was almost similar. The time taken by the different stages of the predator to consume or kill the life stages of the prey showed variation. It took about 2 -3 minutes for the consumption / killing of prey eggs while 5-10 minutes could be recorded for the adult/nymphs of pest mites. While feeding on eggs, both the predators made punctures on the egg surface with the help of chelicerae, through which the contents were sucked in.

Results on the study on the interaction of *O.coffeae* and the predatory phytoseiid mites, *A.largoensis* and *A.herbicolus* at different prey - predator ratios viz., 2:1, 5:1 and 10:1 are presented in Tables 36 & 37. As shown in the table at a prey – predator ratio of 2:1, *A.largoensis* took 2.8 ±0.37 days for the complete consumption or killing of the prey mite, *O.coffeae.* The consumption time taken by the predator at a prey – predator ratio of 5 : 1 and 10 : 1 was observed to be 5.8 ± 0.37, 10.4 ± 0.51 days respectively. When compared to the rate of prey consumption by *A. largoensis*, *A. herbicolus* took slightly more duration for the complete removal of *O.coffeae* from the experimental culture under laboratory conditions. The time taken by *A. herbicolus* for the complete consumption or killing of *O.coffeae* was recorded as 3.2 ± 0.2, 6.6 ± 0.24 and 11.6 ± 0.51 days respectively at the prey – predator ratios of 2:1, 5:1 and 10:1.

The feeding preference of the various life stages of the predatory mite, *A.largoensis* to the different life stages of *O.coffeae* was tested under laboratory conditions and the results of which are shown in tables 38 & 39. *A.*

largoensis was found actively feeding on the pest mite during the present study. Table 36 & Plate 42 illustrate the average number of different life stages of the prey mite consumed and the percentage of consumption by *A. largoensis.* The per cent consumption of the larva of the predator on *O.coffeae* was very low when compared to the other stages. It consumed an average of 7.2 % eggs and 4.8 % larvae of the prey mite in 24 hours. The larva of the predator did not exhibit any signs of predation on the nymphal and adult stages of the prey mite, *O.coffeae*. The rates of consumption by the protonymph and deutonymph of *A. largoensis* were 18.8 %, and 45.2 % eggs, 19.2 % and 49.6 % larvae, 12.8 % and 35.2% protonymphs, 0 % and 10.4 % deutonymphs and 0% and 4.8 % adults. The per cent consumption by the adult male of *A. largoensis* on different life stages of *O. coffeae* could be recorded as 45.2, 51.2, 34.4, 9.6 and 4.8 for eggs, larvae, protonymphs, deutonymphs and adults respectively. The adult female of *A. largoensis* was recognized as the most voracious predator, consuming 72% of eggs, 65.6 % of larvae, 51.2 % of protonymphs, 13.6 % of deutonymphs and 6.4 % of adults. Statistical analysis of the results by conducting ANOVA supported the significant interactions of the predator *A. largoensis* on *O.coffeae* at 0.05 level.

DISCUSSION

DISCUSSION

Tea is one of the most popular beverages all over the world owing to its distinct aroma, flavor and health benefits.It is a heterogeneous plant with many overlapping morphological, biochemical and physiological attributes. India is the second largest producer of tea in the world. Similar to any other plantation crop, tea plants also are subjected to the attack of a large number of insects, mites and nematodes. Crop loss in tea due to pests, diseases and weeds varies between 15 and 20 percent. In south India, mite infestation causes severe damage to tea plantation and thereby causes considerable loss to our economy.

Considering the extent of damage induced by mites on tea, the present project was undertaken to understand the common species of mites inhabiting the tea plantations of Kerala and also to record data on the seasonal patterns of distribution, nature and extent of damage induced on host plants, developmental pattern, duration of life cycle and morphological features of immature and adult stages of selected dominant and most injurious species of local importance.Identification of natural enemies of the major pest mites, study of their feeding potential and evaluation of bioefficacy of selected plant extracts upon these pests were also undertaken.

Mites representing two distinct feeding groups were found infesting the tea plantations of North Kerala as evidenced during the present study. The phytophagous group was represented by species like *O. coffeae, B.phoenicis, A. theae,* C. *carinatus* and *P. latus* whereas the predatory group was represented by species like *A.largoensis, A. herbicolus A.channabasavannai* and *N. longispinosus.* In most of the tea-growing Asian and African countries, presence of *O.coffeae, B. phoenicis, A. theae*, and *C. carinatus* was reported as the most abundant mites infesting tea (Muraleedharan, 1992) and *O.coffeae* is considered as the most important mite pest of tea (Watt and Mann, 1903). The most abundant phytophagous mites infesting the tea plantations of North Kerala are observed in the present study were *O. coffeae, B. phoenicis* and *A.theae.*

During the present study, population density of the Red Spider Mite (RSM), *O.coffeae* could be observed in the maximum level during April- May and then it started to decline in June and reduced further in July and August. This was due to the occurrence of heavy rainfall which washed off large number of mites from the surface of the tea leaves.Rainfall would physically dislodge the mites from the upper surface of the unshaded tea leaves. The effect is more or less of a mechanical nature rather than a physiological one. The present observation is in support of the earlier findings on the species from various tea plantations of India (Das 1959; Puttaswamy and Channabasavanna, 1983; Saikia *et al*., 1999; Selvasundaram and

Muraleedharan 2003; Choudhury *et al.* 2006; Mazid *et al*., 2015) which showed that population buildup of the mite begins in February or March and attains peak level in April/May in South India and April -June in Assam and the density becomes low during wet, rainy months of July to October.The RSM suffers high mortality during heavy rain and a combination of wind and rain stops its development in Japan (Osakaba, 1965). Immersion in water causes metabolism to stop, eggs do not hatch and the mites stop feeding, moulting or ovipositing (Herne, 1968). The results of the present study revealed a significant and positive relationship between mite population and minimum temperature, thereby supporting the earlier findings on *O. coffeae* (Mazid, 2015).

In the current study, the flat mite, *B.phoenicis* also showed a more or less similar trend of population distribution. The mite attained the peak population in the dry season, from March to May and during monsoon season population was scanty, from June to September and then it increased again to moderate levels during October- January period. These observations were in parity with the earlier findings on the same species (Karmakar and Saha, 2005) on another host plant, the invasive weed plant, *M. micrantha* in West Bengal.The results of studies on population distribution of *B.phoenicis* upon statistical analysis enabled to establish a significant positive correlation with the maximum temperature and a strong negative correlation with rainfall. The rate of development of *Brevipalpus* spp. was reported to be strongly

influenced by climatic factors like temperature, relative humidity and host plant (Lal, 1978).

Incidence of the eriophyid mite, *A.theae* on tea was recorded throughout the year and its population was found to fluctuate in accordance with the seasonal factors. It attained a peak population size in the month of May. Statistical analysis of the results of population studies of the mite disclosed a significant positive correlation between mite population and maximum temperature while population density was in negative correlation with rainfall. Despite this, a negative correlation had been established previously between the population size of the mite and temperature (Muraleedharan and Chandrasekharan, 1981). Generally, most species of plant mites including the red spider mite of tea, *O. coffeae* show direct correlation between population build up and temperature and an increase in temperature was found to lead to increase in rate of development and a decrease in duration of developmental stages (Chakraborty *et al*., 2015) and an inverse relationship was attributed between the rate of development and duration of different instars.The results of the present study support the findings of the above authors. However, the disparity observed between the findings of Muraleedharan and Chandrasekharan (1981) and the present findings on *A. theae* needs further analysis of other environmental parameters. Probably the prevalence of natural enemies like the predatory mites and

insects would have exerted a negative impact on the mite population, inspite of increase in temperature.

Results of field observation on the distribution pattern of *O.coffeae* revealed that it could infest almost all age groups of tea leaves except the very tender ones. In spite of such preference for leaves, the mite exhibited variation in its distribution pattern among the leaves. Accordingly, the population density of the mite was high on the middle aged leaves. Probably, the biochemical constituents of the leaves at this age would have supplemented the ideal nutritional components, leading to the rapid build up of the mite. Too old (Dhooria, 1985) or too young (Sobha and Haq, 1999) leaves harboured comparatively lesser population of adult mites. In the present study, *O.coffeae* was found to prefer the less turgid tissues of mature leaves. This observation is in line with that of Jeppson *et al.,* (1975) who described *O. coffeae* as a species which prefer less turgidity. *O.coffeae* was often found occurring on the upper surface of tea leaves also, especially where the veins meet. The shallow concavity available in such areas would provide some kind of protection for its eggs. In addition to this, the veins and veinlets provide a firm grip to these mites during oviposition (Banu and ChannaBasavanna, 1972; Dhooria, 1982) and avoid dislodgement of the various life stages from the leaf surface.This indicated a high degree of thigmokinesis and thereby supporting the earlier findings of Jeppson *et al.*(1975).

Webs made by *O.coffeae* were found to protect the eggs and immature stages and the latter remained fully confined within the covering of the webs. Viability of eggs was maintained by these webs and removal of eggs from the web often resulted in reduced hatchability (Hazan *et al.,* 1974). Webbing was also found helping in the transport of the individuals within or between the host plants. These webs often enhanced the accumulation of dust particles on the leaves, weakening the easy movement of the predatory mites. This finding corroborated the reports of Griffiths and Fischer (1950) who recorded a positive effect of inert dusts on spider mite population and adverse effect on the population of predatory mites.

Tenuipalpid mites induce numerous types of abnormalities on their host plants (Jeppson *et al*. 1975; Beard *et al*. 2012).The direct feeding symptoms of these mites are less intense when compared to these of tetranychids and eriophyids.These mites are known to transmit various phytopathogenic microbes which affect the plant vigour and yield (Kitajima *et al.*, 2003). Apart from these, they inject toxic saliva into the tissues of their host plants (Childers *et al.* 2003). Feeding activity of *B. phoenicis* on different host plants disclosed the preference of the mite to the lower surface of the leaf blade, adjacent to the midrib or veins (Prabheena and Ramani, 2013). The injured parts gradually became necrotic, particularly when large numbers of mites were present (Childers, 1994). Severely infested leaves showed the presence of diffused chlorotic spots on the leaf lamina and most often on the

veins and midribs, generally called as the 'phoenicis blotch' (Knorr *et al*. 1968, Jeppson *et al*. 1975; Prabheena and Ramani 2013). The damage induced by this species on *C.sinensis* during the present study was also in parity with the earlier findings. The feeding activity of *B.phoenicis* was found to induce discolouration of leaves. Symptoms of infestation were mainly visible on either side of the midrib which gradually got extended to the entire leaf lamina. Initial symptoms of damage were recognized by the appearance of various chlorotic spots which on progressive feeding by mites, gradually turned to brown patches.These observations were in support of the findings mentioned above on the damage symptoms due to *B. phoenicis* on different host plants.

A good number of eriophyid mites are capable of inducing an array of host abnormalities ranging from simple erinea to complex galls (ChannaBasavanna, 1966; Mondal *et al*., 1981). In the present study, the adults, nymphs and eggs of the pink mite of tea, *A.theae* were mostly found on the lower surface of young tea leaves. However, in cases of severe infestation, the upper surfaces of tea leaves also showed symptoms of infestation and such leaves became leathery and assumed a brown colouration. Often in the affected leaves, apart from the leathery nature, the veins and veinlets show pink colouration (Das and Sengupta, 1958; Das, 1965) thereby giving them the name 'pink mite'.

The phytophagous mites recovered from tea leaves were found inducing varying types of abnormalities, leading to altered levels of various biochemical constituents. In the present study, biochemical estimation of chlorophyll pigment was carried out in order to elucidate the extent of damage induced by selected species of pest mites on the photosynthetic activity of tea leaves. In plants, chlorophyll pigments are essential for absorbing light energy from the sun for its subsequent conversion to chemical energy during photosynthesis. The chlorophyll content of the leaves is regarded as one of the parameters determining the photosynthetic efficiency of the plant (Maithra and Sen, 1988; Ekanayake and Adeleke, 1996; Lahai *et al.,* 2003). Results of the present study clearly established the feeding impact of 3 species of mites infesting tea plants viz. *O.coffeae, B.phoenicis* and *A.theae* on the chlorophyll contents.The potential of tetranychid mites in inducing quantitative reduction in chlorophyll pigments was already established on various host plants. A very high loss in chlorophyll content was recorded by Haq (1997) on okra leaves infested by *T. macfarlanei* and Park and Lee (2002) on cucumber leaves infested by *T. urticae.* Results of studies made by Nachman and Zemek (2002) on leaves of *Phaseolus vulgaris* infested by *T.urticae* and those of Sangeetha and Ramani (2007) on leaves of *M. oleifera* infested by *T. neocaledonicus* further corroborated the fact that leaf chlorophyll content decreased with increase in mite density and duration of feeding. The results of the present study also enabled to support the findings of Bounfour *et al.*

(2002) who made measurements of chlorophyll fluorescence and chlorophyll contents of raspberry leaves damaged by spider mites and reached at a conclusion that mite feeding primarily affected the plastoquinone pool, which in turn would play a significant role in electron transport during photosynthesis. The chlorophyll metabolism of injured cells may be influenced by the water stress induced by mite feeding (Tomezynsk and Kropzynska, 1985). Based on the results of the present study, it may be concluded that, the infestation of *O.coffeae*, *B. phoenicis* and *A.theae* would significantly affect the concentration of chlorophyll in tea plants, and thus restrict their photosynthetic efficiency which in turn would result in stunted growth of plants. Moreover, in the case of severe infestation by *O.coffeae,* the leaves were found glued with faecal pellets, egg cases and exuviae of various life stages. Such leaves along with extensive webbing of the mites would help in settling of dust particles, thereby making a separate coating over the leaf surface. This also would cause a reductionin photosynthesis by hindering the absorption of light (Sadana, 1985; Sumangala and Haq, 2000). In addition, feeding activity of the members of the individual species could induce heavy loss of water from the leaf tissue. The overall effect of the above processes had caused the total destruction of the photosynthetic machinery of the plant. These results have clearly manifested the potential of the leaf sucking forms in damaging the host plants (Ekanayake and Adeleke, 1996; Prabheena and Ramani, 2013).

Results of analysis of the feeding response of the mite species viz.*O.coffeae, B.phoenicis* and *A. theae* through estimation of total phenolics in the infested tea leaves further proved their potential in damaging the tea leaves. Phenols, the aromatic compounds with hydroxyl groups are wide spread in plants and which offer resistance to pests and diseases. As certain phenolics have the ability to precipitate plant proteins and render them indigestible, they have been considered as defense compounds. An increased level of phenolics was reported in castor, eucalyptus and cassava due to pest attack and it was also observed that higher phenolic content would enhance the resistance of host plants against the insects (Ananthakrishnan *et al*. 1992). Increased levels of phenolics were noticed in roots and leaves of resistant pearl millet than that of the sensitive strains (Gupta, 2001). In the present study, results of phenol estimation in mite infested and control leaves of tea plants clearly revealed the elevation of phenol concentration in the infested leaves, thereby supporting the previous reports on mite infested leaves of eucalyptus (Khattab, 2005).The per cent increase in phenol content of tea leaves was highest in the case of *O.coffeae* infestation which recorded 71.82 ± 3.6 % when compared to the infestations by *A.theae* and *B.phoenicis,* which caused an increase of 34.95 ± 2.99% and 20.65 ± 1.39% respectively.Thus the present study clearly revealed that tea plants infested with *O.coffeae, A. theae* and *B.phoenicis.* could synthesize increased amount of phenol to protect themselves from further damage through mite infestation An increase in

phenolic content owing to spider mite infestation in 'Conica' leaves was reported earlier (Puchalska,2006), estimating upto 50% fall in photosynthesis rate after a period of 3 weeks of heavy infestation by *O. ununguis.* Hence, it is possible to suggest that these pest mites can cause considerable reduction in photosynthesis by making mechanical damage intensified by biochemical changes.

Proline is a universal osmolyte accumulated in response to several stresses and has a utility in plant defense reactions (Öncel *et al*. 1996; Chakraborty *et al*. 2002).Water stress in the plant tissues results in the accumulation of proline which acts as water-stress adjuster (Rehman *et al*. 2013) and its concentration can be used as a marker for water stress in plants (Maritim *et al*. 2015). The proline contents of certain plants become raised many folds during microbial infection in sensitive and resistant cultivers (Gupta, 2001). In the present investigation, the amount of proline was found increased significantly on tea plants due to the infestation by mite species under study. This supports the results of earlier studies showing the impact of mite infestation on eucalyptus (Khattab, 2005). The percentage rise in proline content was higher due to the infestation by *O.coffeae* (*87.0* ± 6.79 *%*) when compared to that of *A.theae* (41.85±3.08%) and *B. phoenicis (*35.45±2.02 %) infested tea plants. It can be concluded that the tea plants accumulate proline to resist the stress induced by the infestation of pest mites and the amount of

proline in infested leaves can be correlated with the severity of infestation and type of pest mite.

Information gathered on the developmental aspects of the mites studied currently depicted a more or less common pattern of developmental process. In *O.coffeae,* the development involved a larval and 2 nymphal instars before attaining the adult stage. These immature stages are followed by a quiescent phase. Mites in general, exhibit certain degree of site selection for oviposition. Majority of the tetranychid species were reported to deposit eggs adjacent to the midrib of the leaves of the host plant (Banu and ChannaBasavanna, 1972; Sangeetha and Ramani, 2007). Ovipositing females of *O. coffeae* preferred areas close to the mid rib and major veins of the leaf of the upper surface. Temperature as well as relative humidity (RH) were known to influence the development and reproduction of several species of tetranychid mites (Boudreaux, 1958; Das and Das, 1967; Boyne and Hain, 1983; Congdon and Logan, 1983; Bonato *et al.*, 1990; Childers *et al.,* 1991; Liu and Tsai, 1998; Bounfour and Tanigoshi, 2001; Fu *et al.,* 2002; Kasap, 2003; Sakunwarin *et al.,* (2003); Gotoh *et al.,* 2004; Geraldo *et al.,* 2004; Sangita and Bhardwaj, 2004; Ghoshal *et al.,* 2006). Temperature exerted a significant effect on all developmental stages of *O. coffeae* (Haque *et al.,* 2007). Accordingly, at higher temperatures, the development of *O. coffeae* occurred rapidly. This seems to explain the high population density of this mite during the drier and hotter months of the year in Kerala. *O.coffeae*

showed variation in the durations of their development as influenced by temperature and relative humidity.The durations of pre-oviposition, oviposition and post oviposition periods of *O.coffeae* were found to decrease with an increase in temperature. An increased daily egg production, short oviposition period and shorter adult longevity with an increase in temperature was previously recorded (Gotoh and Nagata, 2009; Chakroborty *et al.,* 2015) for this mite and the present study further support these findings. The durations of postembryonic development of *O.coffeae* recorded during the present study were 13.23 ± 0.14 days, 12.23 ± 0.14 days and 11.98 ± 0.14 days at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH respectively, disclosing a steady increase with increase in temperature. This observation is further supported by the earlier studies on the breeding biology of *O.coffeae* on a different host plant, rose (Haque *et al,* 2007) which also revealed that the higher temperature accelerated the developmental rate and reduced the duration of developmental stages.

Results of developmental studies carried out on the the tea red spidermite *O.coffeae* revealed a dual mode of reproduction in this species, getting multiplied by parthenogenetic as well as sexual modes. The sequence of events in both modes of reproduction were similar, though slight variations were observed in the durations of individual instars. Besides, in parthenogenetic modes of reproduction, all the resulting progeny was comprised of males and under the sexual mode, both male and female

offsprings were produced in the sex ratio of 1:10. The duration of development was comparatively shorter under the parthenogenetic mode of reproduction in all the temperature-humidity parameters studied. Adoption of arrhenotokous parthenogenesis was already reported among a number of tetranychid mites (Boudreaux, 1963; Helle and Bollard,1967) and the present study further supports these findings.

The rate of development of tenuipalpid mites is greatly influenced by various factors like temperature, relative humidity, and type of host plant (Haramoto, 1969; Lal, 1978; Chiavegato, 1986). During the present study, the pre-oviposition, oviposition and post- oviposition periods of *B. phoenicis* on *C.sinensis* were found to be varying with different temperature-humidity conditions.The number of eggs laid by a single female of *B. phoenicis* during its oviposition period also showed variation depending upon temperature and relative humidity. A maximum fecundity of 25 - 31 was shown at 30 ± 2ºC & 70 ± 5%. These results support the earlier observations made on the species by recording a shorter ovipositional duration and maximum fecundity at 30^0C (Gotoh and Nagata, 2009).

Initiation of hatching was marked by the appearance of a semicircular slit at the apical pole of egg. Then the slit continued to either sides followed by the movement of larva. As the slit got widened, the emerging larva protruded its first pair of legs followed by the swift movement of

propodosoma which helped it to come out. The process of hatching was completed within 15 - 20 minutes. A similar pattern of moulting was observed in many species of plant mites, especially in spidermites (Banu and ChannaBasavanna, 1972; Sangeetha and Ramani, 2007).

The duration of development from egg to adult stage of *B. phoenicis* as observed during the present study was also subjected to variation depending upon variations in temperature and relative humidity.The mean duration of development of *B. phoenicis* from egg to adult were recorded as 31.45 ± 0.26 days at 25 ± 2ºC & 80 ± 5% RH, 27.8 ± 0.37 days at 30 ± 2ºC & 70 ± 5% RH and 29.15 ± 0.33 days at 35 ± 2ºC & 60 ± 5% RH. Earlier studies also could establish variations in the duration of development from egg to adult stage of the species depending up on the temperature humidity conditions (Gotoh and Nagata, 2009) and host plant differences (Teodoro and Reis, 2006). Accordingly, *B. phoenicis* completed its development from egg to the adult stage with an average of 17.27 ± 1.11 days on citrus and 25.18 ± 1.58 days on coffee.

The results of the present study enabled to gather knowledge on the sex ratio in tenuipalpid mite population. Interestingly, results of field cum laboratory studies revealed that *B.phoenicis* populations recovered from tea comprised entirely of female individuals. This result is confirmative with the earlier reports (Haramoto, 1969). In many theletokous populations of *B.*

phoenicis, the association of a feminizing bacteria of the genus *Cardinium* was reported earlier (Weeks *et al.,* 2001; Rodrigues *et al.,* 2013). In the present study, the detection of the entirely theletokous progeny of *B. phoenicis* may be a reflection of the impact of such feminizing bacteria, and which need further investigation for confirmation.

Unlike *O.coffeae* and *B.phoenicis,* the postembryonic development of *A.theae* disclosed only two active immature life stages viz. the first nymph and the second nymph.Two quiescent stages, the nymphochrysalis and imagochrysalis were also observed during the development of the species.The duration of development from egg to adult stage of *A.theae* as observed during the current study was found to be varying depending up on the variations in temperature and relative humidity. The mean duration of development of *A.theae* from egg to adult could be recorded as 8.45± 0.10 days at 25 ± 2ºC & 80 ± 5% RH, 6.68± 0.13 days at 30 ± 2ºC & 70 ± 5% RH and 7.73 ±0.10 days at 35 ± 2ºC & 60 ± 5% RH indicating 30 ± 2ºC & 70 ± 5% RH as the most suitable temperature - humidity conditions for development.The minimum duration required for the development of the species as recorded earlier was 5.5 to 7.0 days (Das and Sengupta, 1958) and the results of the present study would further confirm the earlier findings.

Integrated Pest Management (IPM) approaches, create opportunities for increased inclusion of biologically based pest management tools such as

parasitoids and predators, semiochemicals, phytochemicals and microbials. IPM gives much stress in the implementation of biological control of pests using their natural enemies. Predatory mites constitute a highly significant group owing to their potential in regulating the insect and mite pest populations below the economic injury level. Among the predatory mites, species of Phytoseiidae are potentially important in the control of phytophagous mites. Numerous earlier studies have well described the bioefficacy of a number of phytoseiid mites in controlling phytophagous mites (Gupta *et al.* 1971; Kropezynska, 1973; Puttaswamy and ChannaBasavanna, 1979; Hall *et al.,* 1980; Dhooria, 1980; Yousef *et al.,* 1982; Hayes and McArdle, 1987; Neelu Nangia and ChannaBasavanna, 1989; Zang *et al.,* 2000; Messelink *et al.,*2006; Ahn *et al.,* 2010; Rahman *et al.,* 2012). Despite this, not many studies were in report on the natural enemies of RSM to evaluate their potential as biological control agents. However, the feeding potential of *S. gilvifrons* (Perumalsamy *et al*., 2010) and *N.longispinosus* (Rahman *et al*., 2013) on *O.coffeae* was reported from South India in the recent past.

Of the various species of predatory mites recovered during the survey, 2 species of the genus *Amblyseius* viz. *A. largoensis* and *A. herbicolus* showed high population density, wide distribution trend and voracious feeding habits. These species were always found in constant association with the major pest species, *O.coffeae* on tea. There are earlier reports

(Somchoudhari *et al*., 1995) on the joint occurrence of *A. herbicolus, A. largoensis, A.pruni* and *A.ovalis* with RSM. The same authors also reported the presence of *A. herbicolus* uniformly on all the three tiers of a tea bush, indicating it as a successful biocontrol agent as it could exploit all the habitats of prey. In the present study, feeding potential of these two predatory mites on RSM was tested at different prey-predator ratios. The time taken by *A. largoensis* for the complete consumption or killing of *O.coffeae* could be recorded as 2.8 ± 0.37, 5.8 ± 0.37, 10.4 ± 0.51 days respectively at the prey – predator ratios of 2:1, 5:1 and 10:1 while *A. herbicolus* required slightly more duration for the complete removal of *O.coffeae* from the experimental culture under laboratory conditions. The time taken by *A. herbicolus* for the complete consumption or killing of *O.coffeae* was recorded as 3.2 ± 0.2, 6.6 ± 0.24 and 11.6 ± 0.51 days respectively. From the above, it is concluded that *A.largoensis* is a more potential species to be used effectively as a biocontrol agent against *O.coffeae*.This prompted to extend the present work to evaluate the feeding preference of individual stages of the predatory mite, A. *largoensis* to the different stages of the pest mite, *O.coffeae.*

A.largoensis was found actively feeding on the pest mite during the present study. The percent consumption of the larva of the predator on *O.coffeae* was very low when compared to the other stages. It consumed an average of 7.2 % eggs and 4.8 % larvae of the prey in 24 hours. The larva didn't exhibit any signs of predation on the nymphal and adult stages of

O.coffeae. The rates of consumption by protonymph and deutonymph of *A. largoensis* were 18.8 %, & 45.2 % eggs, 19.2 % & 49.6 % larvae, 12.8 % & 35.2 % protonymphs, 0 % & 10.4 % deutonymphs and 0% & 4.8 % adults. The percent consumption on different life stages of *O.coffeae* by the adult male of *A. largoensis* were 45.2, 51.2, 34.4, 9.6 and 4.8 for eggs, larvae, protonymphs, deutonymphs and adults respectively. The adult female was the most voracious stage of *A. largoensis* which consumed 72% of eggs, 65.6 % of larvae, 51.2 % of protonymphs, 13.6 % of deutonymphs and 6.4 % of adults. All the stages of *A. largoensis* showed a preference to the eggs of prey mites, thereby supporting the earlier findings on *A.bibens* (Blommers and Etten, 1975) and on *A. fallacis* (Santos, 1975). Similar results were also reported on *N.anonnymus* feeding on *T.urticae* and *E.dioscoridis* (Mesa and Bellotti, 1986).

The most voracious predatory stage recognized during the study was the adult female which possessed the maximum rate of consumption. The feeding efficacy of the deutonymphs of all the predators appeared more vigourous when compared to that of the larvae and protonymphs and which fed largely upon the eggs and early instars of the pest species. On the other hand, the adult males differed from the females in their predatory potential. Normally, the consumption rate of adult male predators was found comparable to that of the deutonymphal stages of predator. Similar results were recorded on *T.occidentalis* on *T.urticae* (Lee and Davis, 1968). The

feeding potential of the predator under the study, decreased in the sequence of Female> male>Deutnonymph>Protonymph> Larva. The results of the present study revealed that different life stages of the predatory mite, *A.largoensis* had a preference to the early stages of the prey mite like the eggs and larvae, thereby supporting the earlier findings (Rahman *et al*, 2012) on the predatory mite, *N.longispinosus* on the same pest mite, *O. coffeae*. This feeding trend of the predator can be useful in rating the species as a potential natural enemy which can be successfully exploited as a biocontrol agent against the RSM, especially in checking early stages of the prey, which in turn would be helpful to prevent the proliferation of pest population. The conservation and augmentation of this predator in the tea ecosystem may prove to be an important component in the IPM strategy against the RSM. This is only a pilot study and more works need to be carried out in detail on this both under laboratory and field conditions.

The red spider mite, *O. coffeae*, is one of the major pest, causing severe crop loss in tea plantations in south India (Muraleedharan *et al*. 2005; Babu *et al*. 2008). In India, these mites are mainly controlled by the spraying of synthetic acaricides such as dicofol, propargite, lime sulphur, fenpyroximate and hexythiazox (Roobakkumar *et al.* 2010). However, the indiscriminate use of such synthetic acaricides over a long period of time has led to a number undesirable effects like resurgence of primary pests (Hazarika *et al*. 2009), secondary pest outbreak (Cranham 1966), resistance development (Roy *et al*.

2010), pesticide residues on made tea (Muraleedharan *et al*. 1988), environmental contamination (Painuly and Dev 1998), health hazards to warm blooded animals (Mobed *et al.* 1992), and increased costs of application, causing a serious drain on the economy of developing countries (Pimental *et al.* 1992.). India has a vast number of herbal plants with medicinal and pesticide properties, which are used for the production of biopesticides in pest management. A good number of botanicals, like *V. negundo*, *G. maculata*, *W. chinensis, M. tinctoria* and *P. glabra* (Vasanthakumar *et al.,*2012), *A. calamus*, *X. strumarium*, *P.hydropiper* and *C. infortunatum* (Sarmah *et al*., 2009), *C. viscosum* (Roy *et al.,* 2011) neem kernel, pongam kernel and garlic (Roobakkumar, 2010) have been used so far to test their efficacy against RSM both in laboratory and field conditions.

These crude plant extracts often consist of complex mixtures of active compounds. Benefits of using these complex mixtures in pest control are that natural mixtures may act synergistically (Berenbaum, 1985) and may show better overall bioactivity when compared to the individual constituents (Berenbaum*et al*., 1991; Chen *et al.*, 1995) and pesticide resistance is much less likely to develop with these mixtures (Feng and Isman, 1995). These factors support the use of crude, unrefined plant extracts which contain mixtures of bioactive plant compounds rather than the use of the pure individual chemical compounds.

In the present study, three plant species having insecticidal properties were selected for the preparation of biopesticides. viz., *G. sepium, S. nux-vomica* and *C. frutescens.* The results of the study showed that application of

C.frutescens caused maximum egg and adult mortality of RSM at all concentrations used. Fruit and seed powders of *C. frutescens* have got insecticidal properties and could be used in the control of stored product pests, C. *maculatus* and *S.zeamais* (Oni, 2011). Both the fruit and leaf extracts of C.*frutescens* contained tannins, alkaloids, steroids and glycosides and showed insecticidal properties and was also successful against the larvae of *A. aegypti* (Vinayaka and Kekuda, 2010).

Highest egg mortality was registered during the study at higher concentration (10.0%) of *C. frutescens* and *S. nux-vomica* to the level of 82.66 and 72.67 % respectively, whereas lowest egg mortality of 40.67 % was recorded for *G.sepium.* At lower concentrations also, *C. frutescens* and *S. nux-vomica* caused higher ovicidal activity when compared to that of *G.sepium.* Sarmah *et al.* (2009) stated that the chemical substance present in the leaf extracts may block the micropyle region of the egg, thereby preventing gaseous exchange and ultimately killing the embryo during the egg stage.

Different concentrations (2.5, 5.0 and 10.0%) of aqueous extracts of *C. frutescens*, *S. nux-vomica* and *G.sepium* were tested to evaluate their toxic effect at 24, 48 and 72 hours against adult red spider mites under laboratory conditions and the results showed that in all cases, mortality was in a linear trend i.e., increasing with increase in the concentration of biopesticides. Such a linear relation between the concentration of plant extracts and rate of mortality was already in report (Sarmah *et al*, 2009) using the aqueous plant extracts of *P. hydropiper*, *X. strumarium*, *A. calamus*, and *C. infortunatum* at

different concentrations against *O. coffeae.* The results of the present study provide further confirmation of earlier findings.

At all concentrations of aqueous plant extracts, *C. frutescens* showed maximum(94.67%) acaricidal activity followed by *S.nux-vomica* (83.87%) as evidenced during the present study.Aqueous extract of *G.sepium* showed 50.6 % adult mortality after 72 hours of application. This was in line with the previous works conducted using the same plant material (Vasanthakumar,*et al.* 2012). A gradual increase in mortality rate was also observed as the time elapsed. The percent of mortality rate recorded at 72 hours after treatment of extracts *C. frutescens*, *S. nux-vomica* and *G.sepium* were 94.67, 83.87 and 77.33% respectively.

Thus the results of laboratory trials have provided promising results on the potential of the selected plant extracts for the effective suppression of the pest mite life stages. Further field studies are needed for the effective extension of these findings to incorporate these botanical preparations in developing an ecofriendly and environmentally safe method for the management of red spider mite.

SUMMARY

Tea is one of the most popular beverages all over the world owing to its distinct aroma, flavor and health benefits. It is a heterogeneous plant with many overlapping morphological, biochemical and physiological attributes. India is the second largest producer of tea in the world. Similar to any other plantation crop, tea plants also are subjected to the attack of a vast number of insects, mites and nematodes. Since tea is a perennial crop and grown as monoculture, the tea ecosystem provides a stable favorable environment and unbroken food supply to the pests. Crop loss in tea due to pests, diseases and weeds varies between 15 and 20 percent. In south India, mite infestation causes severe damage to tea plantation and thereby causes considerable loss to our economy. In many instances, lack of information about the correct identity of mites, their biology and ecology caused serious consequences to tea planters. Considering the varying levels of pest problems experienced in the tea plantations of North Kerala, the present study was proposed with a view to undertake detailed survey on the mites, both of the phytophagous and predatory category and to study the distribution pattern, seasonal abundance, effect of climatic conditions on the population density of pest mites and also to elucidate the damage potential of the most injurious species of local

importance through qualitative and quantitative measures. The study was also extended to locate some natural enemies like the predatory phytoseiid mites which have promising potential to exert significant regulation of selected pest mite population under laboratory conditions. Simultaneously, initiatives have also been made during the present study, to develop some biopesticide formulations comprised of plant extracts in different concentrations against selected pest mite species.

The present study on the mites associated with tea mites of North Kerala is arranged in three parts, viz. Part **I**, **II** and **III**. Part **I** deals with a detailed survey carried out on mites associated with the tea plantations of Wayanad, viz. Mananthavadi, Periya, Vythiri, Chundale and Meppadi. The distribution pattern of the species recovered from the tea plants collected from different localities of Wayanad district of Kerala with respect to seasonal variation, especially of the common and abundant species of local importance are also dealt in this section. Part **II** deals with the biological studies carried out on three common and injurious species of tea mites associated with the tea plantations of North Kerala and this section is further divided in two subsections viz. Feeding biology and Breeding biology. Results of the qualitative and quantitative studies carried out on the damage induced by the selected species of tea mites are presented in the feeding biology section. Data on the durations of postembryonic development of the selected common species under different temperature-humidity parameters have been presented

in the breeding biology section. **Part III** deals with the study pertaining to the feeding potential of selected predatory mites on the phytophagous mite which induce the most significant damage to tea as observed during the present investigation. This section also contains the results of the laboratory evaluation of acaricidal properties of some aqueous plant extracts on the major pest mite infesting tea.

In order to find out the general faunal diversity as well as the common and abundant species of mites, extensive surveys were carried out on the tea plantations grown in 5 sites distributed over the Wayanad district of North Kerala. Results of the survey revealed evidences of infestation by members of 3 superfamilies, such as Tetranychoidea, Tarsonemoidea and Eriophyoidea.

In the present study, the following species were recovered from the tea plantations of Kerala viz.*Oligonychus coffeae* (Neitner), *Brevipalpus phoenicis* Geijskes, *Acaphylla theae* (Watt), *Calacarus carinatus* (Green), *Polyphagotarsonemus latus* (Banks) and the predatory mites of the genus *Amblyseius* viz. *A.largoensis* (Muma), *A. herbicolus* (Chant), *A.channabasavannai* Gupta and Daniel and *Neoseiulus longispinosus* (Evans). Of these mites, three species were recognized as very common and abundant and hence they were considered for detailed biological studies. The above 3 species were *O. coffeae, B.phoenicis* and *A.theae.* Studies on the seasonal distribution pattern of these species of mites revealed their

infestation in the peak during April/May months, moderate during September/ October and scanty levels during monsoon periods of the year.

Part II of the thesis provides data on the feeding, breeding and morphological details of the 3 selected species of mites mentioned above.The leaves and leaflets that confirmed mite infestation were collected and transferred to polythene bags and transported to the laboratory. They were further transferred to fresh leaves/leaflets for subsequent biological studies comprising the feeding and breeding parameters.

Morphological studies of the selected species were made by preparing permanent slides in Hoyer's medium and illustrations of the developmental stages were presented with morphological descriptions supported by camera lucida drawings. Measurements of the various life stages were taken under the high powers of a Meopta Research microscope, calibrated with the stage and ocular micrometers. Identification of the species recovered from various host plants was made following relevant literature, keys etc. and with the help of experts.

Detailed biological studies were also carried out on the selected species of mites mentioned above**.** Cultures of these mite species were raised in the laboratory on tea leaves by adopting leaf flotation technique. Qualitative assessment of damage potential of the above selected species of mites was made by making regular observation on the feeding activities of the various

life stages and recording the damage symptoms developed on the host plants through simultaneous field cum laboratory observations. Data on the nature and severity of infestation, population density of the species, damage symptoms induced, and differences in the external structure of the infested and uninfested leaves etc.were noted for individual species.

The quantitative assessment of damage potential was made through biochemical studies including comparative estimation of chlorophyll ‘a’ and ‘b’ contents and total chlorophyll content, phenolic content, proline content etc. of mite infested as well as uninfested (control) leaves of tea plants. The chlorophyll contents of mite infested and uninfested (control) leaf samples were estimated following Arnon’smethod. The total phenolic content was estimated following Folin-Ciocalteu colorimetric method, based on oxidation-reduction reaction and proline content of the mite infested and uninfested leaf samples were estimated following the method of Bates *et al.* (1973)

All the species studied were found to induce significant loss in chlorophyll. The percent loss of chlorophyll 'a', 'b', and total chlorophyll induced by *O.coffeae* were recorded as 61.14 ± 0.57, 46.81 ± 2.89 % and *57.36* ± 0.75*%* respectively while infestation by *B. phoenicis* resulted in the reduction of these pigments by 12.84 ± 0.66 %, 23.07 ± 1.89 % and 15.73 ± 0.53 respectively. *A.theae* induced a loss in Chlorophyll ‘a’, ‘b’ and total content by 23.24 ± 0.82 %, 25.34 ± 2.53% and 23.89 ± 0. 83 % respectively.

On analysis, the total phenol content showed an increase of about 71.82 ± 3.6 % for *O.coffeae* infestation, 20.65±1.39 % for *B. phoenicis*, and 34.95±2.99 % for *A.theae*. The total proline content revealed an increase of about 87.0 ± 6.79 % due to *O.coffeae* infestation, 35.45 ± 2.02% for *B. phoenicis* and 41.85 ± 3.08 % for *A.theae.*

In the section on breeding biology, the durations of development of the above 3 selected species of pest mites were traced under different temperature-relative humidity conditions. Cultures of individual species were kept in petridishes and maintained in the following temperature-humidity conditions viz., 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH . Regular observation was made to collect data on mating, oviposition, hatching, durations of pre-oviposition, oviposition and post – ovipositon periods, durations of life stages, moulting, total duration of life cycle, longevity of adults, pattern of development etc. Results of the studies on breeding biology of *O.coffeae* and *B.phoenicis* revealed the occurrence of three immature stages prior to attaining adulthood. Each of the active immature stage was followed by a quiescent period, which then moulted in to successive stages of development. Both sexual reproduction as well as parthenogenesis could be observed in *O.coffeae* while *B.phoenicis* reproduced only by means of parthenogenesis. Studies on breeding biology of *A.theae* revealed the presence of two active immature stages before attaining

adulthood. These two active immature stages were followed by a quiescent period which underwent moulting to enter the next stage of development.

Results of studies on the duration of life cycle of *O.coffeae* under different temperature-humidity conditions enabled to record shorter duration of development (11.98 ± 0.14 days) at 35℃ ± 2ºC & 60 ± 5% RH and longer duration (13.23 ± 0.14 days) at 25 ± 2ºC & 80 + 5% RH. At the same time, *B. phoenicis* produced more generations at 30 ± 2ºC & 70 ± 5% within a short span of time (27.8 ± 0.37 days). The most favoured temperature-humidity combination for *A.theae* was 30 ± 2ºC & 70 ± 5% RH at which, the developmental period recorded was 6.68 ± 0.13 days.

Part III of the thesis provides data on the feeding potential of predatory mites and acaricidal activites of certain selected plant extracts on *O.coffeae.* During the present study, the feeding potential of two phytoseiid predators viz. *A. largoensis* and *A. herbicolus* seen in association with the population of the Red Spider Mite, *O. coffeae* was tested under laboratory conditions. Effect of prey-predator interaction on *O.coffeae* with these two predatory phytoseiids was recorded at different prey - predator ratios viz., 2:1, 5:1 and 10:1 in the laboratory. When compared to the rate of prey consumption by *A. largoensis*, *A. herbicolus* took slightly more duration for the complete consumption / killing of *O.coffeae* in the experimental culture under laboratory conditions. Feeding preference of individual stages of the

predatory mite, A. *largoensis* to the different stages of *O.coffeae* was tested under laboratory conditions. The most voracious predatory stage recognized during the study was the adult female which exhibited the maximum rate of consumption. The predatory potential of the *A.largoensis* decreased in the sequence of Female> male>Deutnonymph>Protonymph> Larva. Besides this, different life stages of the predatory mite, *A.largoensis* showed more preference to the early stages of the prey like the eggs and larvae. This feeding trend would be useful for the selection of this mite as a natural enemy to be used for the biocontrol of pest mite, based on its preference to the early stages, which would prevent the proliferation of pest population. The conservation and augmentation of this predator in the tea ecosystem may prove to be an important component in the IPM strategy against the RSM. This is only a pilot study and more works are to be carried out in detail both under laboratory and field conditions, for gathering confirmative data on this aspect.

Field and laboratory studies conducted during the present work revealed that *O.coffeae* is the most serious mite pest of tea causing severe damage to the tea plantations of Wayanad district when compared to the other mite species which were subjected to detailed biological studies. So, an attempt was made to explore the potential and possibility of using the aqueous plant extracts of some commonly available and ecofriendly botanicals viz. *C.frutescens, S. nux-vomica* and *G.sepium* for the management of the RSM,

O.coffeae by analyzing their ovicidal and acaricidal activities under laboratory conditions. Different concentrations (2.5, 5.0 and 10.0%) of aqueous extracts of *C. frutescens*, *S. nux-vomica* and *G.sepium* were tested to evaluate their toxic effect on eggs and adults of *O. coffeae* under laboratory conditions and in all the cases aqueous plant extracts of *C. frutescens* showed the maximum acaricidal activity while *G.sepium* induced minimum mortality of mites.

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PLATE 1

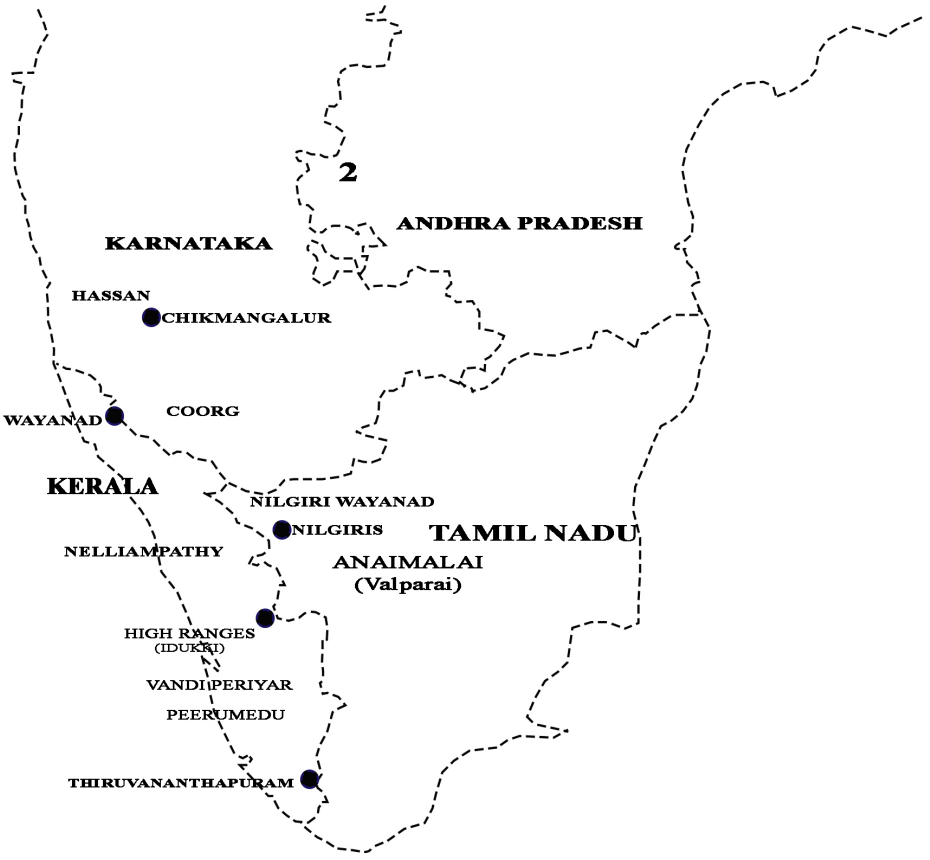


Fig.**1.** Tea growing areas of Southern India

PLATE 3

Figs.**1&2**. Showing Tea plantations in Wayanad district of North Kerala, India

PLATE 2

Sampling Localities

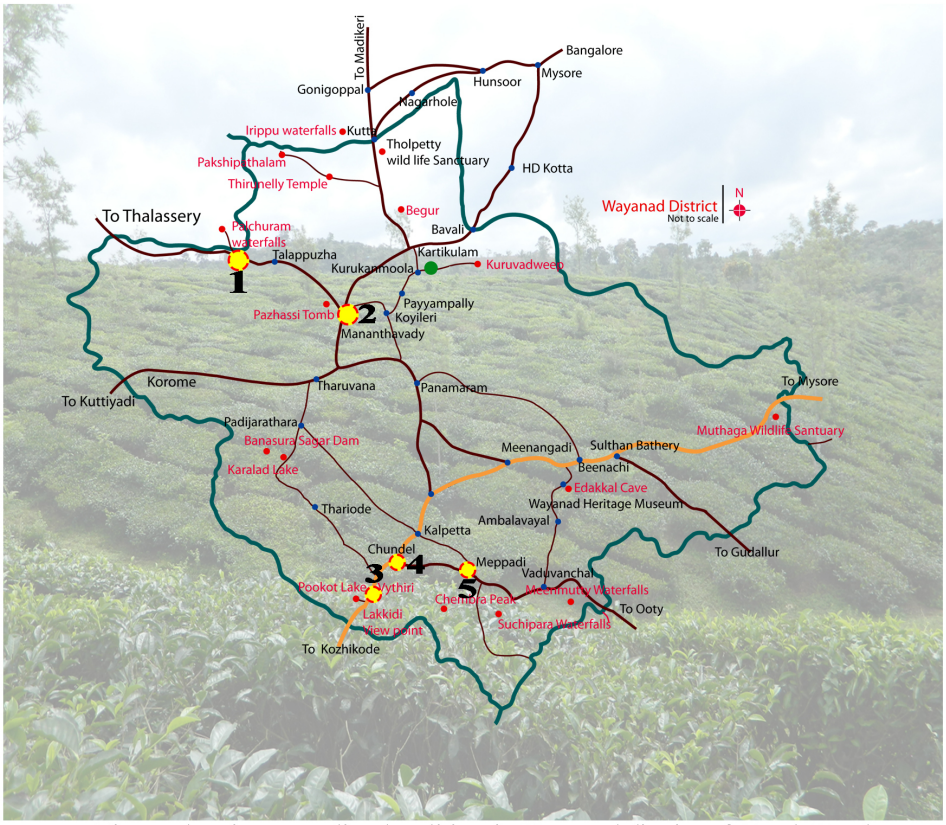


Figure showing sampling localities in Wayanad district of North Kerala,
1.Periya; 2. Mananthavady; 3.Vythiri; 4. Chundale; 5. Meppadi

PLATE 5

Damage caused by *Oligonychus coffeae* on tea plants

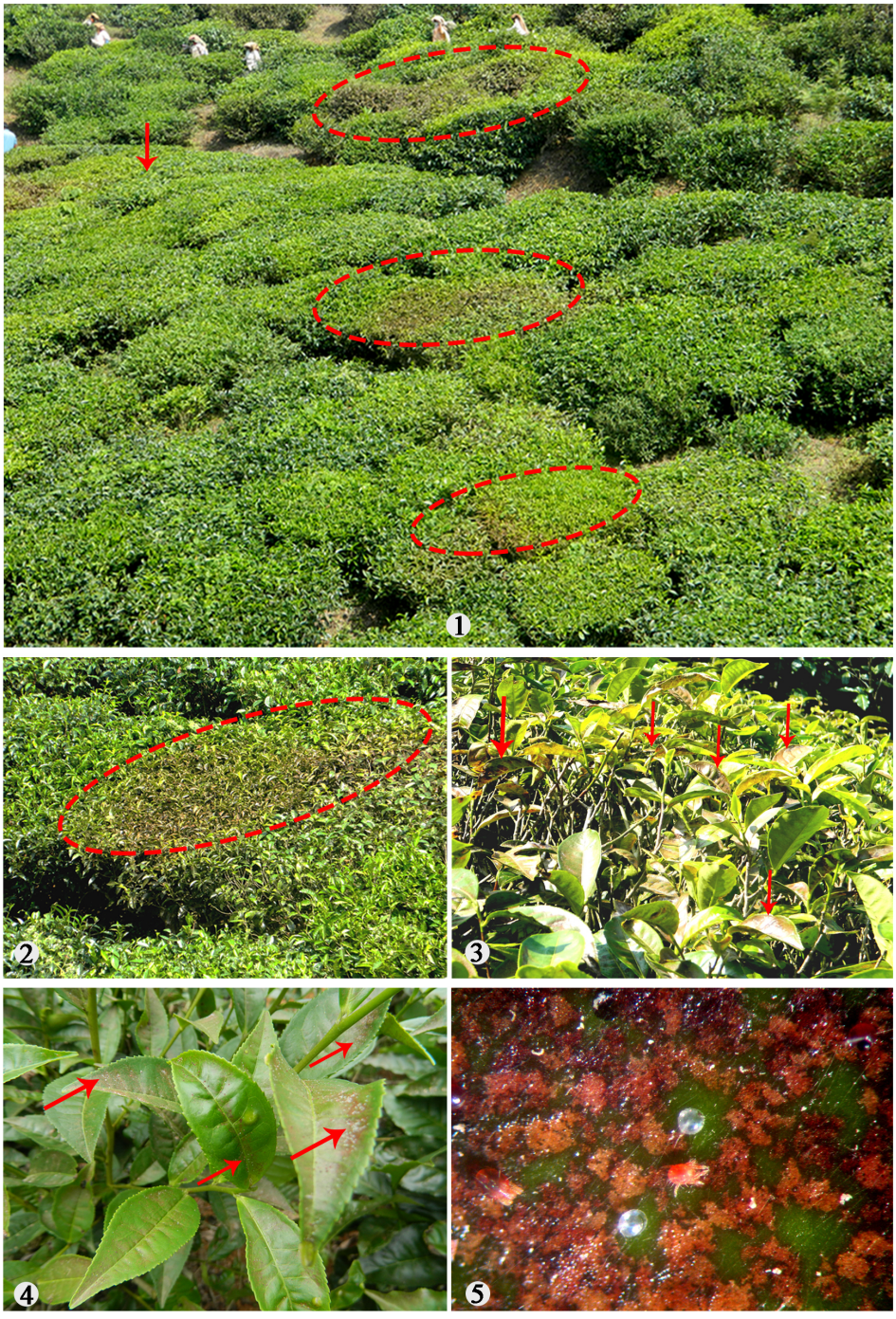
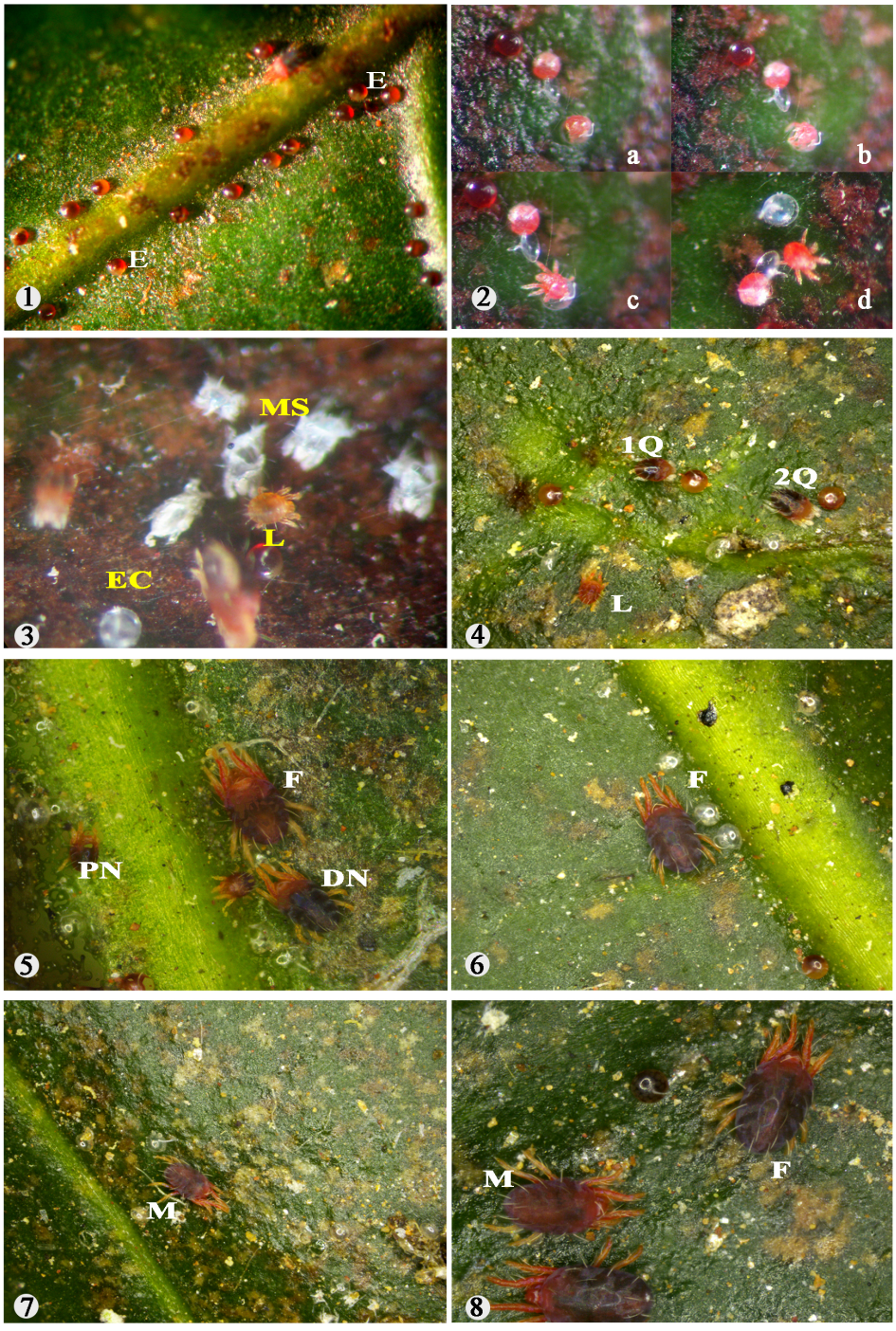


Fig.**1**.Heavy infestation of *O.coffeae* on tea plantation; **2-4.** View of infested tea leaf; **5.** Upper-surface of a heavily infested leaf.

PLATE 16

Postembryonic developmental stages of *O. coffeae* on the leaves of *Camellia sinensis*



Figs.**1-8.** Heavily infested leaves with various life stages: **1**. Eggs (**E**); **2a-d**.Hatching; **3.** Larva (**L**) and Moulting Skin (**MS**) and Egg Case (**EC**); **4.** Larva **(L),** First quiescent **(1Q),** Second quiescent **(2Q); 5.** Protonymph (**PN**); **6-8.** Adult Female (F) and Adult Male (**M**).

PLATE 22

Postembryonic developmental stages of *Brevipalpus phoenicis* on *Camellia sinensis*

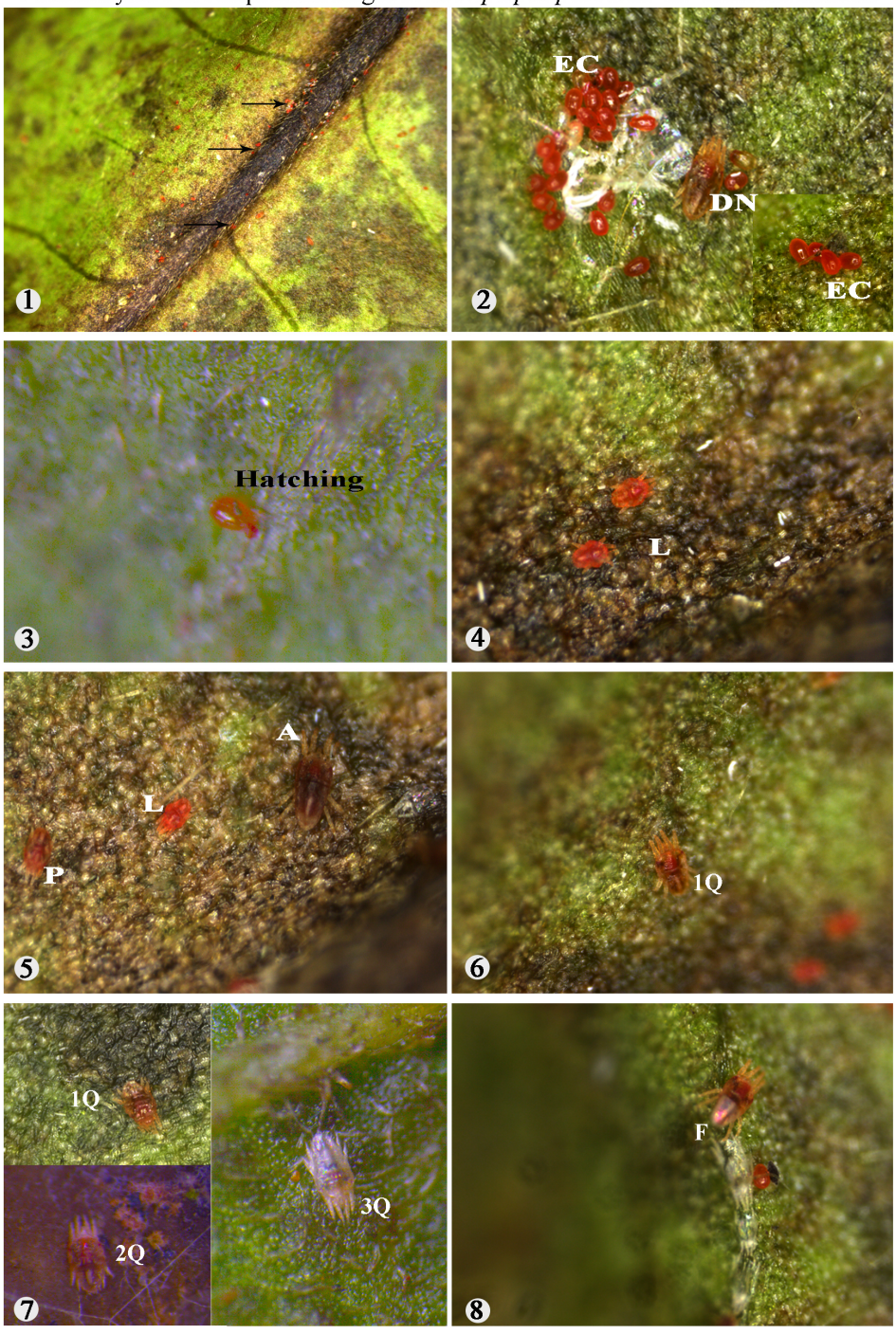


Fig.**1**.Heavy infestation of *B.phoenicis* (Arrow); **2**. Egg Clusters **(EC)** & Deutonymph **(DN)**; **3.**Hatching; **4 & 5.** Larva **(L),** Protonymph **(PN)** and Adult Female **(F); 6 &7.** First quiescent **(1Q),** Second quiescent **(2Q) &**Third quiescent **(3Q); 8.** Adult Female **(F)**.

PLATE 35

Infestation and postembryonic development of *Acaphylla theae* on *Camellia sinensis*

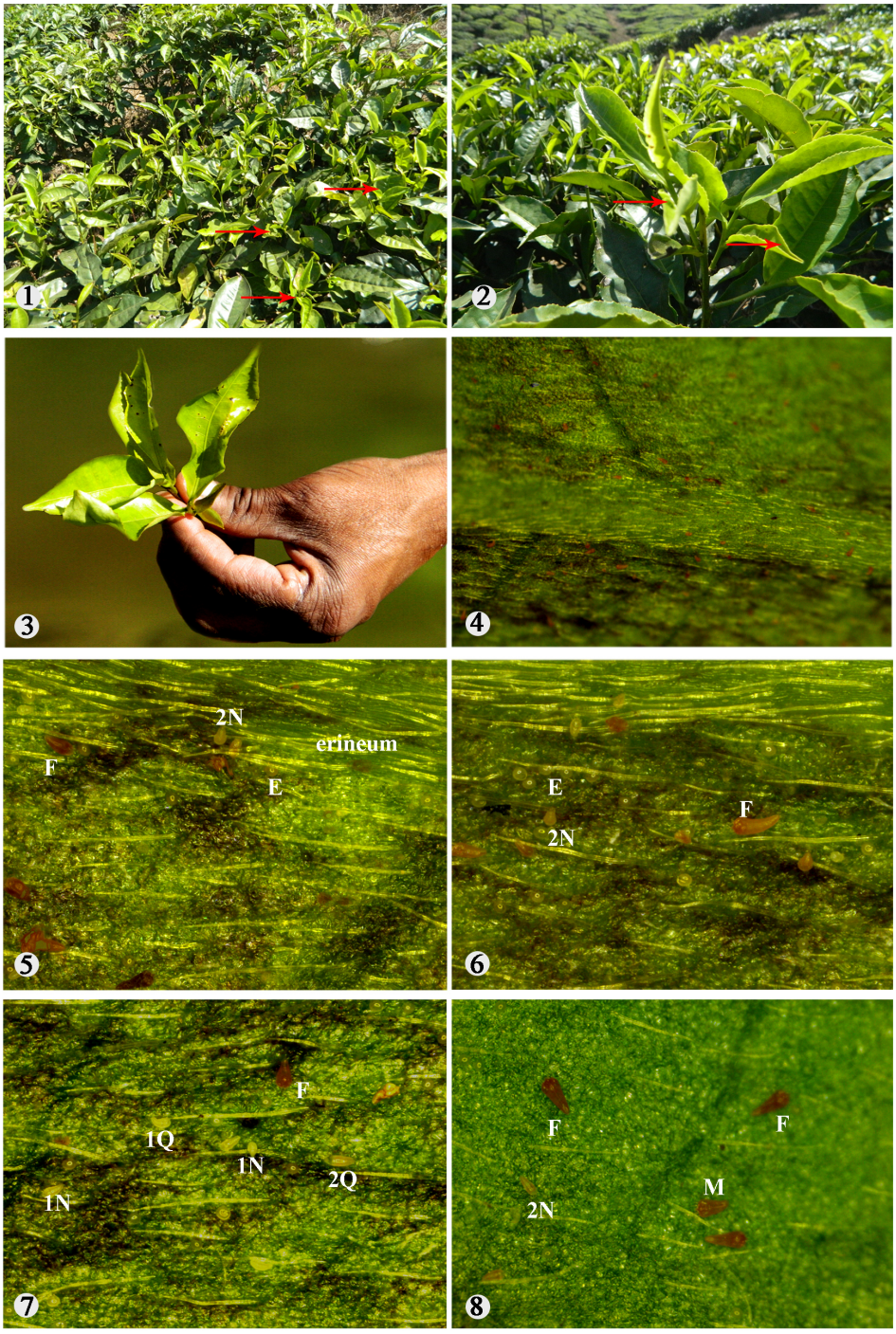


Fig.**1**.Heavy infestation of *A.theae* (Arrow); **2& 3**. Curling of tender leaves due to heavy mite infestation; **4.**Heavy mite infestation ; **5 &6.** Erineum formation, Egg **(E),** First Nymph **(1N)** Second nymph **(2N)** and Adult Female **(F); 7.** First quiescent **(1Q),** Second quiescent **(2Q); 8.**Second nymph **(2N)** Adult Male **(M)** & Female **(F)**.

PLATE 38

Figs.**1-3a.** Selected plants for the preparation of aqueous plant extracts (APE), **1-1a**.*Capsicum frutescens;* **2-2a.** *Glyricidia sepium;* **3-3a.** *Strychnos nux-vomica*

PLATE 39

Glass atomizer

PLATE 17

Morphological features of developmental stages of *Oligonychus coffeae* (Neitner, 1861)

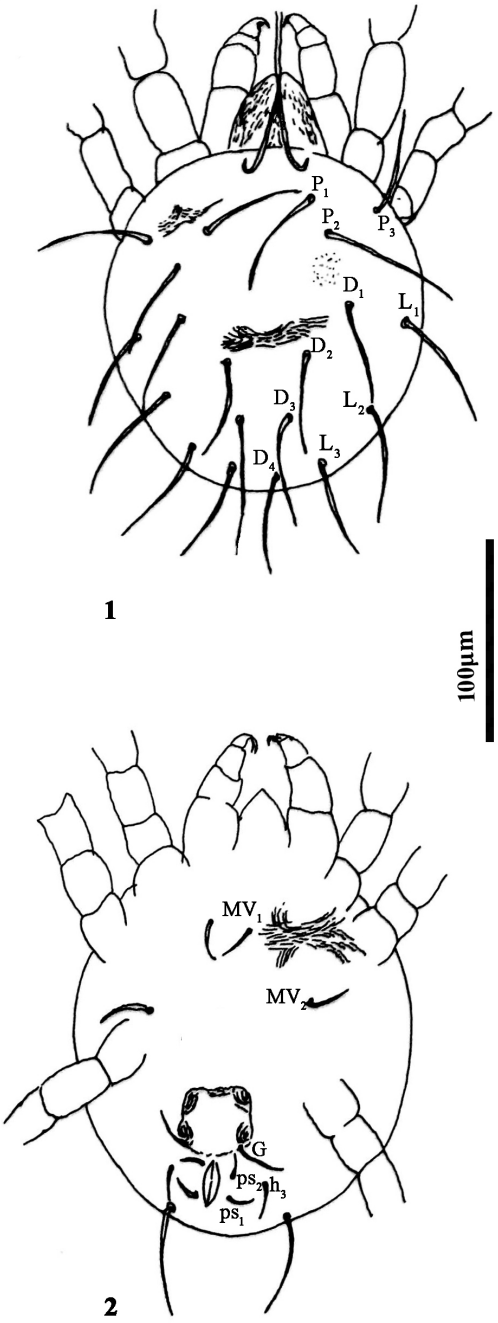
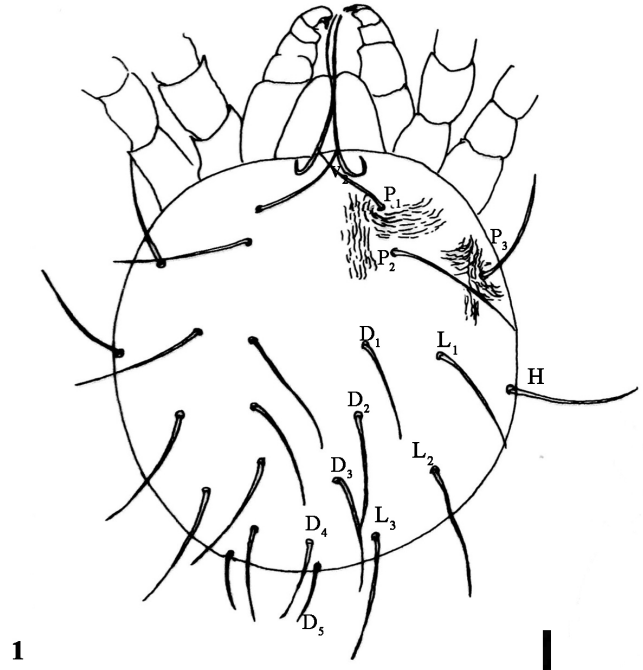


Fig. 1. Larva - Dorsal View; **2**.Ventral View.

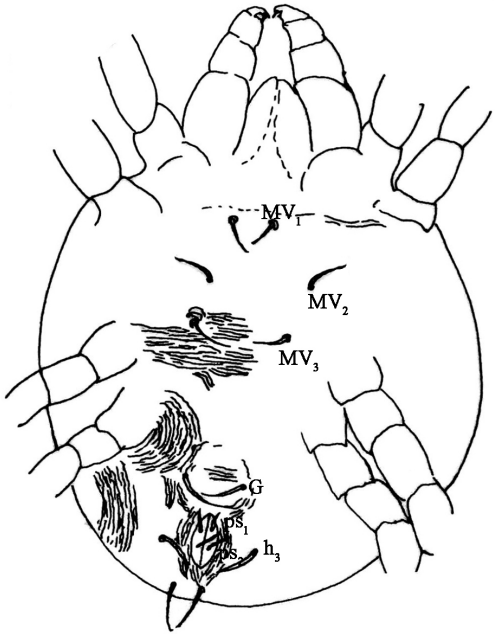
PLATE 18

Morphological features of developmental stages of *O. coffeae* (Neitner, 1861)



1

100µm

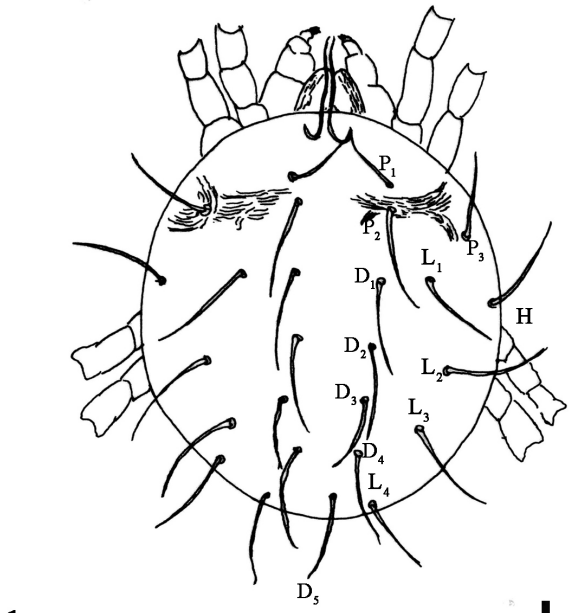


2

Fig. 1. Protonymph - Dorsal View; **2**.Ventral View.

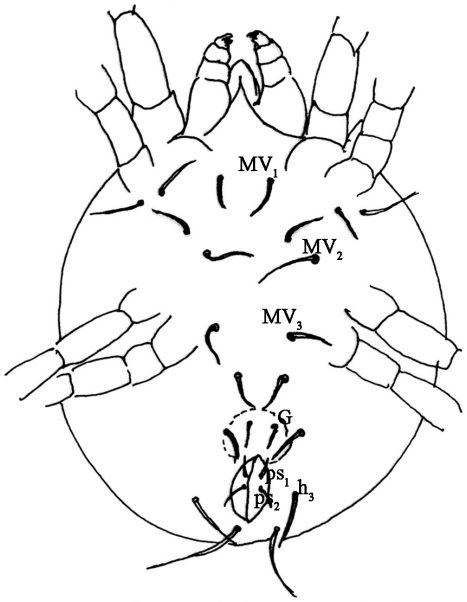
PLATE 19

Morphological features of developmental stages of *O. coffeae* (Neitner, 1861)



1

100µm

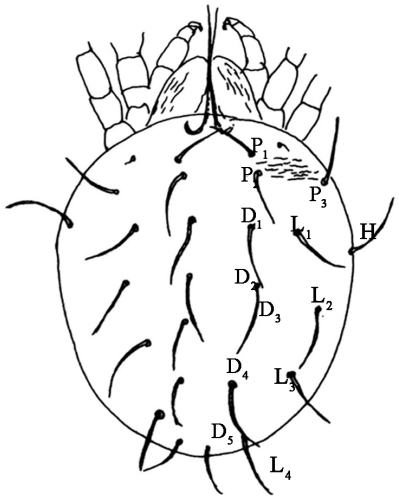


2

Fig. 1. Deutonymph - Dorsal View; **2**. Ventral View.

PLATE 20

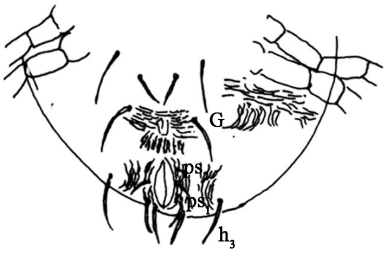
Morphological features of developmental stages of *O. coffeae* (Neitner, 1861)



1

a

100µm

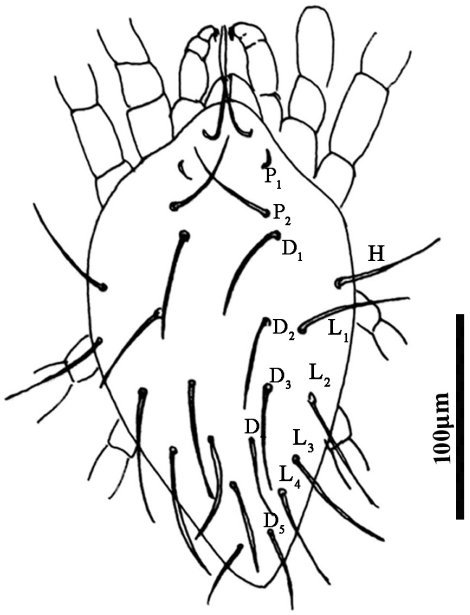


b

Fig. 1. Adult female **-a.** Dorsal View; **b. V**entral view

PLATE 21

Morphological features of developmental stages of *O. coffeae* (Neitner, 1861)



a

1

b

Fig. 1. Adult Male **-a.** Dorsal View; **b. V**entral view

PLATE 27

Morphological features of developmental stages of *Brevipalpus phoenicis* (Geijskes, 1939)

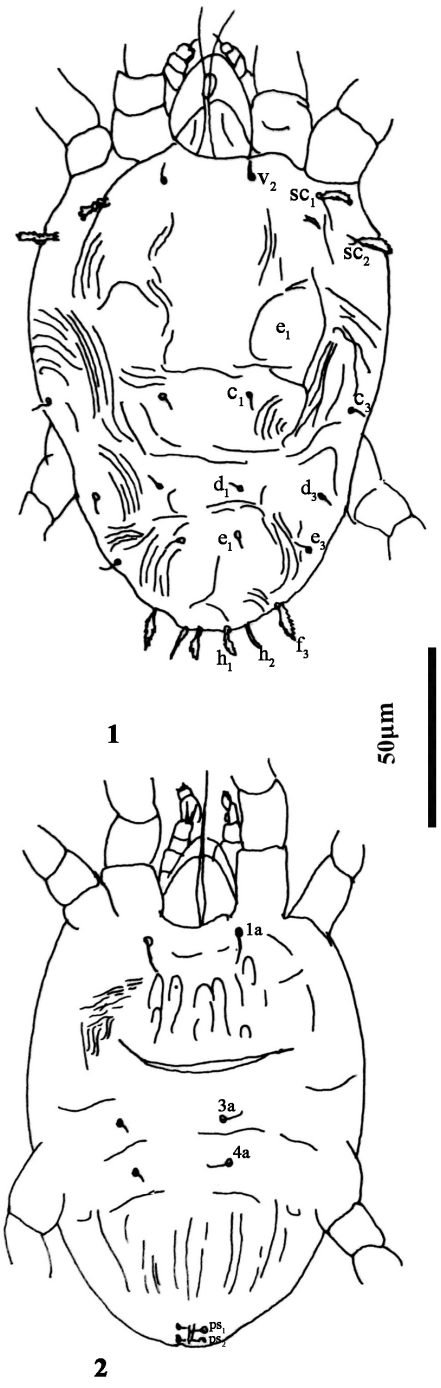


Fig. 1. Larva - Dorsal View; **2**.Ventral View.

PLATE 28

Morphological features of developmental stages of *B. phoenicis* (Geijskes, 1939)

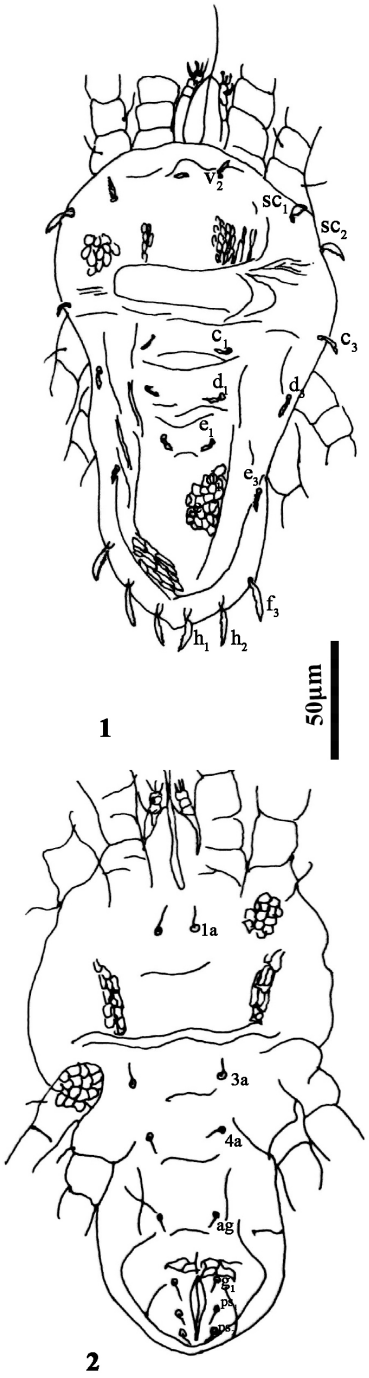


Fig. 1. Protonymph- Dorsal View; **2**.Ventral View.

PLATE 29

Morphological features of developmental stages of *B. phoenicis* (Geijskes, 1939)

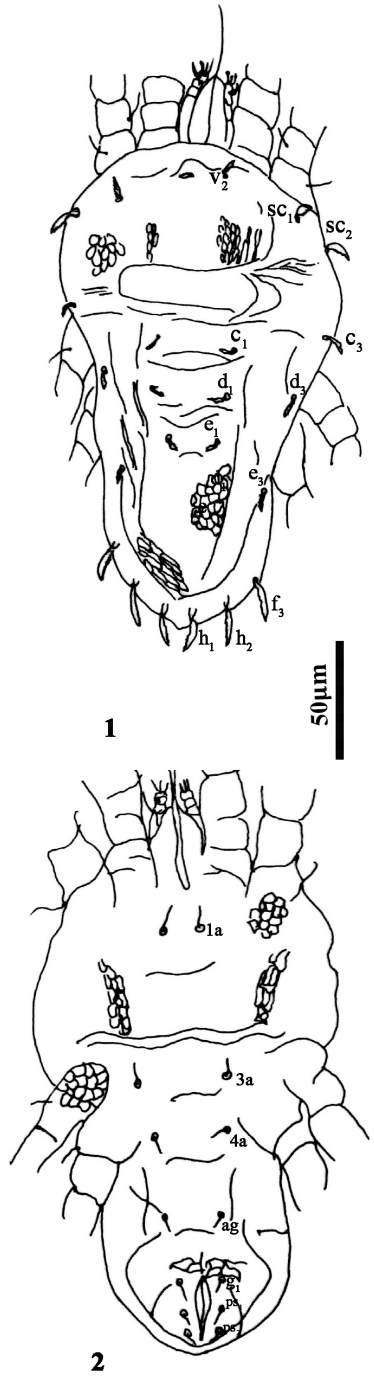


Fig. 1. Deuto
nymph- Dorsal View; **2**. Ventral View.

PLATE 30

Morphological features of developmental stages of *B. phoenicis* (Geijskes, 1939)

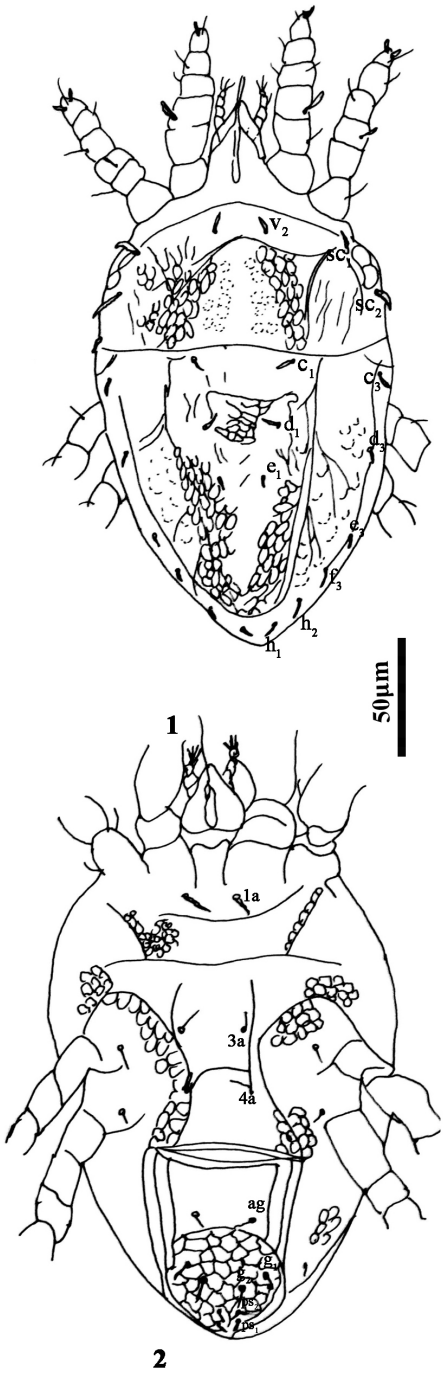


Fig. 1. Adult female- Dorsal View; **2**.Ventral View.

PLATE 37

Morphological features of developmental stages of *A. theae* (Watt, 1898)

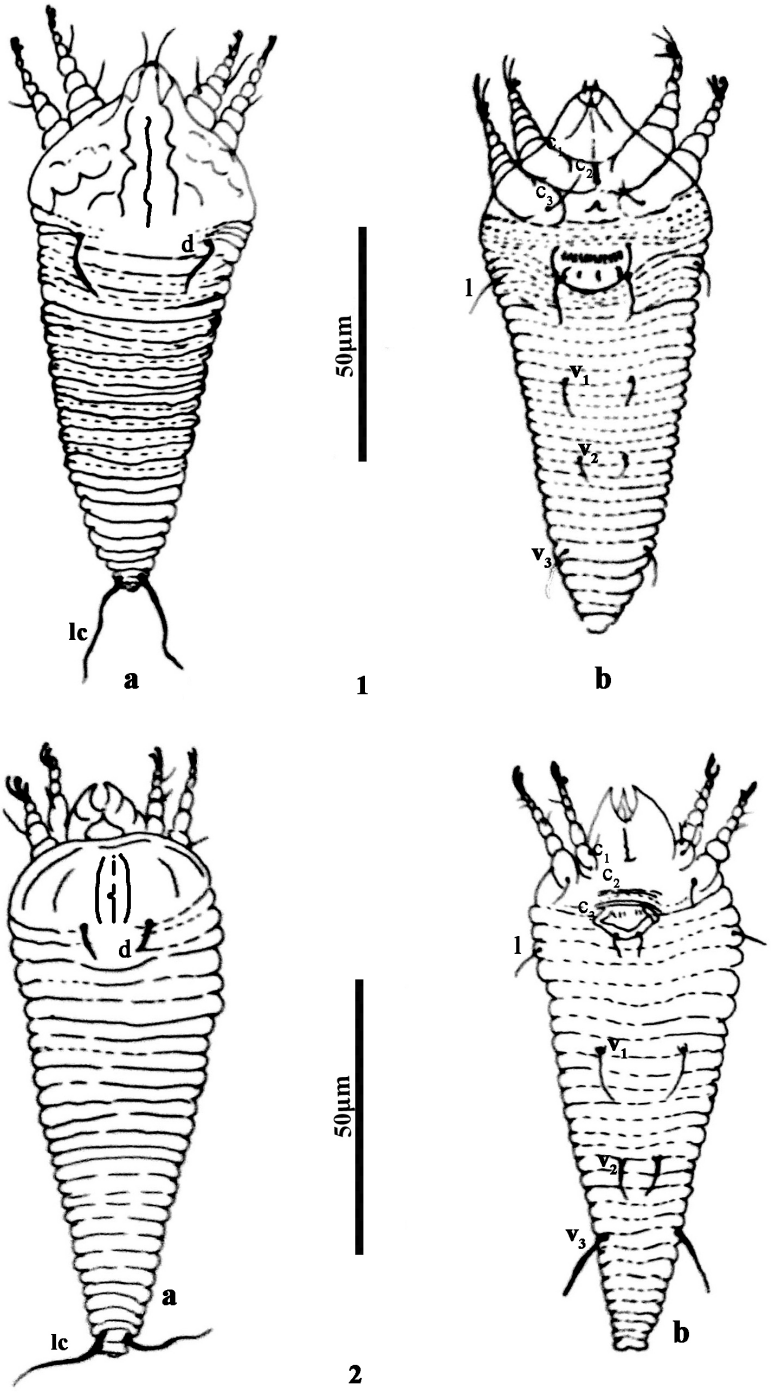
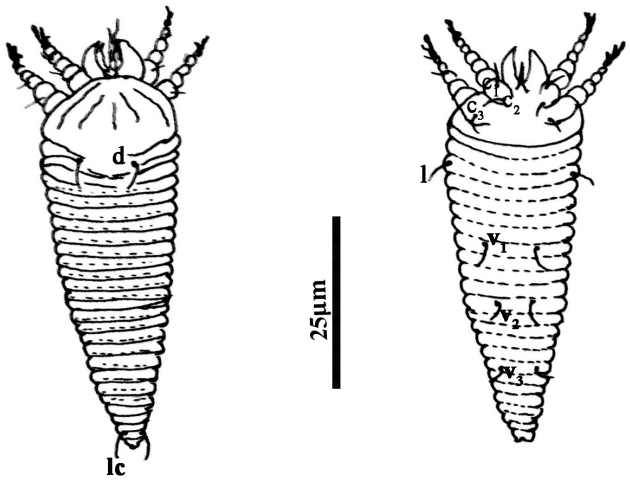


Fig. 1. Adult Male , **a** - Dorsal View; **b-** Ventral View **2**. Adult Female, **a** -Dorsal View; **b-** Ventral View

PLATE 36

Morphological features of developmental stages of *Acaphylla theae* (Watt, 1898)



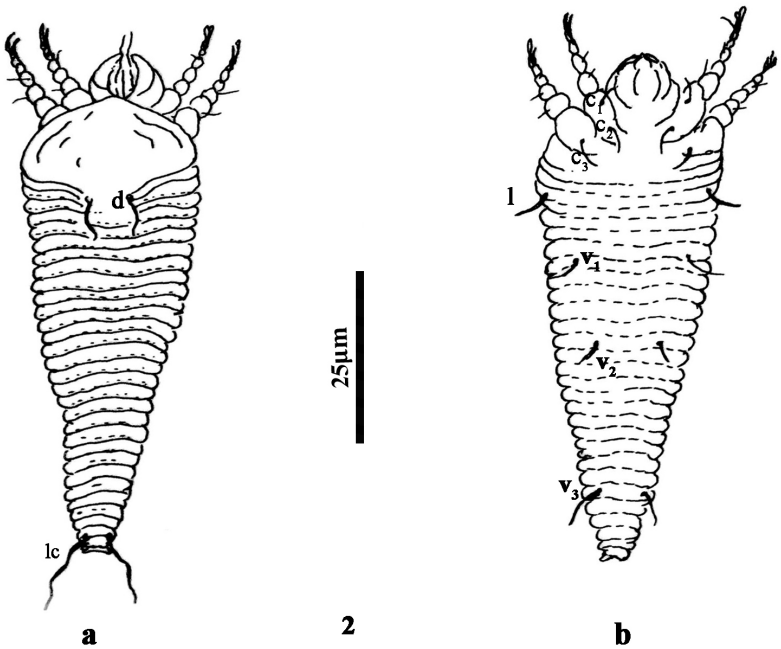


Fig. 1. First nymph, **a** - Dorsal View; **b-** Ventral View **2**. Second nymph, **a** -Dorsal View; **b-** Ventral View

PLATE 41

Predatory mites recovered along with *O. coffeae* infesting *Camellia sinensis*

Fig.**1**.Adult *Amblyseius largoensis*; **2**. Adult *A.herbicolous*;**3.**Adult *A.largoensis* feeding on *O.coffeae* egg; 4**a**. Larva of *A. largoensis.***b.** Deutonymph of *A. largoensis.*

Table No 1: Seasonal abundance of red spider mite (*O.coffeae*) on tea leaves in 2011 at monthly interval.

Month	Average number of mites / leaf	Average minimun temp.	Average maximum temp.	Max. Relative Humidity (%)	Min. Relative Humidity (%)	Rainfall (mm)
January	8.4 ± 0.2	15.4	28.1	83.7	40.9	0.0
February	14.6 ± 0.2	15.9	28.9	85.0	43.5	38.8
March	32.9 ± 2.4	17.7	30.9	88.6	45.2	50.0
April	68.2 ± 3.2	19.2	29.6	93.2	61.7	184.8
May	74.6 ± 4.1	19.6	29.1	92.9	68.3	82.2
June	56.1 ± 1.2	19.0	24.9	96.9	84.4	510.6
July	2.7 ± 0.1	18.6	24.7	94.6	82.8	362.8
August	3.9 ± 0.2	18.6	25.3	95.4	79.9	354.6
September	26.3 ± 1.1	18.4	25.6	92.5	72.0	179.0
October	32.4 ± 1.6	18.4	27.8	93.8	73.0	245.6
November	16.6 ± 0.8	16.9	26.1	90.6	67.1	61.0
December	11.1 ± 0.1	16.0	26.6	86.7	51.0	0.0

Table No. 2 Seasonal abundance of *B.phoenicis* on tea leaves in 2011 at monthly interval

month	Average number of mites / leaf	Average minimun temp.	Average maximum temp.	Max. Relative Humidity (%)	Min. Relative Humidity (%)	Rainfall (mm)
January	8.2 ± 0.2	15.4	28.1	83.7	40.9	0.0
February	9.6± 0.3	15.9	28.9	85.0	43.5	38.8
March	11.3± 0.7	17.7	30.9	88.6	45.2	50.0
April	14.7±1.6	19.2	29.6	93.2	61.7	184.8
May	16.1± 2.4	19.6	29.1	92.9	68.3	82.2
June	2.4±0.2	19.0	24.9	96.9	84.4	510.6
July	1.2± 0.2	18.6	24.7	94.6	82.8	362.8
August	2.3±0.8	18.6	25.3	95.4	79.9	354.6
September	5.1± 0.8	18.4	25.6	92.5	72.0	179.0
October	7.4± 1.3	18.4	27.8	93.8	73.0	245.6
November	8.2± 1.4	16.9	26.1	90.6	67.1	61.0
December	7.2± 0.9	16.0	26.6	86.7	51.0	0.0

Table No. 3 Seasonal abundance of *A.theae* on tea leaves in 2011 at monthly interval

Month	Average number of mites / leaf	Average minimun temp.	Average maximum temp.	Max. Relative Humidity (%)	Min. Relative Humidity (%)	Rainfall (mm)
January	21.6 ± 1.8	15.37	28.08	83.68	40.90	0.00
February	27.2 ± 2.4	15.91	28.88	85.00	43.46	38.80
March	35.4 ± 2.8	17.73	30.88	88.58	45.19	50.00
April	27.2 ± 3.2	19.16	29.61	93.23	61.73	184.80
May	45.6± 3.2	19.60	29.10	92.94	68.26	82.20
June	5.6 ± 1.6	18.99	24.90	96.90	84.37	510.60
July	2.1 ± 1.2	18.63	24.68	94.65	82.84	362.80
August	3.3 ± 0.9	18.59	25.26	95.35	79.94	354.60
September	9.5 ± 1.4	18.38	25.65	92.47	71.97	179.00
October	12 ± 1.6	18.44	27.75	93.81	72.97	245.60
November	16 ± 2.2	16.90	26.06	90.60	67.13	61.00
December	22 ± 2.4	15.98	26.56	86.71	51.00	0.00

Table No.4 Quantitative loss in chlorophyll content (mg/g) of *C. sinensis* leaves due to infestation by *O. coffeae.*

	Chlorophyll *a*			**Chlorophyll *b***			**Total Chlorophyll**		
Sl. No	Non infested	Heavily infested	Percentage of reduction	Non infested	Heavily infested	Percentage of reduction	Non infested	Heavily infested	Percentage of reduction
1	0.84	0.33	60.89	0.33	0.20	40.60	1.17	0.53	54.70
2	0.91	0.35	61.84	0.37	0.16	56.25	1.28	0.51	60.15
3	0.84	0.34	60.06	0.38	0.17	54.77	1.22	0.51	58.19
4	0.95	0.37	61.50	0.42	0.20	53.73	1.38	0.56	59.42
5	0.94	0.35	62.40	0.35	0.24	31.18	1.29	0.59	54.26
6	0.91	0.38	57.82	0.40	0.22	44.88	1.31	0.60	54.19
7	0.93	0.34	63.28	0.38	0.23	41.08	1.32	0.57	56.82
8	0.92	0.37	59.70	0.41	0.18	55.22	1.33	0.55	58.64
9	0.93	0.35	62.51	0.36	0.20	43.58	1.29	0.55	57.36
Mean	**0.91**	**0.35**	**61.14**	**0.38**	**0.20**	**46.81**	**1.29**	**0.55**	**57.36**
SEM	**0.014**	**0.01**	**0.57**	**0.01**	**0.01**	**2.89**	**0.02**	**0.01**	**0.75**

*Significant at P≤0.01

Table No 5 Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *O. coffeae*

Sl. No	Uninfested	Infested	Increase in phenolic content	% increase in phenolic content
1	50.24	92.46	42.22	84.04
2	46.42	86.78	40.36	86.95
3	53.86	94.65	40.79	75.73
4	48.35	86.45	38.10	78.80
5	62.48	102.64	40.16	64.28
6	58.54	104.52	45.98	78.54
7	62.50	96.86	34.36	54.98
8	52.86	93.28	40.42	76.47
9	56.42	89.34	32.92	58.35
10	61.78	98.88	37.10	60.05
Mean	55.35	94.59	39.24	71.82
SEM	1.88	1.97	1.20	3.60

Table No. 6 Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *O. coffeae*

Sl. No	Uninfested	Infested	Increase in proline content	% increase in proline content
1	0.43	0.83	0.41	95.53
2	0.38	0.85	0.47	125.00
3	0.47	0.82	0.35	75.48
4	0.49	0.92	0.43	88.91
5	0.52	0.98	0.47	91.07
6	0.40	0.84	0.45	112.37
7	0.53	0.97	0.44	84.38
8	0.51	0.83	0.31	61.33
9	0.61	0.94	0.32	52.94
10	0.41	0.75	0.34	83.01
Mean	0.47	0.87	0.40	87.00
SEM	0.02	0.02	0.02	6.79

*Significant at $P \leq 0.01$

Table No. 10

Quantitative loss in chlorophyll content (mg/g) of *C. sinensis* leaves due to infestation by *B. phoenicis.*

	Chlorophyll *a*			**Chlorophyll *b***			**Total Chlorophyll**		
	Non infested	**Heavily infested**	**Percentage of reduction**	**Non infested**	**Heavily infested**	**Percentage of reduction**	**Non infested**	**Heavily infested**	**Percentage of reduction**
1	0.75	0.68	8.85	0.34	0.23	31.74	1.09	0.91	15.95
2	0.77	0.69	10.95	0.31	0.25	18.40	1.08	0.94	13.07
3	0.79	0.69	13.53	0.29	0.22	24.27	1.08	0.90	16.40
4	0.85	0.74	12.94	0.34	0.27	19.56	1.19	1.01	14.81
5	0.87	0.77	12.38	0.32	0.24	26.14	1.20	1.00	16.09
6	0.89	0.77	12.87	0.31	0.22	28.26	1.20	1.00	16.86
7	0.81	0.69	14.47	0.34	0.26	24.16	1.15	0.95	17.34
8	0.83	0.70	15.41	0.30	0.23	22.42	1.13	0.93	17.26
9	0.87	0.74	14.14	0.27	0.24	12.67	1.14	0.98	13.79
Mean	**0.83**	**0.72**	**12.84**	**0.31**	**0.24**	**23.07**	**1.14**	**0.96**	**15.73**
SEM	**0.02**	**0.01**	**0.66**	**0.01**	**0.01**	**1.89**	**0.02**	**0.01**	**0.51**

*Significant at P≤0.01

Table No.11 Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *B. phoenicis*.

Sl. No	Uninfested	Infested	Increase in phenolic content	% increase in phenolic content
1	53.24	64.24	11.00	20.66
2	56.42	68.28	11.86	21.02
3	43.86	56.42	12.56	28.64
4	58.35	67.82	9.47	16.23
5	52.48	63.76	11.28	21.49
6	48.54	60.25	11.71	24.12
7.	52.50	60.78	8.28	15.77
8	62.86	71.46	8.60	13.68
9	66.42	81.88	15.46	23.28
10	51.78	62.96	11.18	21.59
Mean	54.65	65.79	11.14	20.65
SEM	2.10	2.26	0.66	1.39

Table No. 12 Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *B. phoenicis*

Sl. No	Uninfested	Infested	Increase in proline content	% increase in proline content
1	0.43	0.55	0.12	28.24
2	0.38	0.49	0.11	29.32
3	0.46	0.65	0.19	41.67
4	0.42	0.58	0.16	37.26
5	0.48	0.61	0.13	27.31
6	0.41	0.58	0.17	40.29
7	0.40	0.57	0.17	43.43
8	0.38	0.54	0.16	41.05
9	0.45	0.58	0.13	28.57
10	0.56	0.77	0.21	37.37
Mean	0.44	0.59	0.15	35.45
SEM	0.02	0.02	0.01	2.02

*Significant at $P \leq 0.01$

Table No. 7 Quantitative loss in chlorophyll content (mg/g) of *C. sinensis* leaves due to infestation by *A. theae.*

	Chlorophyll *a*			**Chlorophyll *b***			**Total Chlorophyll**		
	Non infested	Heavily infested	Percentage of reduction	Non infested	Heavily infested	Percentage of reduction	Non infested	Heavily infested	Percentage of reduction
1	0.82	0.64	21.06	0.30	0.21	29.82	1.12	0.86	23.43
2	0.91	0.65	28.16	0.29	0.24	16.63	1.20	0.89	25.37
3	0.82	0.63	22.55	0.29	0.25	12.46	1.11	0.89	19.90
4	0.92	0.68	26.10	0.32	0.24	24.29	1.24	0.92	25.64
5	0.91	0.69	23.69	0.32	0.25	21.71	1.22	0.94	23.18
6	0.88	0.70	19.78	0.31	0.22	29.00	1.19	0.92	22.19
7	0.86	0.65	24.54	0.37	0.23	37.83	1.23	0.88	28.51
8	0.88	0.70	20.33	0.32	0.23	27.53	1.20	0.93	22.24
9	0.86	0.66	23.00	0.32	0.23	28.75	1.18	0.89	24.56
Mean	0.87	0.67	23.24	0.31	0.23	25.34	1.19	0.90	23.89
SEM	0.01	0.01	0.82	0.02	0.00	2.53	0.01	0.01	0.83

*Significant at P≤0.01

Table No. 8 Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *A. theae.*

Sl. No	Uninfested	Infested	Increase in phenolic content	% increase in phenolic content
1	44.64	62.34	17.70	39.65
2	40.24	55.48	15.24	37.87
3	43.76	60.47	16.71	38.19
4	51.68	62.78	11.10	21.48
5	46.76	64.82	18.06	38.62
6	38.88	59.42	20.54	52.83
7	44.22	54.98	10.76	24.33
8	46.90	58.34	11.44	24.39
9	39.64	55.32	15.68	39.56
10	52.34	69.38	17.04	32.56
Mean	44.91	60.33	15.43	34.95
SEM	1.48	1.47	1.05	2.99

Table No. 9 Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *A. theae*

Sl. No	Uninfested	Infested	Increase in proline content	% increase in proline content
1	0.56	0.72	0.16	27.66
2	0.43	0.63	0.21	48.36
3	0.48	0.61	0.12	25.73
4	0.47	0.63	0.16	34.76
5	0.40	0.60	0.20	50.25
6	0.38	0.57	0.20	52.66
7	0.49	0.73	0.24	47.97
8	0.42	0.60	0.18	44.02
9	0.47	0.65	0.18	37.97
10	0.45	0.67	0.22	49.11
Mean	0.45	0.64	0.19	41.85
SEM	0.02	0.02	0.01	3.08

*Significant at $P \leq 0.01$

Table No. 13 Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *O. coffeae* on *C. sinensis* at different temperature - humidity conditions

Temperature & Humidity	Sl. No.	Pre-oviposition	Oviposition	Post oviposition	Adult longevity
25 ± 2°C & 80 ± 5% RH.	1	1	8	1	10
	2	1	7	1.5	9.5
	3	1.5	8	2	11.5
	4	1	9	1	11
	5	1	8	1.5	10.5
	6	1.5	8	2	11.5
	7	1.5	9	2.5	13
	8	1	7	1.5	9.5
	9	1	8	1	10
	10	1	9	1.5	11.5
	Mean	1.15	8.1	1.55	10.8
	SEM	0.078	0.23	0.16	0.35
30 ± 2°C & 70 ± 5% RH.	1	0.5	7	0.5	8
	2	0.5	8	0.75	9.25
	3	0.75	7	1	8.75
	4	0.5	8	0.75	9.25
	5	0.75	8	0.5	9.25
	6	0.5	7	0.5	8
	7	1	7	0.5	8.5
	8	0.5	8	1	9.5
	9	0.5	7	1	8.5
	10	0.5	7	1	8.5
	Mean	0.6	7.4	0.75	8.75
	SEM	0.06	0.16	0.07	0.17
35 ± 2°C &65 ± 5% RH.	1	0.5	7	0.5	8
	2	0.5	6	0.5	7
	3	0.75	7	0.5	8.25
	4	0.5	6	1	7.5
	5	0.5	6	0.5	7
	6	0.5	7	0.5	8
	7	0.5	7	0.5	8
	8	0.5	7	0.5	8
	9	0.5	6	1	7.5
	10	0.5	7	0.5	8
	Mean	0.53	6.6	0.6	7.73
	SEM	0.03	0.16	0.07	0.14

Table No. 17 Duration (in days) of development of *O. coffeae* on *C. sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonymph	2nd Q	Deutonymph	3rd Q	Total duration	Male/ Female	Nature of development
1	6	2	0.75	2	0.5	1.5	0.75	13.5	Female	sexual
2	6.5	1.5	0.5	2	0.5	1.5	0.5	13	Male	Parthenogenesis
3	6	2	0.5	2	0.5	1.5	0.5	13	Female	sexual
4	5.75	1.5	0.5	1.75	0.75	2	0.5	12.75	Male	sexual
5	6	2	0.5	1.75	0.5	2	0.5	13.25	Female	sexual
6	5.5	1.75	0.75	2	0.5	1.75	0.5	12.75	Male	Parthenogenesis
7	6.5	2	0.5	1.75	0.5	2	0.5	13.75	Female	sexual
8	7	1.5	0.5	2.25	0.75	1.5	0.5	14	Female	sexual
9	6	2	0.75	2	0.5	1.5	0.75	13.5	Female	sexual
10	6.25	1.75	0.5	1.75	0.5	1.5	0.5	12.75	Male	Parthenogenesis
MEAN	6.15	1.8	0.58	1.93	0.55	1.68	0.55	13.23	S 13.39 ± 0.16	
SEM	0.14	0.07	0.04	0.05	0.03	0.08	0.03	0.14	P 12.83 ± 0.08	

Table No 18 Duration (in days) of development of *O.coffeae* on *C.sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonymph	2nd Q	Deutonymph	3rd Q	Total duration	Male/ Female	Nature of development
1	5	2	0.5	1.75	0.5	2	0.5	12.25	Female	sexual
2	6	1.5	0.5	1.5	0.75	1.75	0.75	12.75	Female	sexual
3	5.75	2	0.5	1.75	0.5	1.75	0.5	12.75	Female	sexual
4	5	1.5	0.75	1.75	0.5	1.5	0.5	11.5	Male	Partheogenesis
5	5.25	1.5	0.5	1.5	0.5	2	0.75	12	Female	sexual
6	5.5	2	0.75	1.5	0.5	1.75	0.5	12.5	Male	Partheogenesis
7	5	1.75	0.5	1.75	0.5	2	0.75	12.25	Male	Partheogenesis
8	6	1.5	0.5	1.5	0.75	1.5	0.5	12.25	Female	sexual
9	5.75	2	0.5	1.5	0.5	1.75	0.5	12.5	Male	sexual
10	5.5	1.5	0.5	1.5	0.5	1.5	0.5	11.5	Male	Partheogenesis
Mean	5.48	1.73	0.55	1.6	0.55	1.75	0.58	12.23	P 11.94 ± 0.26	
SEM	0.13	0.08	0.03	0.04	0.03	0.06	0.04	0.14	S 12.42 ± 0.12	

Table 19 Duration (in days) of development of *O.coffeae* on *C.sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonymph	2nd Q	Deutonymph	3rd Q	Total duration	Male/ Female	Nature of development
1	5	2	0.5	1.5	0.5	1	0.5	11	Male	Parthenogenesis
2	4.75	2.25	0.5	1.5	0.5	1.5	0.5	11.5	Male	Parthenogenesis
3	5	2	0.5	2	0.5	1.75	0.5	12.25	Female	sexual
4	4.5	2	0.5	1.75	0.75	2	0.75	12.25	Female	sexual
5	4.5	2.25	0.75	1.5	0.5	2	0.5	12	Male	sexual
6	4.75	2	0.5	2	0.5	1.5	0.75	12	Male	Parthenogenesis
7	5	2.25	0.5	2	0.5	1.5	0.5	12.25	Female	sexual
8	5	2	0.75	2	0.5	1.75	0.5	12.5	Female	sexual
9	4.75	2	0.5	1.75	0.75	2	0.5	12.25	Female	sexual
10	4.5	2	0.5	1.5	0.5	2	0.75	11.75	Male	Parthenogenesis
MEAN	4.78	2.08	0.55	1.75	0.55	1.7	0.58	11.98	P 11.56 ± 0.21	
SEM	0.07	0.04	0.03	0.08	0.03	0.10	0.04	0.14	S 12.25 ± 0.06	

Table 14 Fecundity of *O.coffeae* on *C.sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total	Female (Virgin/Mated
	1	2	3	4	5	6	7	8	9		
1	1	2	2	8	7	3	2	2	1	28	Mated
2	1	1	2	6	4	3	2	1	0	20	Virgin
3	1	1	2	7	5	4	3	2	1	26	Mated
4	1	2	3	7	7	3	3	1	0	27	Virgin
5	1	1	2	4	5	3	3	2	0	21	Virgin
6	1	2	3	4	6	3	1	1	0	21	Virgin
7	1	2	3	8	6	4	3	2	1	30	Mated
8	1	3	3	6	5	3	2	1	1	25	Mated
9	1	2	3	7	5	3	2	1	0	24	Virgin
10	1	2	2	6	7	5	3	1	1	28	Mated
Mean	1	1.8	2.5	6.3	5.7	3.4	2.4	1.4	0.5	25	M 27 ± 0.87
SEM	0	0.2	0.17	0.45	0.33	0.22	0.22	0.16	0.17	1.09	V 22.6 ±1.29

Table 15

Fecundity and longevity of *O. coffeae* on *C. sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total	Female (Virgin/Mated
	1	2	3	4	5	6	7	8	9		
1	2	2	3	9	5	2	1	0		24	V
2	1	3	3	12	3	2	1	0		25	V
3	1	4	6	13	6	3	3	1		37	M
4	1	2	5	14	6	4	2	1		35	M
5	1	3	2	12	5	4	1	0		28	M
6	1	2	3	11	4	3	2	1		27	V
7	1	3	6	12	6	3	1	1		33	M
8	2	2	4	13	3	2	2	1		29	V
9	1	2	6	9	8	3	1	0		30	M
10	1	1	3	10	4	2	2	1		24	V
Mean	1.2	2.4	4.1	11.5	5	2.8	1.6	0.6		29.2	M 32.6±1.63
SEM	0.13	0.27	0.48	0.54	0.49	0.25	0.22	0.16		1.44	V 25.8 ±0.97

Table 16 Fecundity and longevity of *O. coffeae* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total	Female (Virgin/Mated
	1	2	3	4	5	6	7	8	9		
1	1	6	8	14	7	6	1			42	M
2	2	3	6	20	7	2	0			40	M
3	1	2	5	19	8	2	0			37	V
4	1	2	6	20	5	1	1			35	V
5	1	6	4	18	6	4	2			41	M
6	2	2	7	17	4	1	1			34	V
7	1	2	9	18	6	2	0			38	M
8	1	1	6	18	5	1	0			32	V
9	2	2	7	17	6	3	1			37	V
10	1	4	9	16	9	4	0			43	M
Mean	1.3	3	6.7	17.7	6.3	2.6	0.6			37.9	M 40.8± 0.86
SEM	0.15	0.56	0.52	0.58	0.47	0.52	0.22			1.14	V 35 ± 0.95

Table 20 Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *B. phoenicis* on *C. sinensis* at different temperature - humidity conditions

Temperature-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post- oviposition	Adult Longevity
25 ± 2ºC & 80 ± 5% RH.	1	5	18	3	26
	2	6	17	4	27
	3	5	16	2	23
	4	4	15	3	22
	5	4	18	2	24
	6	5	15	4	24
	7	3	17	2	22
	8	2	17	3	22
	9	4	15	3	22
	10	3	19	2	24
	MEAN	4.1	16.7	2.8	23.6
	SEM	0.38	0.45	0.25	0.56
30 ± 2ºC &70 ± 5% RH.	1	4	16	2	22
	2	5	15	3	23
	3	4	18	2	24
	4	4	16	2	22
	5	3	17	2	22
	6	4	16	3	23
	7	2	17	3	22
	8	2	19	2	23
	9	3	15	3	21
	10	3	17	4	24
	MEAN	3.4	16.6	2.6	22.6
	SEM	0.31	0.4	0.22	0.31
35 ± 2ºC & 65 ± 5% RH.	1	3	18	2	23
	2	5	15	4	24
	3	4	14	3	21
	4	5	15	2	22
	5	3	20	3	26
	6	3	14	2	19
	7	3	15	2	20
	8	3	17	4	24
	9	4	16	2	22
	10	5	13	3	21
	MEAN	3.8	15.7	2.7	22.2
	SEM	0.29	0.67	0.26	0.66

Table 24 Duration (in days) of development of *B. phoenicis* on *C. sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonym-ph	2nd Q	Deutony-mph	3rd Q	Total duration	Male/ Female	Nature of development
1	9	5	2.5	5	3	6	2.5	30.5	Female	Parthenogenesis
2	11	4	2.5	3.5	3	5	2.5	31.5	Female	Parthenogenesis
3	9	4.5	2	5	2.5	6	2	31	Female	Parthenogenesis
4	12	4	2	5	3	5	1.5	32.5	Female	Parthenogenesis
5	10	4	2.5	4	2.5	6	2	31	Female	Parthenogenesis
6	9	5.5	1.5	4	3	5	2.5	30.5	Female	Parthenogenesis
7	12	4	2	3	3.5	6	2.5	33	Female	Parthenogenesis
8	10	5	1.5	4	4	5	2	31.5	Female	Parthenogenesis
9	12	4	2.5	4	2.5	4.5	2.5	32	Female	Parthenogenesis
10	10	3	2	5	4	5	2	31	Female	Parthenogenesis
MEAN	10.4	4.3	2.1	4.25	3.1	5.35	2.2	31.45		
Range	9 -12	3 - 5.5	1.5 - 2.5	3 - 5	2.5 - 4	4.5 - 6	1.5- 2.5	30.5 - 32.5		
SEM	0.40	0.23	0.13	0.23	0.18	0.18	0.11	0.26		

Table 25 Duration (in days) of development of *B. phoenicis* on *C. sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonymph	2nd Q	Deutonymph	3rd Q	Total duration	Male/ Female	Nature of development
1	9	4	2	3.5	2.5	4	1.5	26.5	Female	Parthenogenesis
2	10	4	2	3	3	5	2	29	Female	Parthenogenesis
3	8	4.5	1.5	4	2.5	4	2	26.5	Female	Parthenogenesis
4	9	4	2	5	3	5	1.5	29.5	Female	Parthenogenesis
5	10	4	1.5	4	2	5	2	28.5	Female	Parthenogenesis
6	8	4.5	1.5	4	2	5	2.5	27.5	Female	Parthenogenesis
7	9	4	2	3	3	6	1	28	Female	Parthenogenesis
8	8	4	1.5	4	2	5	2	26.5	Female	Parthenogenesis
9	10	3.5	2	3.5	1.5	4	2.5	27	Female	Parthenogenesis
10	9	3	2	5	3	5	2	29	Female	Parthenogenesis
MEAN	9	3.95	1.8	3.9	2.45	4.8	1.9	27.8		
Range	8 -10	3 - 4.5	1.5 - 2	3 - 5	1.5 -3	4 - 6	1-2.5	26.5 - 29		
SEM	0.26	0.14	0.08	0.22	0.17	0.20	0.15	0.37		

Table 26 Duration (in days) of development of *B. phoenicis* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No	Egg	Larva	1st Q	Protonymph	2nd Q	Deutonymph	3rd Q	Total duration	Male/ Female	Nature of development
1	9	4	2.5	4	2	5	2.5	29	Female	Parthenogenesis
2	8.5	3	2.5	4	2.5	5	2.5	28	Female	Parthenogenesis
3	9	3.5	2	5	2.5	6	2	30	Female	Parthenogenesis
4	10	3	2	5	3	5.5	2	30.5	Female	Parthenogenesis
5	10	3	2.5	4	2	5	2	28.5	Female	Parthenogenesis
6	9	4.5	1.5	3	3	5	2.5	28.5	Female	Parthenogenesis
7	9	4	2	3	3.5	4.5	2.5	28.5	Female	Parthenogenesis
8	9	5	1.5	4	3	5	2	29.5	Female	Parthenogenesis
9	11	3	3	3.5	3.5	4.5	2.5	31	Female	Parthenogenesis
10	9	3.5	2	3	3.5	5	2	28	Female	Parthenogenesis
MEAN	9.35	3.65	2.15	3.85	2.85	5.05	2.25	29.15		
Range	8.5 - 11	3 - 5	2- 3	3 - 5	2 - 3.5	4.5 - 6	2 - 2.5	28 - 30.5		
SEM	0.24	0.22	0.15	0.24	0.18	0.14	0.08	0.33		

Table 21 Fecundity of *B. phoenicis* on *C.sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total
	Days 1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	16-18	
1	2	4	5	5	2	2	2	1	1	24
2	3	5	4	6	3	3	1	0	0	25
3	2	2	3	6	4	3	1	1	0	22
4	3	4	3	4	4	2	2	2	1	25
5	4	4	4	3	2	2	1	1	0	21
6	2	3	5	4	3	3	0	0	0	20
7	1	2	3	4	3	2	1	1	0	17
8	2	5	2	3	4	2	2	2	1	23
9	3	3	3	5	2	3	1	0	0	20
10	2	3	4	4	3	2	1	1	0	20
Mean	2.4	3.5	3.6	4.4	3	2.4	1.2	0.9	0.3	21.7
SEM	0.27	0.34	0.31	0.34	0.26	0.16	0.2	0.23	0.15	0.82
Range	1 - 4	2 - 5	2 - 5	3 - 6	2 - 4	2- 3	0 - 2	0 - 2	0 - 1	17 - 25

Table 22 Fecundity and of *B. phoenicis* on *C.sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total
	Days 1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	16-18	
1	3	4	6	7	4	3	2	1	0	30
2	2	3	4	5	5	4	2	0	0	25
3	4	4	4	6	5	4	3	1	0	31
4	4	4	2	5	5	3	3	1	0	27
5	3	6	5	4	4	3	3	2	0	30
6	2	3	7	4	4	4	1	0	0	25
7	4	4	3	5	5	3	2	1	0	27
8	3	4	4	4	4	2	3	1	0	25
9	2	3	5	6	4	5	1	1	0	27
10	2	5	5	4	5	3	2	0	0	26
Mean	2.9	4	4.5	5	4.5	3.4	2.2	0.8	0	27.3
SEM	0.28	0.3	0.45	0.33	0.17	0.27	0.25	0.2	0	0.72
Range	2 - 4	3 - 6	2 - 7	4 - 7	4 - 5	2 - 5	1 - 3	0 - 2	0	25 - 31

Table 23 Fecundity of *B. phoenicis* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total
	Days 1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	16-18	
1	2	5	5	6	3	2	2	1	0	26
2	3	3	5	7	4	4	1	0	0	27
3	3	3	4	6	4	3	2	1	0	26
4	4	4	3	4	4	3	3	1	0	26
5	4	5	4	5	3	2	2	1	0	26
6	3	4	6	4	3	4	0	0	0	24
7	2	3	3	3	4	2	2	1	0	20
8	4	5	3	5	4	2	2	1	0	26
9	3	4	4	6	3	4	1	0	0	25
10	3	3	6	5	4	3	1	1	0	26
Mean	3.1	3.9	4.3	5.1	3.6	2.9	1.6	0.7	0	25.2
SEM	0.23	0.28	0.37	0.38	0.16	0.28	0.27	0.15	0	0.63
Range	2 - 4	3 - 5	3 - 6	3 - 7	3 - 4	2 - 4	1 - 3	0 -1	0	20 - 27

Table No. 27 Duration (in days) of pre-oviposition, oviposition, post- oviposition and adult longevity periods of *A. theae* on *C. sinensis* at different temperature - humidity conditions

Temperature & Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition	Adult longevity
25 ± 2ºC & 80 ± 5% RH.	1	1.5	8	2	11.5
	2	2	7	2	11
	3	1.5	8	3	12.5
	4	1.75	7	2	10.75
	5	1.75	8	3	12.75
	6	2	7	3	12
	7	2	7	2	11
	8	2	9	2.5	13.5
	MEAN	1.81	7.63	2.44	11.88
	SEM	0.08	0.26	0.18	0.34
30 ± 2ºC & 70 ± 5% RH.	1	1.5	6	2	9.5
	2	1.75	7	2	10.75
	3	1.5	7	2	10.5
	4	2	6	1	9
	5	1.5	7	3	11.5
	6	2	8	2	12
	7	1.5	7	3	11.5
	8	1.75	7	2	10.75
	MEAN	1.69	6.88	2.13	10.69
	SEM	0.08	0.23	0.23	0.36
35 ± 2ºC & 65 ± 5% RH.	1	2	9	3	14
	2	2	7	2	11
	3	1.75	7	2	10.75
	4	2	9	2	13
	5	2	7	3	12
	6	2	8	2	12
	7	1.75	9	2	12.75
	8	2	7	3	12
	MEAN	1.94	7.88	2.38	12.19
	SEM	0.04	0.35	0.18	0.37

Table 31 Duration (in days) of development of *A. theae* on *C. sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No	Egg	Protonymph	1st Q	Deutonyph	2nd Q	Total duration
1	2.5	1.75	0.75	2.25	1	8.25
2	2.5	2.25	1	2.25	0.75	8.75
3	2.5	2	0.75	2.5	1	8.75
4	2.25	2.25	0.75	2.5	0.75	8.5
5	2.25	2	0.75	2.5	1	8.5
6	2	2	1	2.5	1	8.5
7	2.5	2.25	0.75	2.25	0.75	8.5
8	2	2	0.75	2.25	0.75	7.75
9	2.25	2.25	0.75	2.5	1	8.75
10	2.5	2	0.75	2.25	0.75	8.25
MEAN	2.33	2.08	0.80	2.38	0.88	8.45
SEM	0.07	0.05	0.03	0.04	0.04	0.10
RANGE	2 - 2.5	1.75 - 2.25	0.75 - 1	2.25 -2.5	0.75 - 1	7.75 - 8.75

Table 32 Duration (in days) of development of *A. theae* on *C. sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No	Egg	Protonymph	1st Q	Deutonyph	2nd Q	Total duration
1	1.5	1.75	0.5	2	0.75	6.5
2	1.5	1.5	0.5	2	0.75	6.25
3	1.5	1.5	0.75	2.25	0.5	6.5
4	1.5	1.75	0.75	2.25	0.5	6.75
5	1.75	1.5	0.75	2.25	1	7.25
6	2	1.75	1	2	0.75	7.5
7	1.75	1.5	0.5	2	0.75	6.5
8	1.5	1.5	0.5	2.25	0.75	6.5
9	1.75	1.75	0.75	2	0.5	6.75
10	1.5	1.5	0.5	2	0.75	6.25
MEAN	1.63	1.60	0.65	2.10	0.70	6.68
SEM	0.06	0.04	0.06	0.04	0.05	0.13
RANGE	1.5 - 2	1.5 -1.75	0.5 - 1	2 - 2.25	0.5 -1	6.25 - 7.25

Table 33 Duration (in days) of development of *A. theae* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No	Egg	Protonymph	1st Q	Deutonyph	2nd Q	Total duration
1	2	2	1	2.5	0.75	8.25
2	2	1.5	1	2	0.75	7.25
3	2	1.5	0.75	2.5	0.5	7.25
4	2.25	1.75	0.75	2.5	0.5	7.75
5	2.5	1.5	0.75	2.25	1	8
6	2	1.75	0.75	2.5	0.75	7.75
7	2.25	1.5	1	2.25	0.75	7.75
8	2	1.5	1	2.25	0.75	7.5
9	2.5	1.75	0.75	2.5	0.5	8
10	2.5	1.5	1	2	0.75	7.75
MEAN	2.20	1.63	0.88	2.33	0.70	7.73
SEM	0.07	0.06	0.04	0.07	0.05	0.10
Range	2- 2.5	1.5 - 2	0.75 -1	2 - 2.5	0.5 - 1	7.25 - 8.25

Table 28 Fecundity and longevity of *A. theae* on *C. sinensis* at 25 ± 2°C & 80 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									Total
	1	2	3	4	5	6	7	8	9	
1	1	2	2	4	3	3	2	1	0	18
2	1	1	4	4	2	2	1	1	0	16
3	1	1	3	3	2	2	3	2	1	18
4	2	2	2	5	3	2	2	2	1	21
5	1	3	1	3	3	3	3	1	0	18
6	1	2	2	3	4	3	2	1	0	18
7	1	2	3	4	2	3	1	1	1	18
8	2	3	3	2	3	2	2	2	0	19
9	1	1	2	4	3	1	3	1	0	16
10	1	1	3	3	2	3	3	1	0	17
Mean	1.2	1.8	2.5	3.5	2.7	2.4	2.2	1.3	0.3	17.9
SEM	0.13	0.25	0.27	0.27	0.21	0.22	0.25	0.15	0.15	0.46
Range	1-2	1-3	1-3	2-3	2-4	1-3	1-3	1-2	0-1	16-21

Table 29 Fecundity and longevity of *A. theae* on *C. sinensis* at 30 ± 2°C & 70 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition							
	1	2	3	4	5	6	7	Total
1	1	4	4	4	3	3	1	20
2	2	3	5	4	4	3	0	21
3	1	4	4	3	3	3	1	19
4	2	3	4	4	4	2	1	20
5	2	3	3	3	4	3	1	19
6	2	4	4	5	3	2	0	20
7	1	4	5	4	4	3	1	22
8	2	4	4	4	4	2	1	21
9	2	3	5	4	5	2	1	22
10	2	4	4	5	3	2	1	21
Mean	1.7	3.6	4.2	4	3.7	2.5	0.8	20.5
SEM	0.15	0.16	0.2	0.21	0.21	0.17	0.13	0.34
Range	1 - 2	3 - 4	3 - 5	3 - 5	3 -5	2 - 3	0 - 1	19 - 22

Table 30 Fecundity and longevity of *A. theae* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

Sl. No.	Number of eggs laid on different days of oviposition									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
1	1	3	4	4	3	2	2	1	1	21
2	2	3	3	5	4	3	3	2	1	26
3	2	4	4	4	3	2	2	1	0	22
4	2	3	3	3	2	3	2	1	0	19
5	2	4	4	4	3	3	3	2	1	26
6	2	3	3	4	4	2	2	1	0	21
7	2	3	2	3	3	3	2	1	0	19
8	1	2	4	4	3	2	1	0	0	17
9	1	2	4	2	3	3	2	1	0	18
10	1	3	3	2	2	4	2	1	0	18
Mean	1.6	3	3.4	3.5	3	2.7	2.1	1.1	0.3	20.7
SEM	0.16	0.21	0.22	0.31	0.21	0.21	0.18	0.18	0.15	1.01
Range	1 - 2	2 - 4	2 - 4	2 - 5	2 - 4	2 - 4	1 - 3	0 - 2	0 - 1	17 - 26

Table No 36 No. of days taken by *A. Largoensis* for the complete consumption/ killing of *O. coffeae* at different prey – predator ratios

Sl. No.	Prey - Predator ratio		
	2:1	**5:1**	**10:1**
1	2	5	12
2	3	6	10
3	2	5	11
4	4	6	10
5	3	7	9
Mean	2.8	5.8	10.4
SEM	0.37	0.37	0.51

Table No 37 No. of days taken by *A. herbicolus* for the complete consumption/ killing of *O. coffeae* at different prey – predator ratios

Sl. No.	Prey - Predator ratio		
	2:1	**5:1**	**10:1**
1	3	7	13
2	3	7	12
3	4	6	11
4	3	7	10
5	3	6	12
Mean	3.2	6.6	11.6
SEM	0.2	0.24	0.51

Table No. 38 Rate of predation by different life stages of *A.largoensis* on different stages of *O. coffeae* in 24 hours at a temperature of 30 ± 2°C and 70 ± 2% RH.

Predator		Average number of prey consumed in 24 hours				
		Egg	**Larva**	**Protonymph**	**Deutonymph**	**Adult**
Adult	Female	36	16.4	12.8	3.4	1.6
	Male	22.6	12.8	8.6	2.4	1.2
Nymphal stages	Deutonymph	22.6	12.4	8.8	2.6	1.2
	Protonymph	9.4	4.8	3.2	0	0
	Larva	3.6	1.2	0	0	0

Table No. 39 Percentage of predation by different stages of *A. largoensis* on different stages of *O. coffeae* in 24 hours at a temperature of 30 ± 2°C and 70 ± 2% RH.

Predator		Average % of consumption				
		Egg	**Larva**	**Protonymph**	**Deutonymph**	**Adult**
Adult	Female	72	65.6	51.2	13.6	6.4
	Male	45.2	51.2	34.4	9.6	4.8
Nymphal stages	Deutonymph	45.2	49.6	35.2	10.4	4.8
	Protonymph	18.8	19.2	12.8	0	0
	Larva	7.2	4.8	0	0	0

Table No. 34 Ovicidal activity of aqueous plant extracts on eggs of *O. coffeae* under laboratory condition.

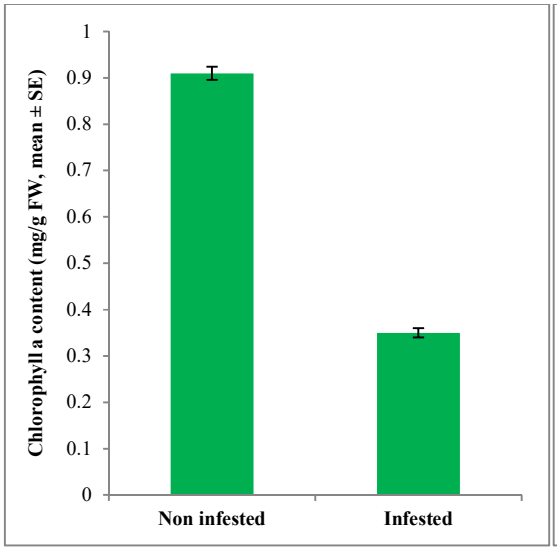
Sl. No	Treatment	Concentration (%)	Egg mortality (%)
1	*C. frutescens*	10.0	82.66
		5.0	60.67
		2.5	42.00
2	*S.nux-vomica*	10.0	72.67
		5.0	56.67
		2.5	29.33
3	*G. sepium*	10.0	40.67
		5.0	28.67
		2.5	19.33
	Control (water)		9.33

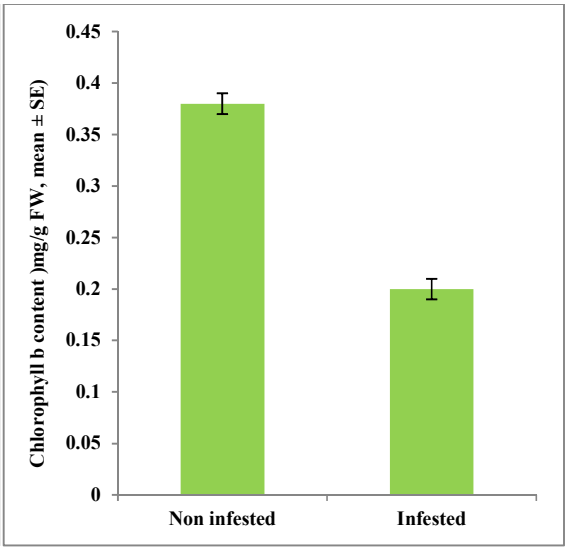
Table No. 35 Acaricidal activity of aqueous plant extracts on adult *O. coffeae* under laboratory conditions.

Sl. No	Treatments	Concentration (%)	% mortality		
			24 Hour	48 Hour	72 Hour
1	*C. frutescens*	10.0	84	94	94.67
		5.0	46	61.33	67.3
		2.5	30	32.67	37.33
2	*S.nux-vomica*	10.0	74.67	79.33	83.87
		5.0	44.67	54	62
		2.5	17.33	19.66	19.66
3	*G. sepium*	10.0	58.67	70.67	77.33
		5.0	39.33	50.67	50.67
		2.5	14	14.67	15.33
	Control (Water)		6	6.67	6.67

Plate7

Quantitative loss in chlorophyll content (mg/g) of *C.sinensis* leaves due to infestation by *O.coffeae*.





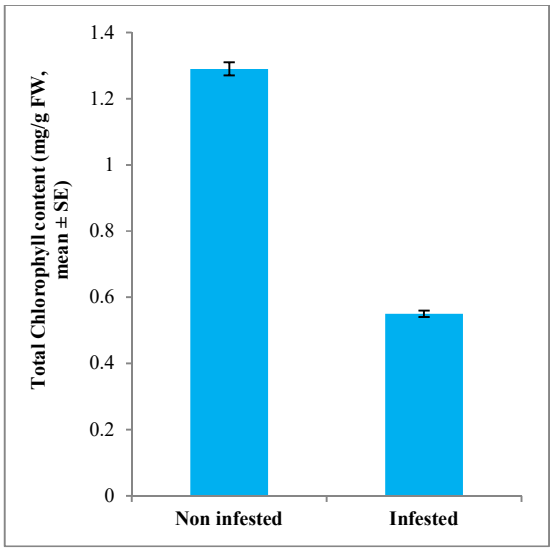
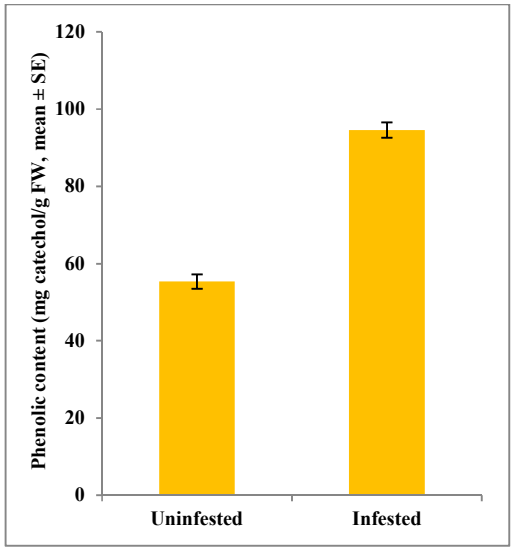


Plate 8

Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *O. coffeae*



Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *O. coffeae*

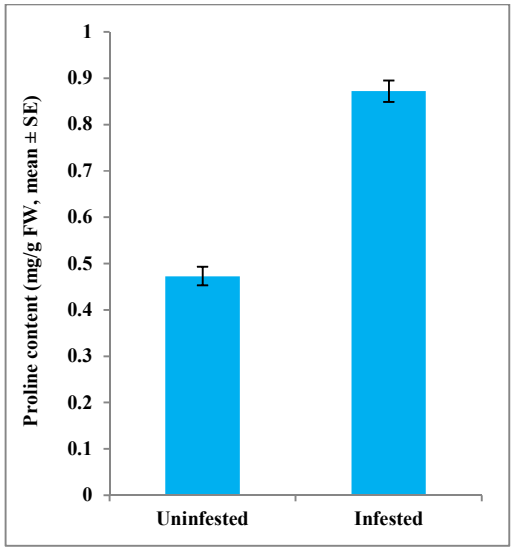


Plate 33

Duration (in days) of pre-oviposition, oviposition and post- oviposition periods of *A. theae* on Tea at different temperature - humidity conditions

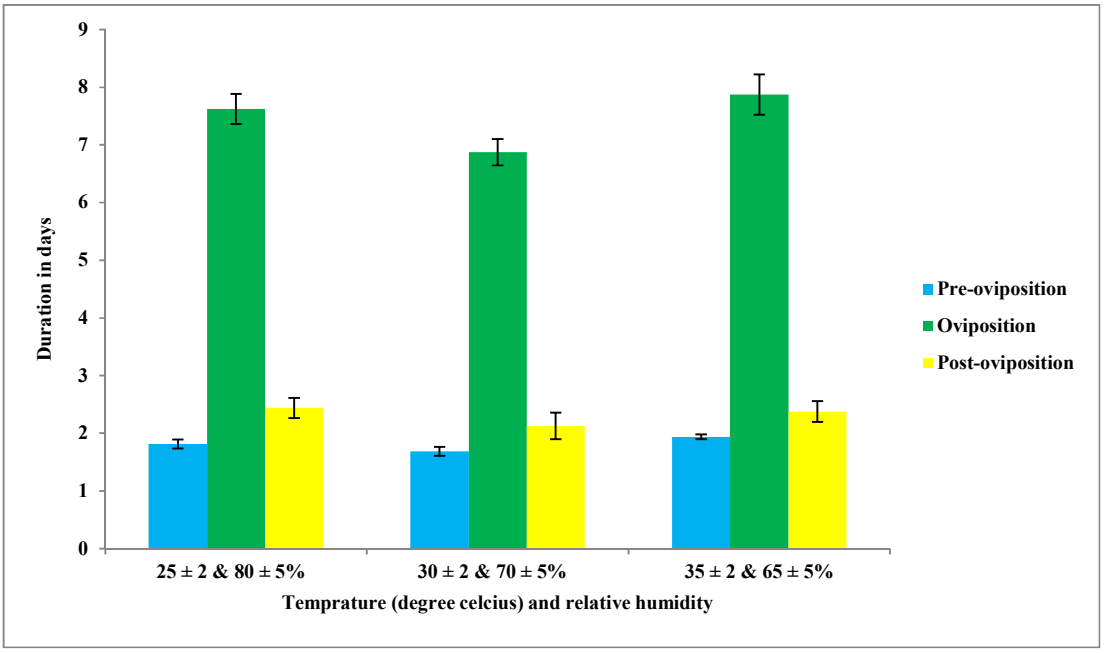
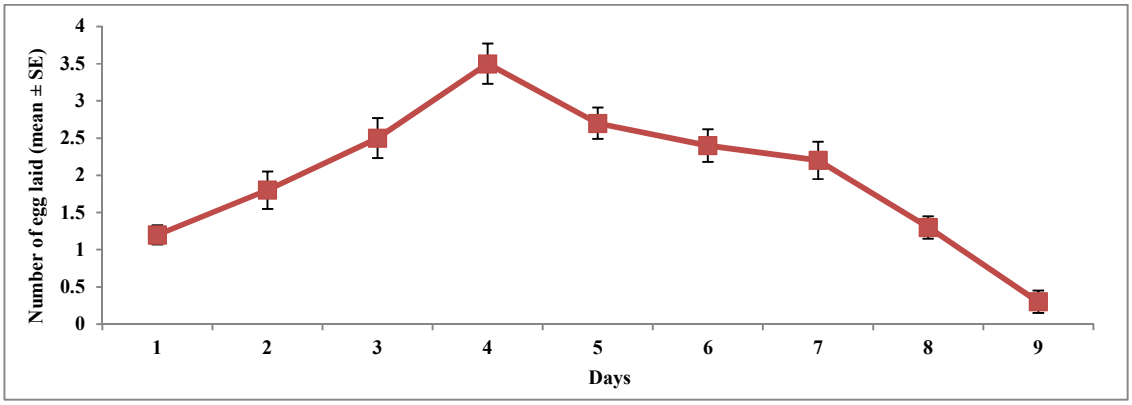
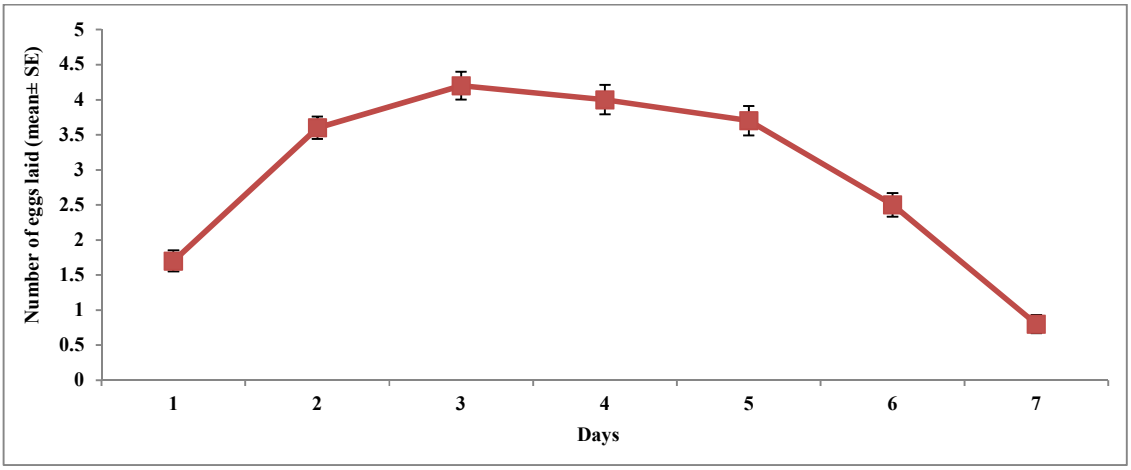


Plate 34

Fecundity of *A. theae* on *C. sinensis* at 25 ± 2ºC & 80 ± 5% RH.



Fecundity and of *A. theae* on *C. sinensis* at 30 ± 2ºC & 70 ± 5% RH.



Fecundity of *A. theae* on *C. sinensis* at 35 ± 2ºC & 65 ± 5% RH.

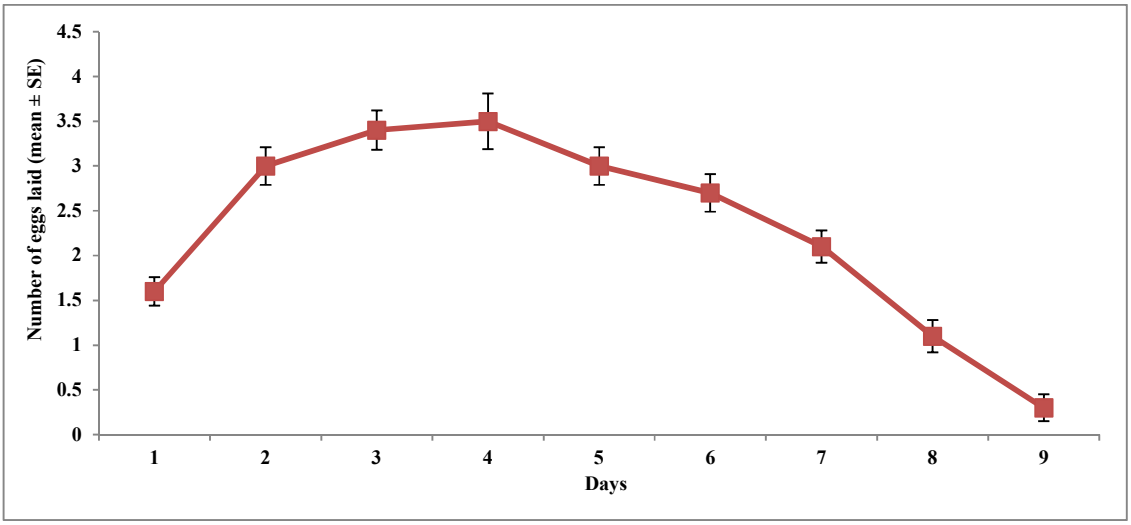
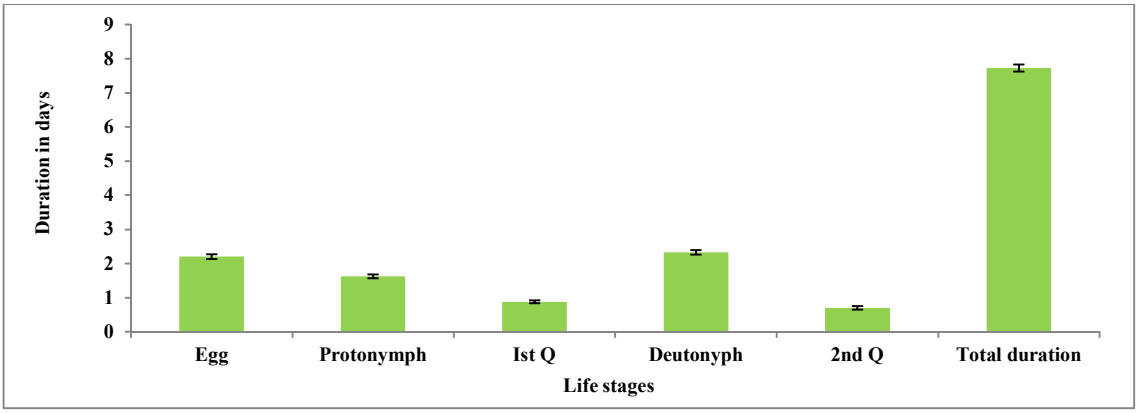
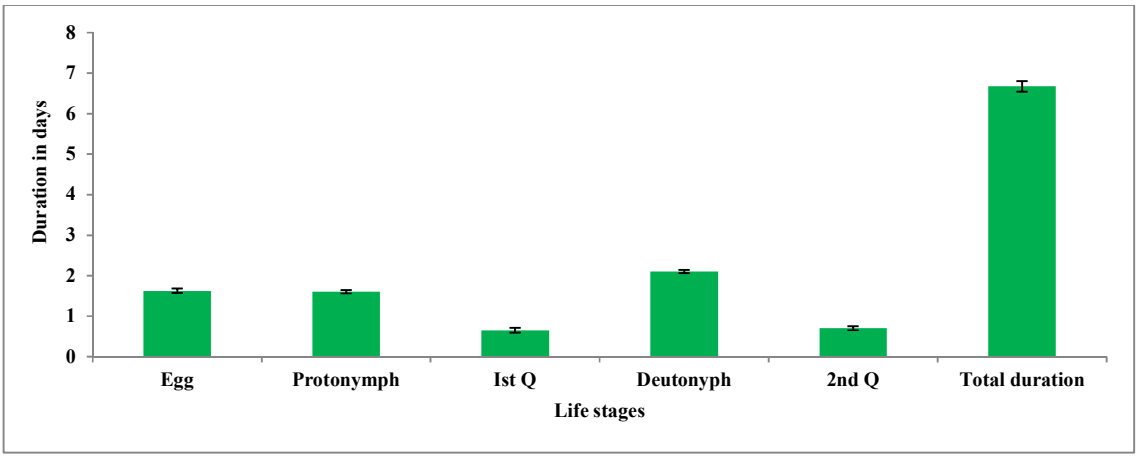


Plate 35

Duration (in days) of development of *A. theae*on *C. sinensis* at 35 ± 2ºC & 65 ± 5% RH.



Duration (in days) of development of *A. theae* on *C. sinensis* at 30 ± 2ºC & 70 ± 5% RH.



Duration (in days) of development of *A. theae* on *C. sinensis* at 25 ± 2ºC & 80 ± 5% RH.

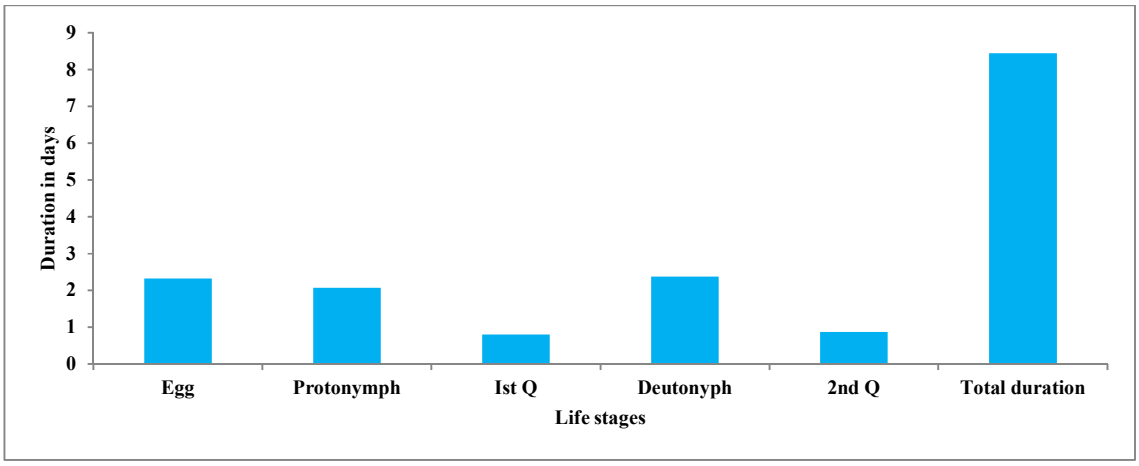


Plate 34

Comparative histogram showing duration of life stages of *A.thea* under different temperature-humidity conditions on Tea

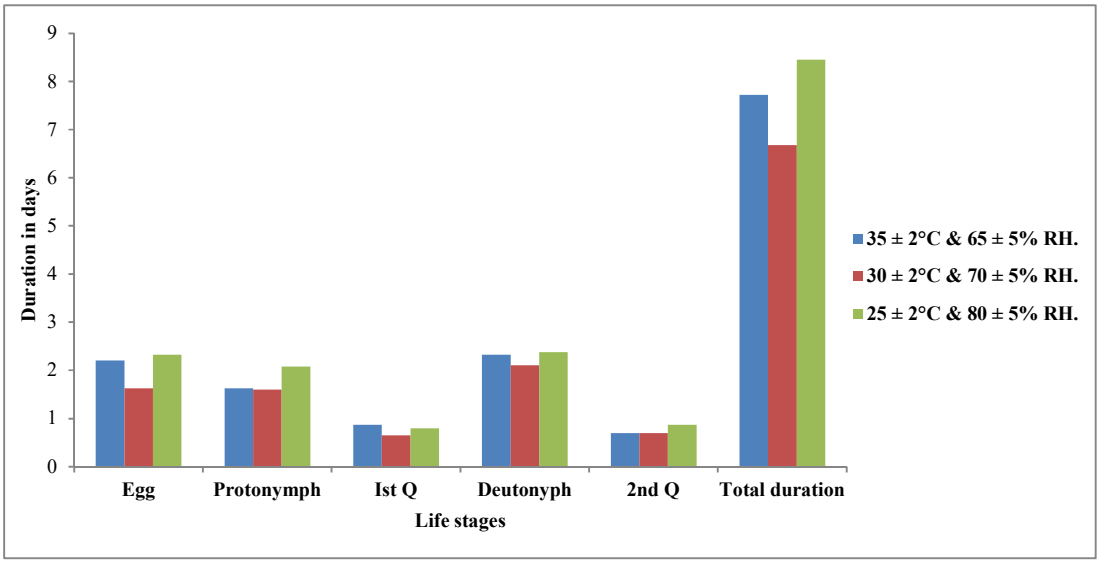
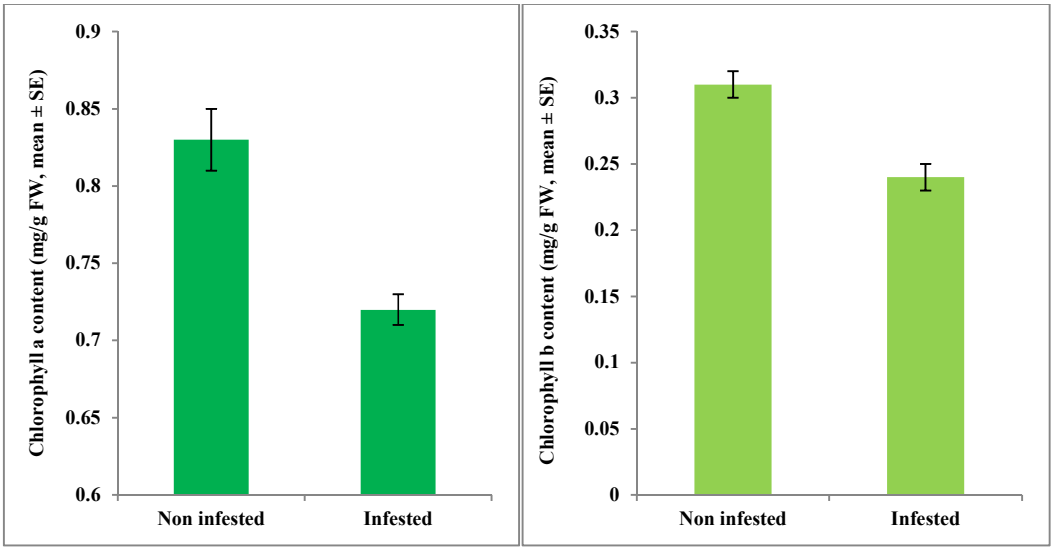


Plate 19

Quantitative loss in chlorophyll content (mg/g tissue) of *C. sinensis* leaves due to infestation by *B. phoenicis*.



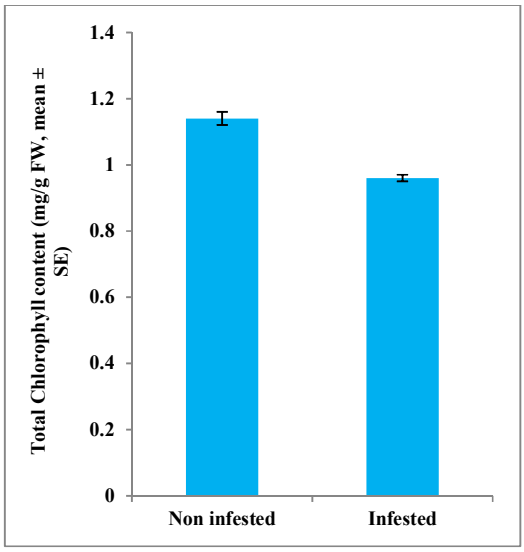
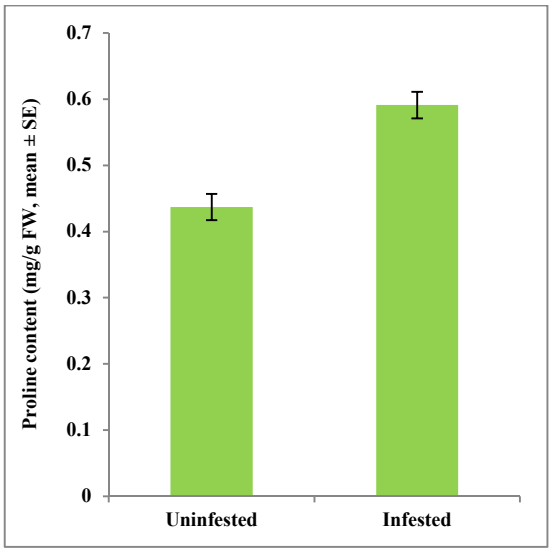


Plate 20

Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *B.phoenicis*



Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *B.phoenicis*

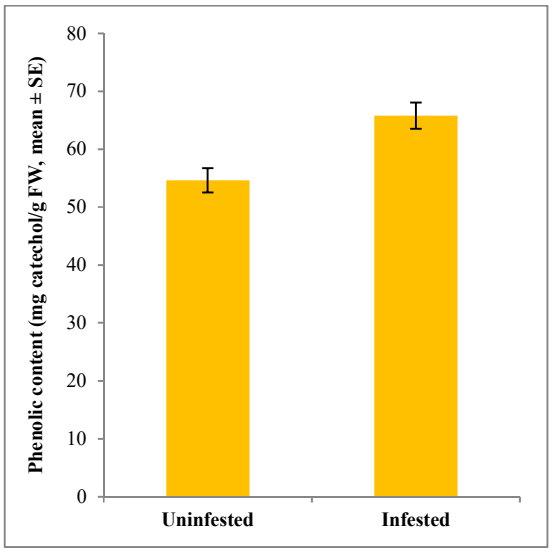


Plate 22

Duration (in days) of pre-oviposition, oviposition, post-oviposition periods of *B.phoenicis* on Tea at different temperature - humidity conditions

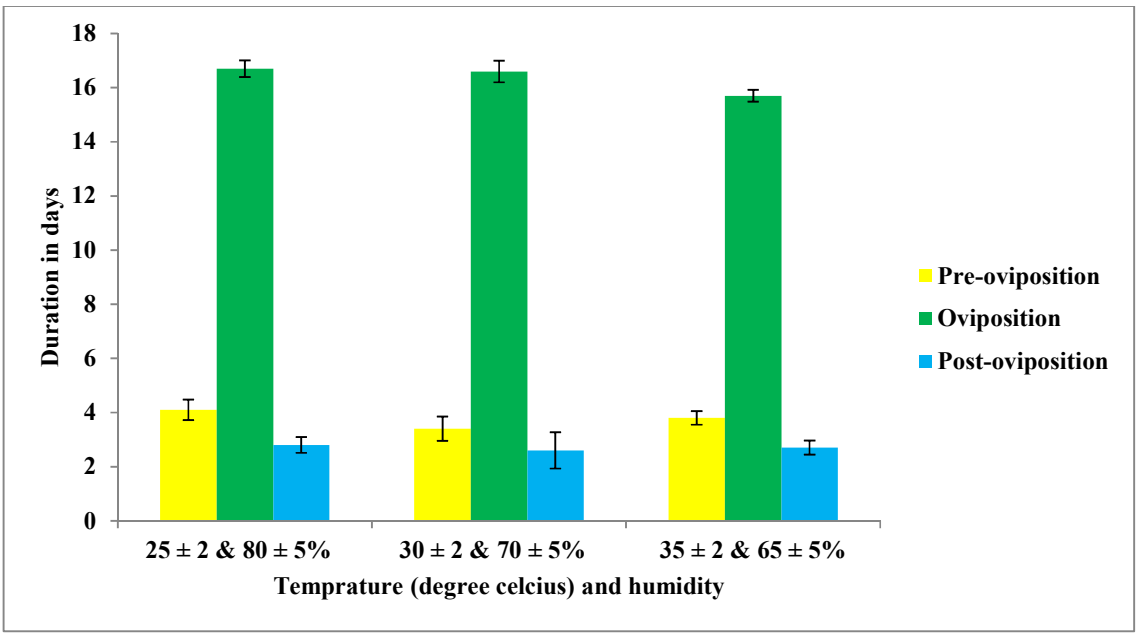
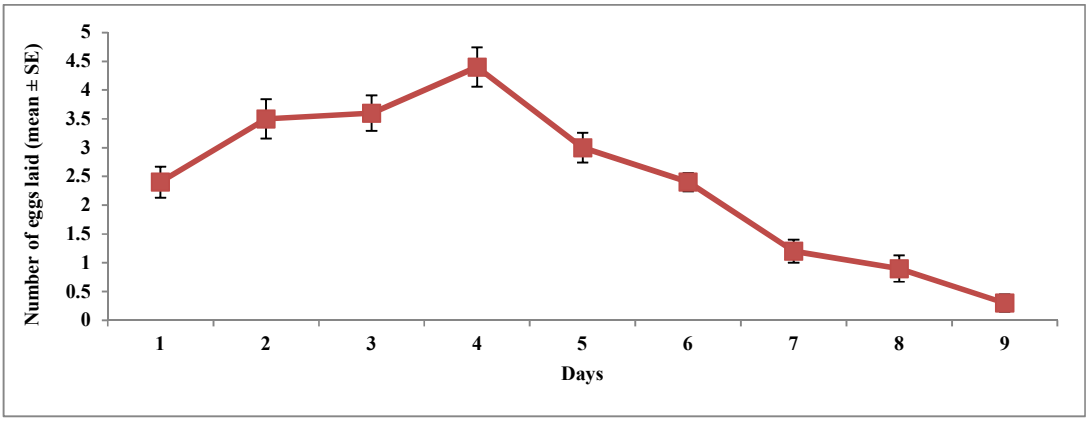
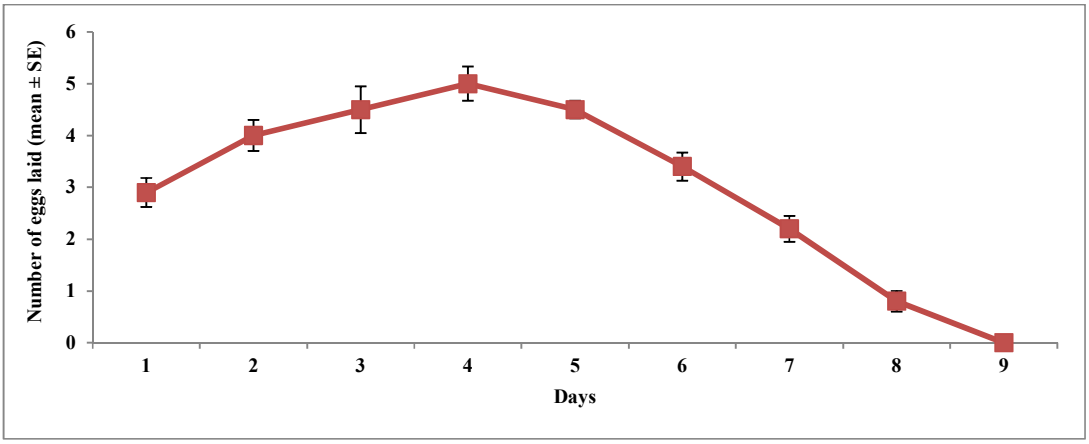


Plate 23

Fecundity of *B. phoenicis* on *C. sinensis* at 25 ± 2°C & 80 ± 5% RH.



Fecundity of *B. phoenicis* on *C. sinensis* at 30 ± 2°C & 70 ± 5% RH.



Fecundity of *B. phoenicis* on *C. sinensis* at 35 ± 2°C & 65 ± 5% RH.

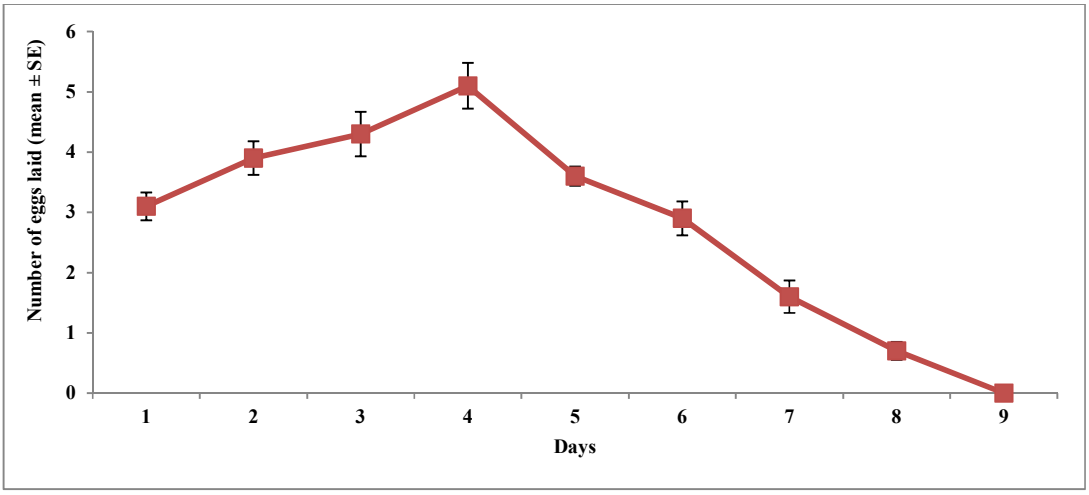
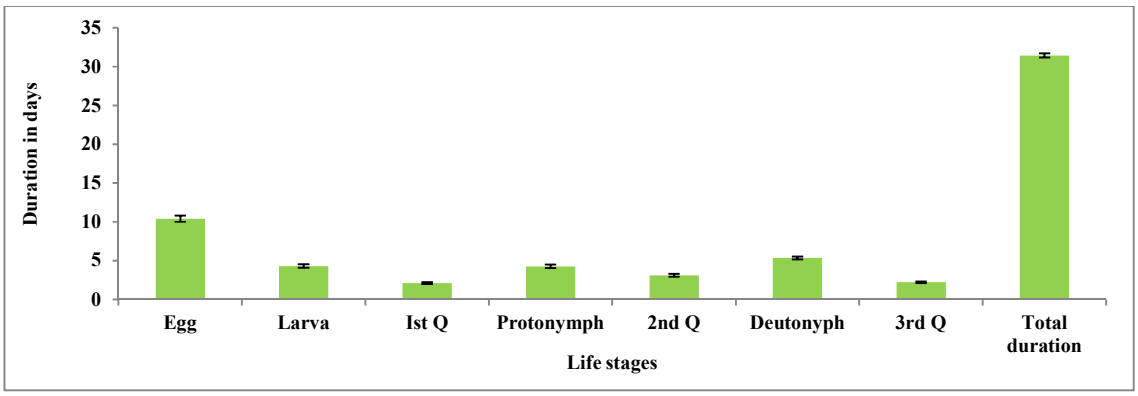
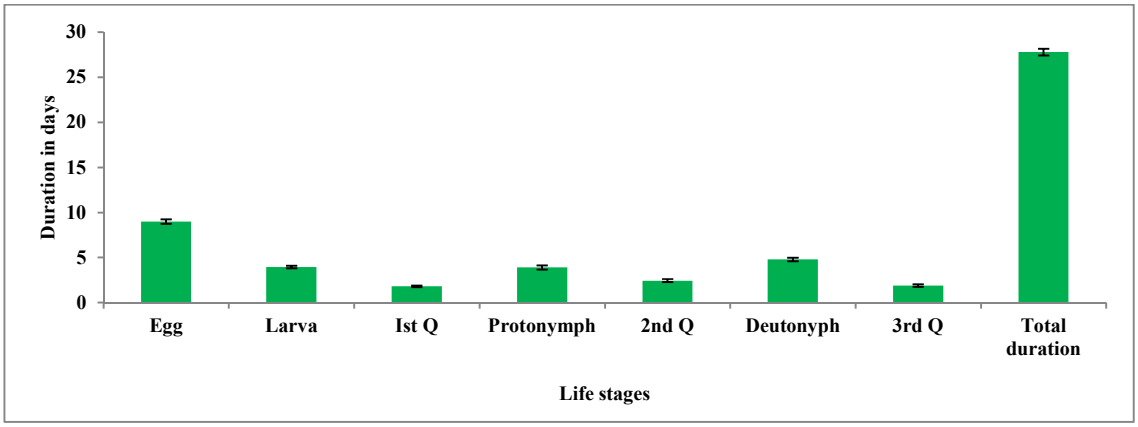


Plate 24

Duration (in days) of development of *B.phoenicis* on *C.sinensis* at 25 ± 2°C & 80 ± 5% RH.



Duration (in days) of development of *B.phoenicis* on *C.sinensis* at 30 ± 2°C & 70 ± 5% RH.



Duration (in days) of development of *B.phoenicis* on *C.sinensis* at 35 ± 2°C & 65 ± 5% RH.

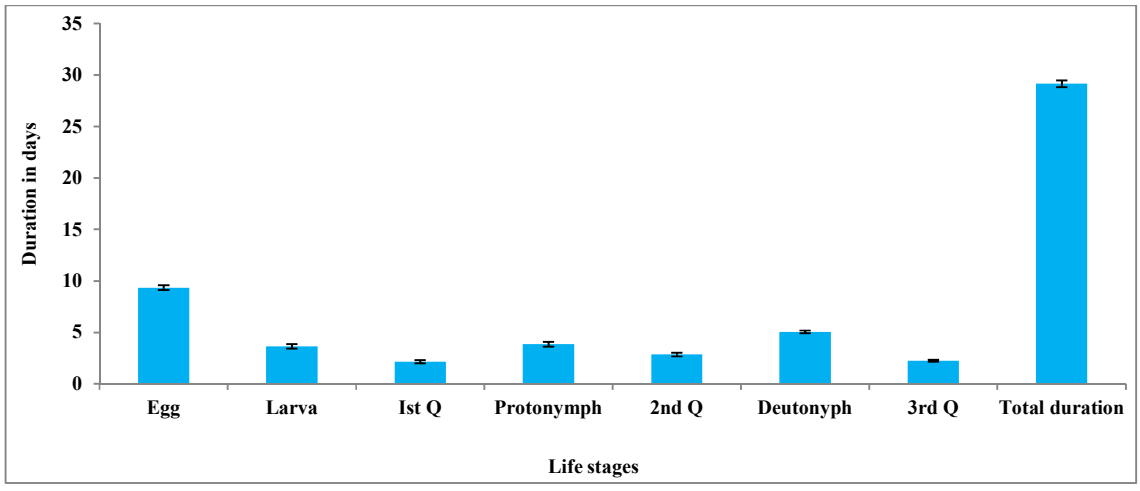


Plate 26

Comparative histogram showing duration of life stages of *B.phoenicis* under different temperature-humidity conditions on Tea

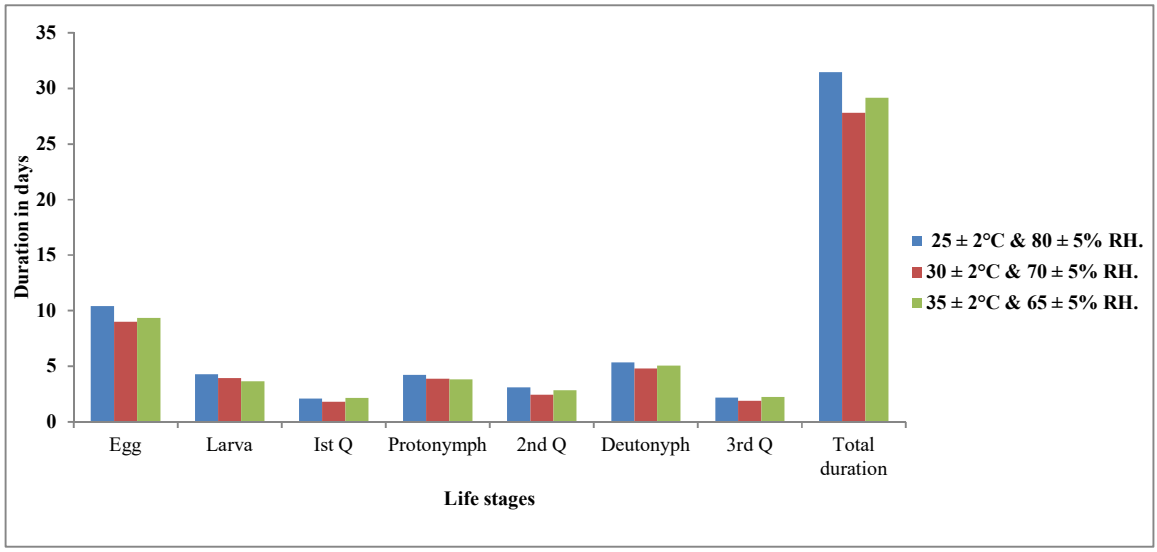
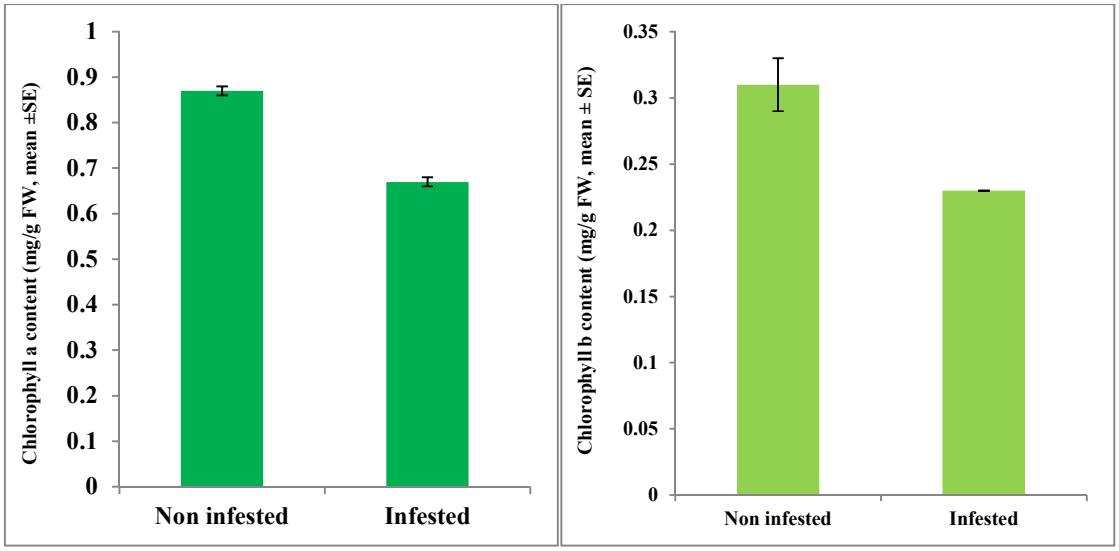


Plate 30

Quantitative loss in chlorophyll content (mg/g tissue) of *C. sinensis* leaves due to infestation by *A.theae*



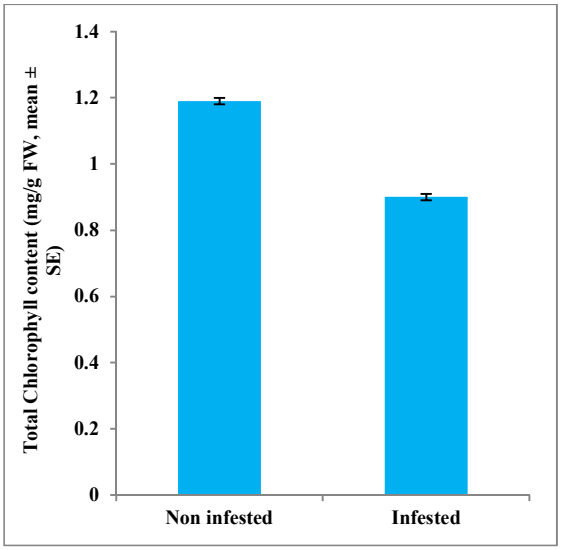
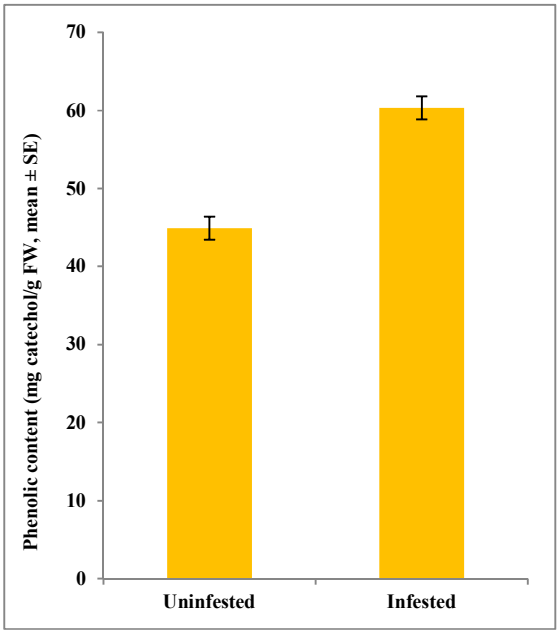


Plate 31

Quantitative difference in phenolic content (mg/g) of *C. sinensis* leaves due to infestation by *A.theae*



Quantitative difference in proline content (mg/g) of *C. sinensis* leaves due to infestation by *A.theae*

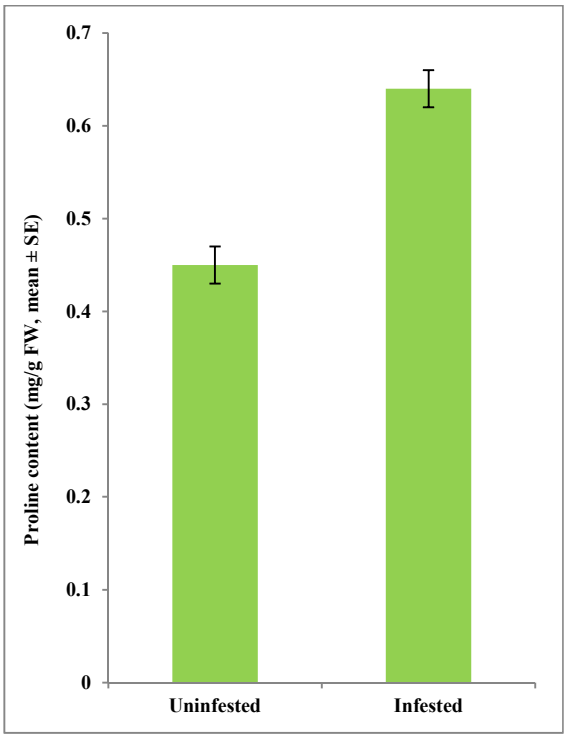
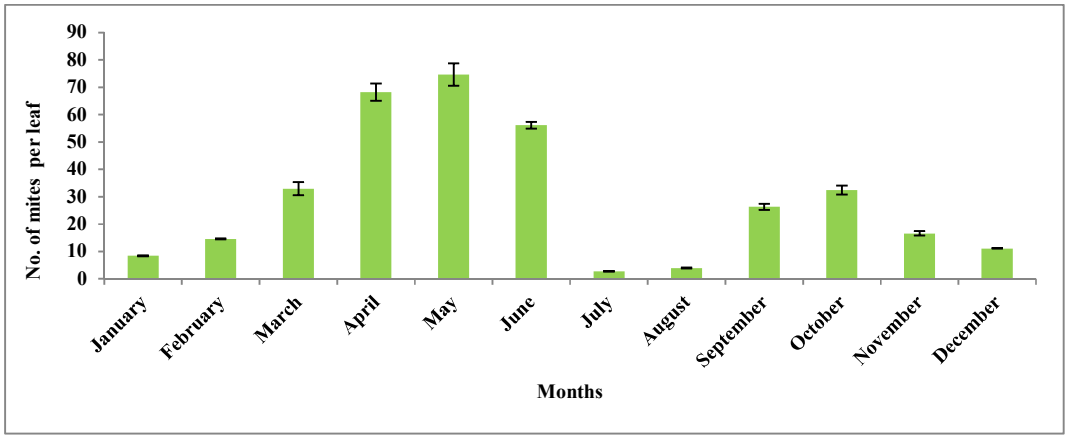
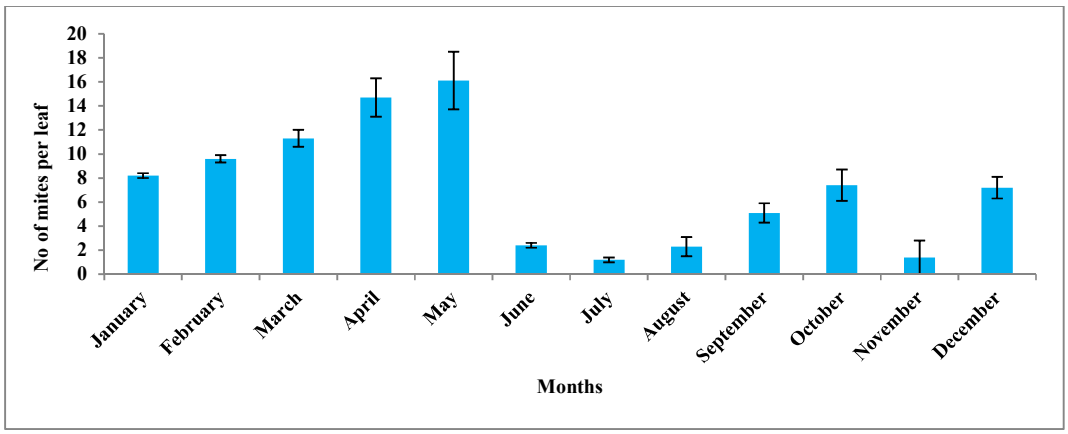


Plate 4

Seasonal abundance of *O. coffeae* on tea leaves in 2011 at monthly interval.



Seasonal abundance of *B. phoenicis* on tea leaves in 2011 at monthly interval



Seasonal abundance of *A. theae* on tea leaves in 2011 at monthly interval

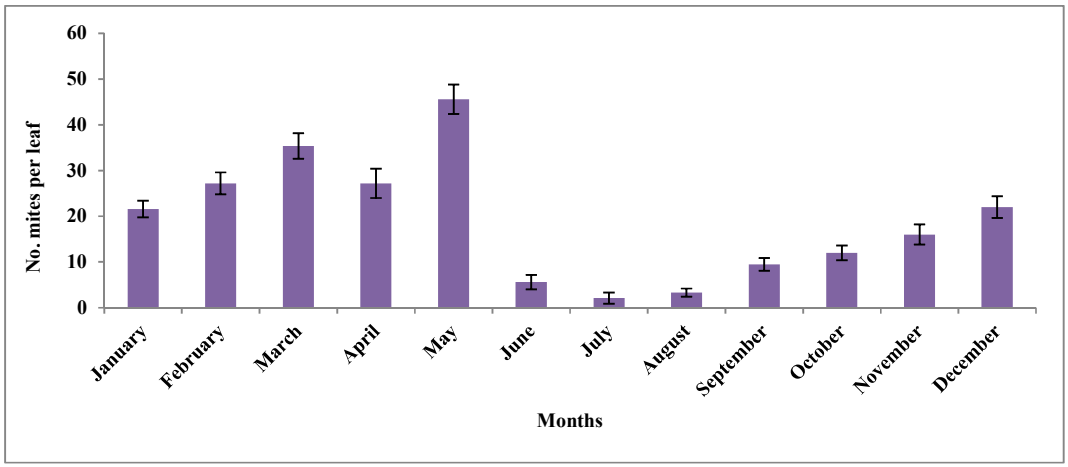


Plate 10

Duration (in days) of pre-oviposition, oviposition and post- oviposition periods of *Oligonychus coffeae* on *C.sinensis* at different temperature - humidity conditions

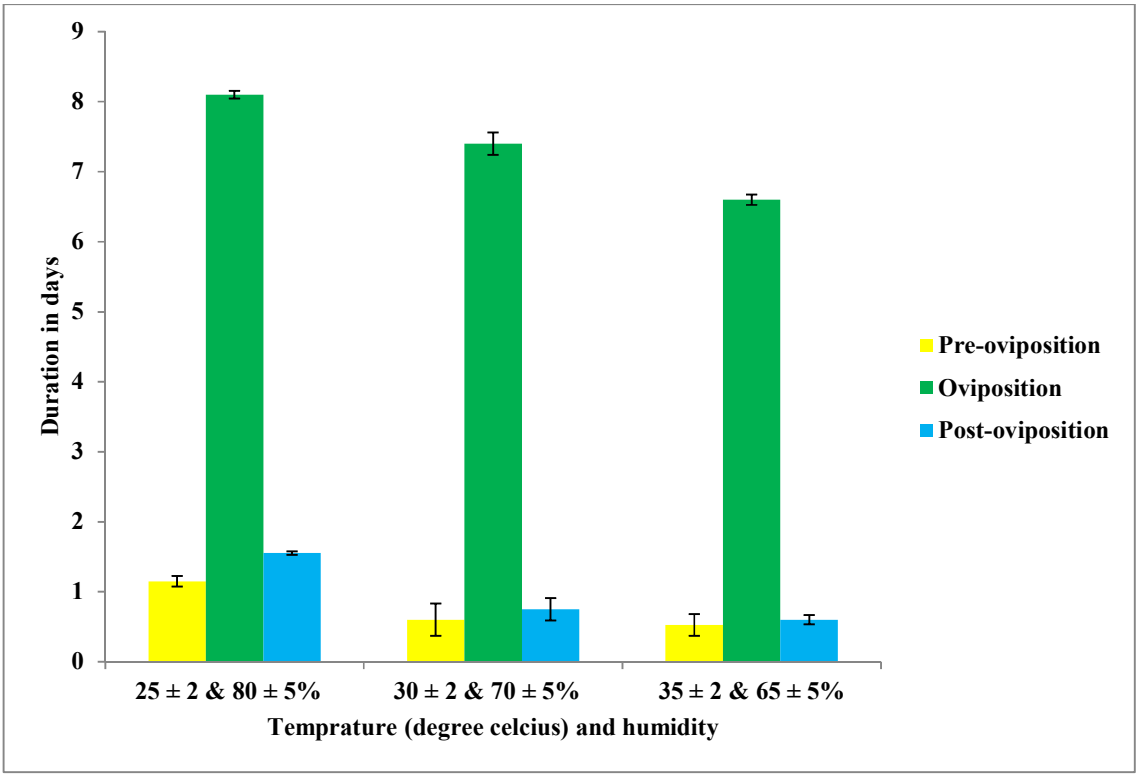
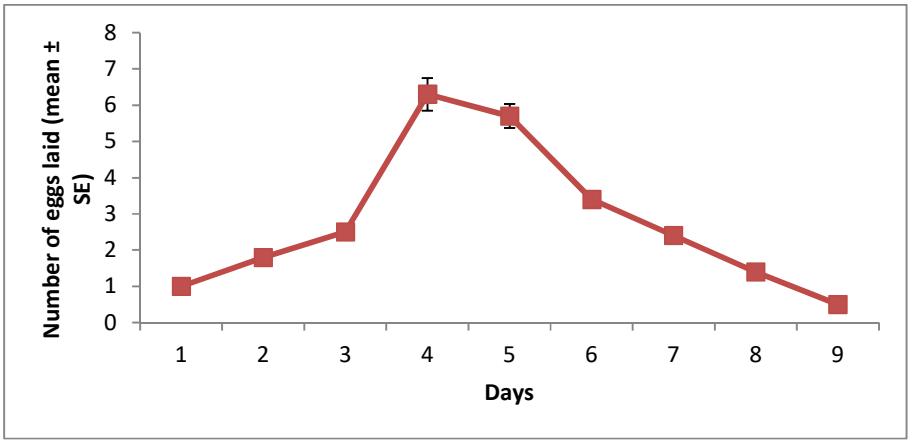
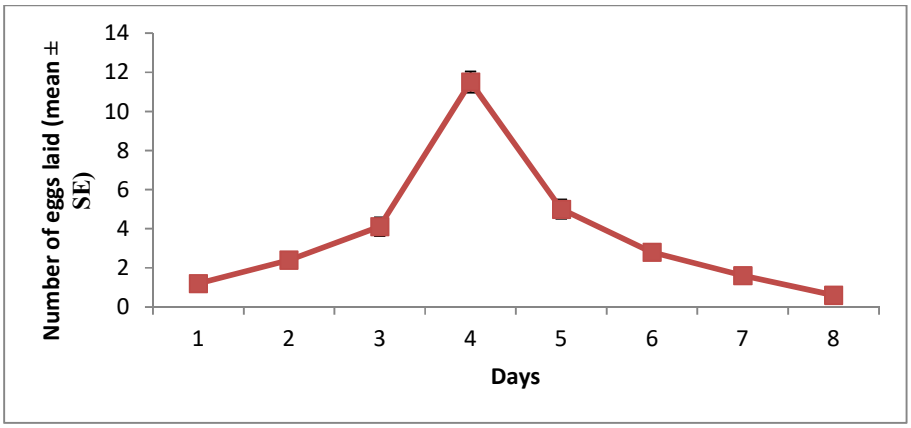


Plate 11

Fecundity of *O.coffeae* on *C.sinensis* at 25 ± 2°C & 80 ± 5% RH.



Fecundity and longevity of *O.coffeae* on *C.sinensis* at 30 ± 2°C & 70 ± 5% RH.



Fecundity and longevity of *O.coffeae* on *C.sinensis* at 35 ± 2°C & 65 ± 5% RH.

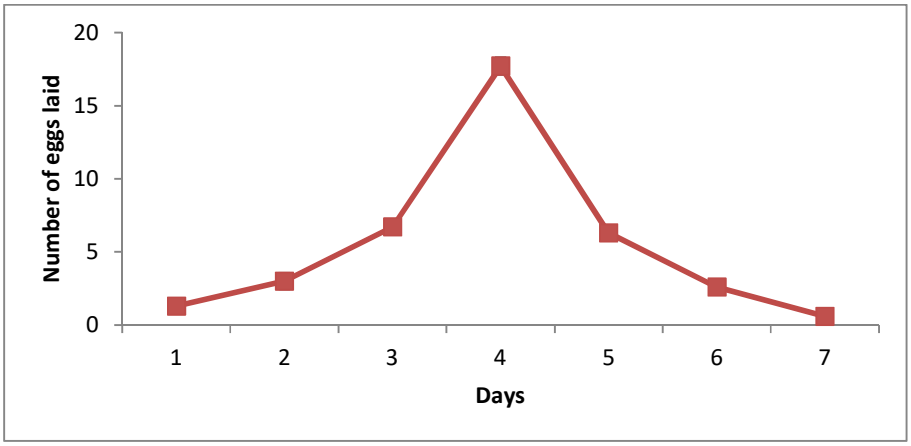
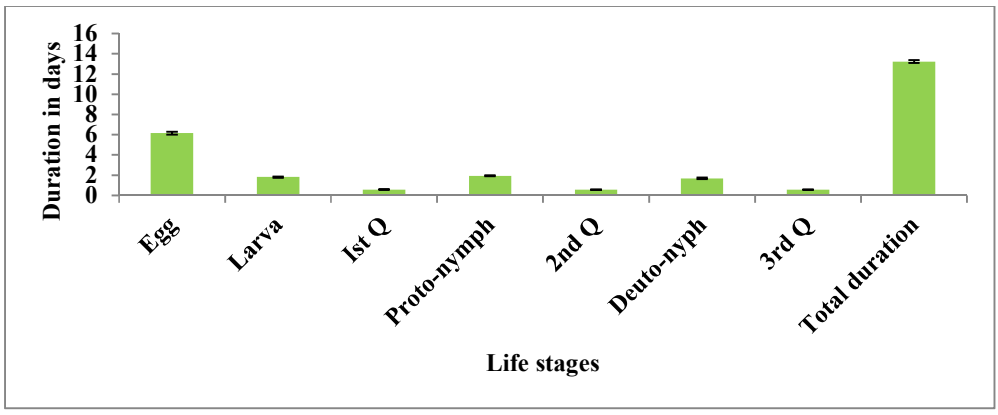
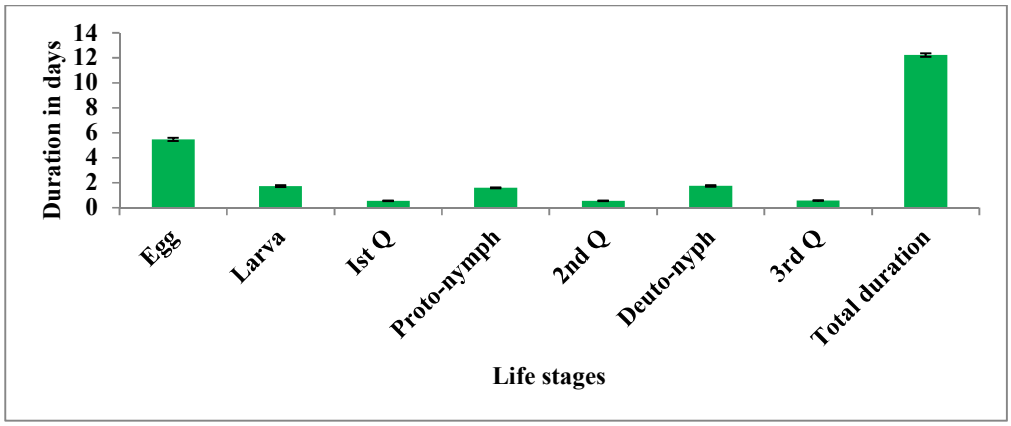


Plate 12

Duration (in days) of development of *O.coffeae on C.sinensis* at 25 ± 2ºC & 80 ± 5% RH.



Duration (in days) of development of *O.coffeae on C.sinensis* at 30 ± 2ºC & 70 ± 5% RH.



Duration (in days) of development of *O.coffeae on C.sinensis* at 35 ± 2ºC & 65 ± 5% RH.

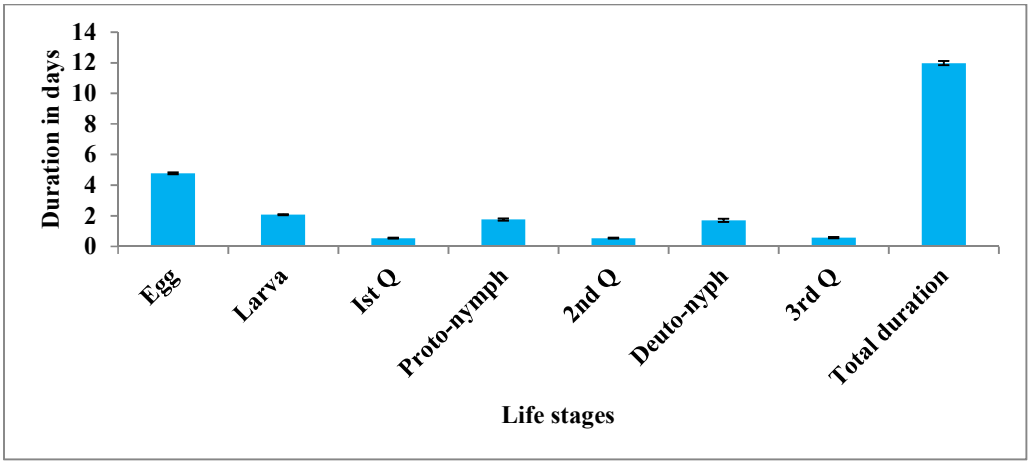


Plate 15

Comparative histogram showing duration of life stages of *O.coffeae* under different temperature-humidity conditions on Tea

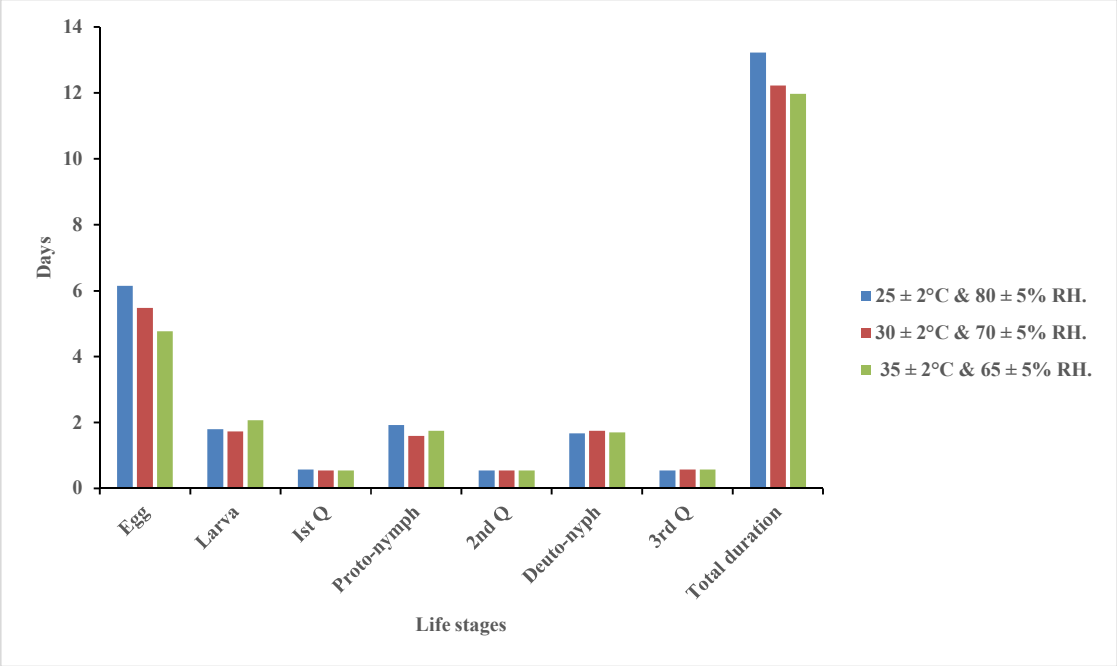
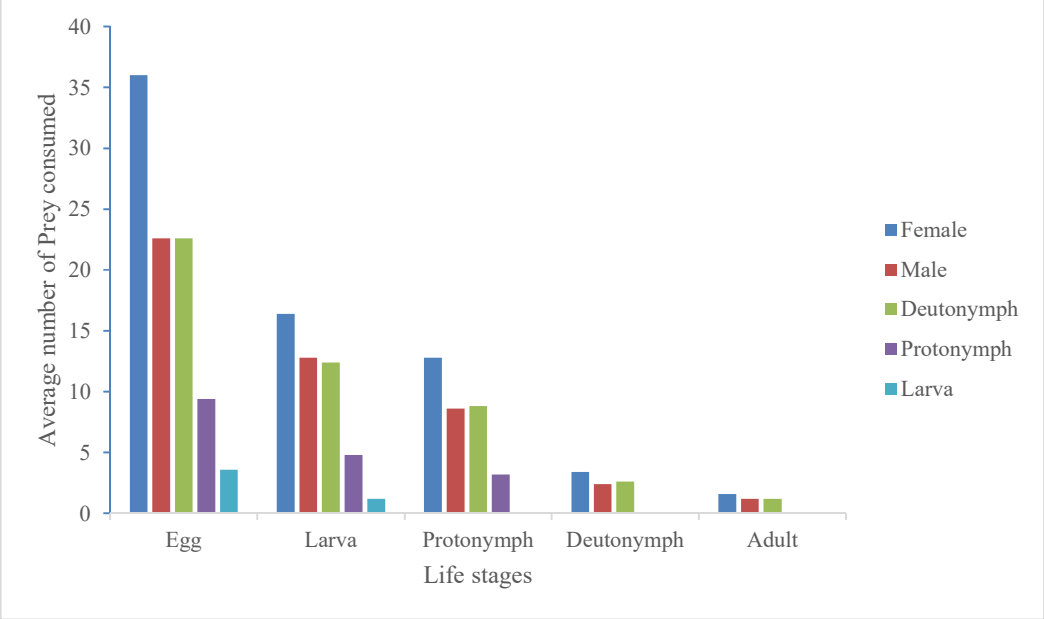


Plate 43

Average number of different stages of prey, *O.coffeae* consumed/killed by different stages of the *A.largoensis*



Percentage consumption of different stages of *A. largoensis* on different stages of *O. coffeae* in 24 hours at a temperature of 30 ± 2ºC and 70 ± 2% RH.

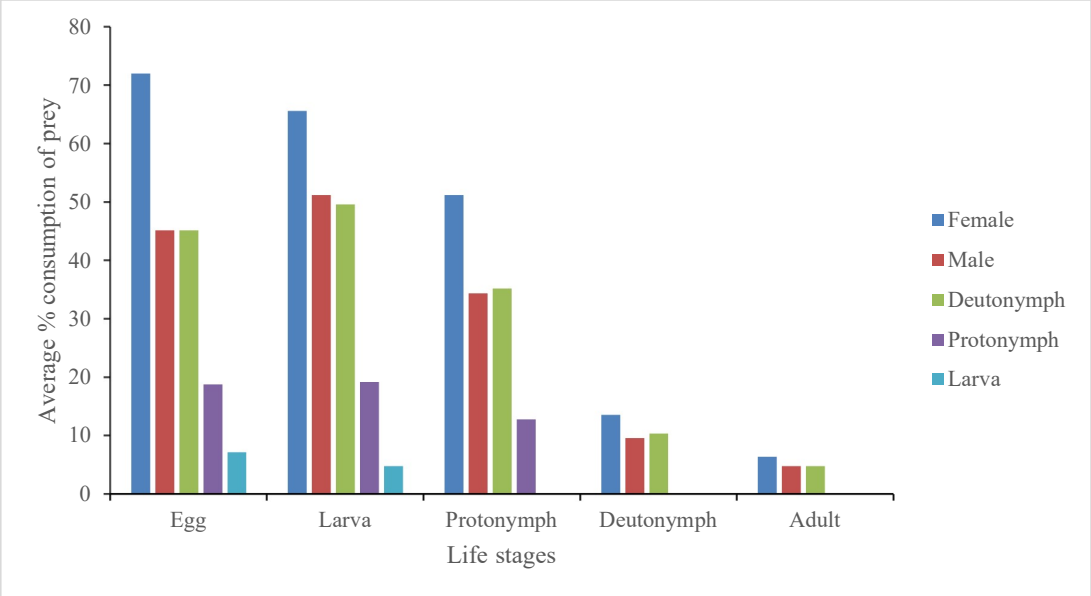
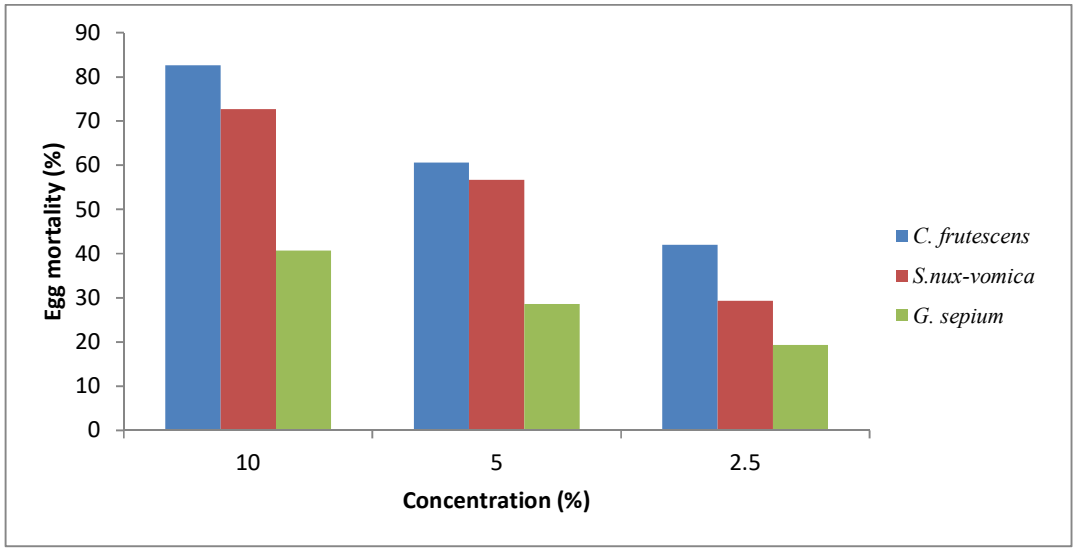


Plate 40

Ovicidal activity of aqueous plant extracts on *O.coffeae* under laboratory condition



Acaricidal activity of aqueous plant extracts on adult *O. coffeae* after 72 hours of treatment under laboratory conditions.