BIOLOGICAL STUDIES ON SOME INJURIOUS TENUIPALPID MITES (ACARI: TENUIPALPIDAE) INFESTING SELECTED FRUIT AND PLANTATION CROPS OF KERALA

Thesis submitted to
the faculty of science, University of Calicut
For the Award of the Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

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October 2015

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CERTIFICATE

This is to certify that the thesis titled **"BIOLOGICAL STUDIES ON SOME INJURIOUS TENUIPALPID MITES (ACARI: TENUIPALPIDAE) INFESTING SELECTED FRUIT AND PLANTATION CROPS OF KERALA"** is an authentic record of the work carried out by **Ms. PRABHEENA P.** 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.

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DECLARATION

I do hereby declare that this thesis titled **"BIOLOGICAL STUDIES ON SOME INJURIOUS TENUIPALPID MITES (ACARI: TENUIPALPIDAE) INFESTING SELECTED FRUIT AND PLANTATION CROPS OF 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.

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ACKNOWLEDGEMENTS

With great pleasure, I express my heartfelt gratefulness and indebtedness to my supervising teacher **Dr. N. Ramani**, Professor, Department of Zoology, University of Calicut for her constant interest; encouragement and input have had a significant impact on the final structure of this work. Her dedicated professionalism, indefatigable efforts and cheerful cooperation are without parallel. She did whatever was required, for the successful completion of the endeavour. She has been instrumental in guiding the many changes instituted with this work and in bringing this work to fruition in a timely manner.

I have immense pleasure in recording my deep sense of gratitude to **Dr. M. Nasser**, Professor and Head, Department of Zoology, University of Calicut, for providing all facilities to carry out this investigation. I am also thankful to **Dr. K.V. Lazar** and **Dr. V.M. Kannan**, Former Heads of the Department of Zoology, University of Calicut for their support for the entire period of my studies.

The am grateful to **Dr. Mohanasundaram**, Professor (Rtd.), Department of Agricultural Entomology, Tamilnadu Agricultural University, Coimbatore for his support in identification of the pest mite affecting areca nut and for his valuable suggestions to complete this work.

I offer my sincerest words of thanks to **Dr. Jose T Puthur**, Associate Professor, Department of Botany, University of Calicut and **Dr. C.D. Sebastian**, Assistant Professor, Deptartment of Zoology, University of Calicut for providing their Lab facility to complete my work.

I owe a debt of gratitude to many colleagues and friends, especially **Dr. K. Mashhoor, Dr. N. Sajitha, Ms. Anitha, Mr. Syamjith, Mr. V.P. Akhilesh, Mr. Jaya**

Krishnan, Mrs. Vibija, Mrs. Anjana, Mrs. Nasreen, Ms. Nithinya and **Ms. Saritha** who have liberally shared their insights and expertise and have helped to create an environment where learning is fun, a motif that I have woven into this work. I offer my thanks to, for their cooperation, professionalism, good humour and unfailing support.

I am very much thankful to **Mr. Bijeesh, Mrs. Limmna** and **Mrs. Anju** my colleagues of Pantheerankave Higher Secondary School for their co-operation and support throughout my study.

I am also thankful to my husband **Mahesh Edakoth** whose companionship and care have unfailingly helped me to refresh my spirit throughout these years. I am grateful for his patience, tolerance, immense help and moral support throughout the study.

Finally, my parents, Brother, Sister, Son and Daughter deserve special mention, for their love, support and goodwill, upon which I have been able to rely in difficult times. I cannot finish without noting the support of family for their interest and words of encouragement; for their calls, messages and enduring support; whose love and support for one another never cease to amaze; at whose side I can find no greater happiness.

I thank all those who have challenged me and helped me think through and clarify my ideas.

I am deeply indebted to the God Almighty for the blessing, showered upon me.

Prabheena P.

Dedicated To

My Guide and Family

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CHAPTER I

INTRODUCTION

INTRODUCTION

Mites and ticks (Acari) constitute the most diverse group of arachnids and they are relatively less known than the other groups of arthropods. Among the Acari, mites are the most diverse representatives of a very old lineage of the phylum Arthropoda, subphylum Chelicerata, subclass Acari and they comprise one of the most assorted groups. The diversity in the acarine morphology is highly reflected in the ecology, reproduction and ethology of mites and which help them to inhabit successfully in all available habitats on earth. Along with ecological and taxonomic diversity, most of the mite species also show high diversity in structure with modified mouth parts for specialized adaptations like elongated attenuated chelicerae for sucking plant or animal fluids in parasitic and very heavy robust chewing mouth parts to feed fungi or dead plant materials.

Even though mites are microscopic organisms, the study of mites, the so called Acarology has gained much attention due to its importance in the various fields such as medical, agricultural, veterinary and forensic fields. It is generally believed that Acarology is about 100 years delayed when compared to the discipline of Entomology. More than 48, 200 species of mites have been described so far, which make up only 5-10% of the estimated number of 0.5-1 million existing species.

The subclass Acari comprises two super orders *viz*. Parasitiformes and Acariformes. Of these Acariformes comprises two orders such as Trombidiformes and Sarcoptiformes. Plant parasitic mites categorised as the false spider mites, spider mites and eriophyid mites are present in the suborder Prostigmata of order Trombidiformes. These exclusively phytopahgous mites have particular mouthparts to nourish on the higher plants vascular tissues and they induce serious losses to agriculture and hence are recognized as economically important pests. Most important taxa of phytophagous mites are members of two superfamilies *viz.* Eriophyoidea and Tetranychoidea and the latter contains two families namely Tetranychidae and Tenuipalpidae.

The family Tenuipalpidae on which the present work is focussed represents an important group of phytophagous Acari which feed voraciously by sucking the cell sap of their host plants and inducing various types of abnormalities like chlorosis, yellowing, necrosis, leaf rolling, blister formation, stunted growth, gall formation etc. Apart from direct damage, many species are known to act as vectors of plant viral diseases, causing more potential loss to growers. The flat mites or false spider mites are found distributed in tropical and subtropical regions with about 1100 species described under more than 35 genera (Mesa *et al.,* 2009; Beard *et al.,* 2012). Genera like *Brevipalpus*, *Tenuipalpus* and *Raoiella* along with a few other genera have been noted as important pests of economic plants, largely on

ornamental plants and tropical fruit crops and they play significant roles in plant virus transmission also.

The false spider mites are as well known as flat mites because of the majority species are dorsoventrally flattened and they are slow-moving. The mites of this family are usually found distributed on the lower plane of the leaves, close to the midrib or veins. Some species nourish on the bark whereas others survive in flower buds, in galls or below leaf sheaths. The family Tenuipalpidae consists of three subfamilies viz. Tegopalpinae, Brevipalpinae and Tenuipalpinae. *Brevipalpus* and *Tenuipalpus* are recognized as the two largest genera of false spider mites which include many economic species.

Species of *Brevipalpus* frequently feed on lower leaf plane and aggregate next to the mid rib or main lateral veins and they inject toxic saliva into bud tissues, fruits, stems and leaves of their host plants. *B. phoenicis* has been observed to feed on the upper leaf face of orchids (Childers *et al.,* 2003). Their mouthparts are long, relative to their body size. The feeding damage induced by *Brevipalpus* mites to citrus fruit is mainly prevalent on inside fruits and the damage to the fruit usually occurs in the lower side of tree canopy, below two meters. Fruit lesions initially become visible as very slight yellowish circular spots in depressions on the fruit surfaces of grapefruit or oranges. The lesions due to mite damage gradually develop a middle brown

necrotic area or spot and ultimately become darker with a corky texture and the brown spots are irregular in shape.

B. lewisi feeds on the nut cluster petioles, stems and nuts of pistachios. Dark, roughened and irregular scab-like blotches form on the surface where the mites aggregate and feed along the edges of damaged tissue and they are most abundant in late July and early August on pistachio in California. *B. phoenicis* is considered as a serious pest of tea in Indonesia (Oomen, 1982). The mite lives on mature or maintenance leaves of tea bushes. *B. phoenicis* feeds on the lower leaf surface from the petiole and leaf base, along the midrib and edges of the leaf. Severe infestations of *B. phoenicis* lead to nearly complete defoliation of the maintenance leaves followed by reduced yields.

Major threat related to *Brevipalpus* is their capacity to vectoring a virus borne disease termed leprosis (Kitajima *et al.,* 1996). Leprosis is a severe disease on citrus in Brazil, Argentina, Paraguay, Venezuela, Colombia, Uruguay and Panama (Childers *et al.,* 2001; Dominguez *et al.,* 2001). *B. phoenicis* has been proved to serve as vector for Citrus leprosis virus C (CiLV-C) and the disease produces localized chlorotic lesions on the fruit, leaves and twigs that do not result in systemic infections. Differences in chlorotic patterns occur in different citrus varieties in Brazil and death of a twig or branch results when they become girdled by individual lesions. Defoliation, Premature fruit drop and death of the twigs can occur with

devastating results and CiLV-C can kill a tree within three years if the mite vector is not controlled. This *Brevipalpus* borne CiLV-C is one of the most serious emerging exotic diseases, threatening sweet orange production within the United States, the Caribbean islands and potentially other citrus producing countries in Africa, Asia, Australasia and Europe. Citrus species, especially oranges can be infected by citrus leprosis viruses.

B. phoenicis is a known vector of passion fruit green spot virus also and during severe outbreaks, the entire orchards of a few hectares have been destroyed. Considerable leaf and fruit drops have been were reported to be associated with high populations of *B. phoenicis*. Mature yellow fruits show characteristic green spotting along with patches of green spotting on the leaves and the most serious damage results from necrotic lesions that girdle the stems and kill the plants. *B. phoenicis* is the known vector of coffee ringspot virus which induce prominent, localized ringspot lesions on both leaves and berries, leading to significant leaf and fruit drop with accompanying reduced coffee berry yields. In addition, *B. phoenicis* and *B. obovatus* have been identified as vectors of *Cestrum* ringspot virus which stimulate the development of chlorotic ringspots on the leaves. Generally *B. obovatus, B. phoenicis* and *B. californicus* constitute the major economically significant species included under the genus *Brevipalpus*.

The red palm mite (RPM), *Raoiella indica* causes severe damage to palm trees of the family Arecaceae, especially to coconut (*Cocos nucifera* L.), and also to bananas (Musaceae) and some other plant families (Flechtmann & Etienne, 2004, Etienne & Flechtmann, 2006). The pest was first reported in India from Coimbatore, Tamil Nadu during 1924. The RPM usually feeds on the underside of palm fronds of various host plants belonging to the orders Arecales and Zingiberales.

R. indica is a polyphagous species that can develop in to very high populations and cause significant damage to various plant species. Young coconut palms are highly susceptible and become most severely injured. *R. indica* lives on lower surfaces of coconut leaves where the eggs are deposited in colonies, ranging in number from 110 to 330, with a higher number on the lower leaves. It is also the first mite species observed, feeding through the stomata of its host plants (Ochoa *et al.,* 2011). Through this specialized feeding habit, *R. indica* interferes with the photosynthesis and respiration processes of their hosts. However, the damage caused by this species to most of its host plants has not yet been characterised.

More than 22 species have been reported in the genus *Dolichotetranychus,* of which serious damages have been reported in South India by two species *viz*. *D. floridanus* and *D. cocos*. *D. cocos* infest the coconut and which inhabits beneath the perianth of coconut and the mite

infested area become dried and cracked. The false spider mite, *D. floridanus* is reported to be monospecific and is proved extremely difficult to eradicate once it is established. This small mite is reported as a pest of pineapples in Florida, Cuba, Puerto Rico, Panama, Honduras, Mexico, Hawaii, Phillipine Islands, Japan, Java, India and Australia. The adult mite is characteristically bright orange in colour and measures with 0.3 mm in length and approximately one third in width.

D. floridanus exhibits no specific preference to a particular variety of pineapple and it affects all varieties and clones equally. It inflicts tissue damage to both leaf and fruit components of the plant as well as planting material. Damage of epidermal tissue leads to drying and cracking of affected region and often permits the entry of fungal and bacterial plant pathogens, leading to tissue rot. The damage caused by this species of false spider mite results in severe alterations to the normal crop cycle of infested plants and underdevelopment of the crop thereby leading to uneven crop establishment and extended harvesting periods. This is further exacerbated in ratoon crops and ultimately leads to higher production costs.

The members of genus *Tenuipalpus* represent another important group under the family of Tenuipalpidae and many species of this genus cause severe damage to economically important plants. The slow-moving species, *T. heveae* has been reported as a potential pest of rubber trees. Infestations by

T. heveae in crops lead to intense defoliation, and therefore probable reduction of latex yield. This species is highly resistant to several agrochemicals often used for mite pest control. *T. pernicis* is a dominant mite species found on guava and its infestation leads to significant depletion of important organic mineral and inorganic compounds in the guava leaves

In the biodiversity scenario, Kerala is home to nearly 10,035 plant species thereby constituting 22 % of the total plant diversity found in India and which includes many fruits crops, plantation crops and other economic trees. Agriculture is one of the major sectors of the economy of the state and it contributes around 50% of the gross income of the state. Many species of tenuipalpid mites cause severe damage to fruit and plantation crops of Kerala. However, despite of the prevalence and intensity of tenuipalpid mite infestation on the crop plants of Kerala, studies on these mites are still in infant stage, especially in South India. Considering this aspect, the present study was undertaken to gather knowledge on the most common, dominant and injurious species of tenuipalpid mites associated with selected fruit and plantation crops of Kerala and also to analyse the feeding damage induced by selected species on their respective host plants. Attention was also focussed during the present study to study the developmental parameters of selected injurious species and also to find out the impact of different temperature – humidity parameters on the postembryonic development.

In many instances, lack of information on the correct identity of the pest mites, their biology, host range, distribution pattern and influence on biochemical constituents and photosynthetic pigments of plants cause great ecological problems in formulating effective management practices. Hence this study will help to design a better strategy for Integrated Pest Management (IPM) to control tenuipalpid mites.

CHAPTER II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The family Tenuipalpidae, commonly known as the flat mites or the false spider mites, enjoys worldwide distribution with about 1100 species described under more than 35 genera. Though phytophagous in habit, most tenuipalpids do not cause any discernible injury to their hosts. However, one or more species under the genera *Brevipalpus*, *Cenopalpus*, *Dolichotetranychus*, *Raoiella* and *Tenuipalpus* are recognized as major pests of various economic crops. They feed directly from the epidermal cells and sub epidermal tissue like mesodermal cells of stems, leaves and fruits of their host plants. Due to the damaging effects induced on host plants the economic significance of these mites has gained considerable importance within the last few decades. In the present review, an attempt has been made to gather and present all available data on the nature and extend of infestation, injurious status, feeding and breeding parameters of these mites.

The family Tenuipalpidae was first described by Berlese in 1913. The red palm mite, *Raoiella indica* as a serious pest of coconut palm in many countries in the tropics of the Eastern and Western hemispheres was first described by Hirst (1924) from the Coimbatore State of Tamil Nadu, in Southern India. *B. phoenicis* was first described by Geijskes (1939) on *Phoenix* species in Holland. The association of mites of the genus *Brevipalpus* with citrus leprosis in Florida was established by Knorr (1950).

The feeding injury induced by *B. lewisi* on walnut leaves leading to the development of a coppery appearance with little or no webbing was brought to light by Michelbacher (1956) and he could observe marked defoliation and large numbers of exuviae on the dropped leaves. Mite infested leaves also disclosed high populations of *B. lewisi,* in the southeast quadrant of the tree canopy, especially around the lower skirt area of the tree in California. Wettable sulphur as an efficient acaricide against the foliage mite, *R. indica* was demonstrated through preliminary tests by Bhat *et al.* (1957), and Puttarudriah and Channabasavanna (1957).

Moutia (1958) reported *Amblyseius caudatus* as the main predator of *R. indica* infesting coconut palms in Mauritius and this species was found in abundance during the period of September to March, except when heavy rains occurred during November and January. A decline of mite population was observed from April and which continued through August. Knorr (1968) demonstrated that *B. obovatus* collected from *Bidens pilosa* was able to induce citrus leprosis symptoms and that *B. californicus* was the vector of leprosis in Florida. *B. phoenicis* as a severe pest of tea in India, especially of the Chinese hybrid varieties was reported by Banerjee (1971). The lower surface of tea leaves of all age groups showed mite infestation similar to tender twigs and branches, and occasionally the auxillary buds were also found attacked. The involvement of a virus in the causation of citrus leprosis was found by Kitajima *et al.* (1972) in Brazil and the authors could identify

nuclear (CiLV-N) virus particles found to be associated with sweet orange leaf lesions that were collected from the field.

Jeppson *et al.* (1975) reported that *B. phoenicis* deposited eggs in cracks, crevices, or other protected niches on citrus fruit surfaces and the eggs were deposited in clusters by more than one female. The association of three species of tenuipalpid mites viz. *B. phoenicis B. californicus* and *Tenuipalpus pacificus* with orchids of Brazil was revealed by Flechtmann (1976). Biological studies of *B. phoenicis* on two different host plants at 21.20^{o}C and 26.60^{o}C were performed by Lal (1979) and the species was found to complete its life cycle with an average of 20.2 and 29.66 days at 21.2^{o}C and 26.6^{0}C on *Orozylum indicum* and 28.34 and 20.20 days on *Clerodendron siphonanthus* respectively. Dager and Singh (1979) reported *B. phoenicis* as a potential biological control agent of the weed, *Parthenium hysterophorous*. While surveying the phytophagous mites of Varanasi, Lakshman and Mukharji (1979) observed high infestation of *B. phoenicis* on medicinal plants such as *C.siphonanthus* and *Bauhinia variegata*.

A revision of the genus *Tenuipalpus* in the Afro tropical Region was made by Meyer (1979). The efficiency of various pesticides for the control of *B. phoenicis* was tested by Mariconi *et al*. (1979) on orange trees and they were not able to get any satisfactory results. The seasonal history of three species of phytophagous mites at Varanasi was studied by Lal and Mukharji

(1980) and they pointed out that climatic factor like temperature, rainfall and humidity could influence the population build up of *B. phoenicis* and that the most favourable conditions for the species were low temperature with moderate humidity.

Detailed study made by Pinacker *et al*. (1980) on the G banding pattern and internal difference during anaphase in *B. phoenicis* indicated that the females were haploid with n=2 and it was concluded that the mode of reproduction in the species was haploid female parthenogenesis. Studies of Helle *et al*. (1980) on the chromosome numbers and types of parthenogenesis in 19 species belonging to 6 genera of tenuipalpid mites revealed the occurrence of thelytokous parthenogenesis with female haploidy in *B. phoenicis* and *B. obovatus*. Influence of climatic and biotic factors on the population density of *B. lewisi* was studied by Buchman *et al*. (1980) which revealed that 28^0C and 35% RH were the optimum temperature-humidity parameters to support the maximum increase in population of the species.

Studies of Srivastava *et al*. (1980) on the chemical control of *B. phoenicis* in commercial citrus orchards of Himachal Pradesh revealed that kelthane and omite could eradicate the mites, though symptoms of infestation persisted. Crocker *et al.* (1981) reported that the false spider mite, *Aegyptobia nomus* induced 'witches brooming' effect on *Buchloe dactyloides* following a hot, dry period in Texas. Presence of the species was recorded on *Distichlis*

stricta and *Bouteloua gracilis* also in Arizona, Florida, North Dakota and Utah. Morphological description along with preliminary biological data of *Tenuipalpus inophylli* were provided by Gutierrez and Bolland (1981) and the authors reported the occurrence of thelytokous parthenogenesis in this species.

The population dynamics of scarlet mite on tea bushes in Indonesia were studied by Oomen (1982) and he pointed out that this mite affected the production of tea .This study revealed that *B. phoenicis* fed on the underside of the tea leaves, on petioles, and non-lignified areas of twigs and moved to young leaves or upper leaf surfaces when the population increased. Feeding damage resulted in petiole necrosis followed by defoliation, leading to excessive thinning of leaf canopies. Growth of mosses and lichens became established on the damaged portions, indicating that the tea hedges or bushes were in poor condition.

Myazaki *et al*. (1983) in Brazil studied the behaviour of *B. phoenicis* on exposure to some acaricides and found that compounds like binapacryl, bromopropylate, chlorobenzilate and dicofol were highly efficient in controlling the population of *B. phoenicis*. Two new species of *Brevipalpus* viz. *B. cucurbitae* and *B. euphorbiaceae* were described by Mohanasundaram (1983) from Tamil Nadu, India.

Host specificity in species of tenuipalpid mites was mentioned by Ghai and Shenhmar (1984) in the review of the world fauna of Tenuipalpidae. The authors found that some species were associated with particular hosts while others were polyphagous exhibiting wide host range. However, generally tenuipalpids were considered to be less host-specific when compared to eriophyid mites. Arias and Nieto (1985) reported that the 'scab mite', *B. lewisi* overwintered on grape vines or in soil litter in Spain. While in the spring, these mites were found feeding on all green tissues and separated inflorescences. Goyal *et al*. (1985) studied the influence of different temperatures like 15,20,25,30 and 35^{o}C + 1^{o}C on the rate of development of *B. obovatus* by rearing it on the leaf of golden rod and found 25^{o}C as the most suitable one. Extensive studies of Channabasavanna (1985) on the mite pests infesting various crops in India proved that spider mites, false spider mites and gall mites could induce serious problems to the crops. Sepasgorian and Angew (1985) prepared a major list comprising the world genera and species of tenuipalpid mites which included 23 genera and 584 species.

Baker and Tuttle (1987) reported that tenuipalpid mites were widely distributed and abundant in warmer zones. The presence of *B. essigi* and *B. russulus* was recorded for the first time in New Zealand by Ashley and Manson (1987). The rate of development of *B. phoenicis* on seedless guava at three humidity- temperature parameters like 20, 25 & 30+1^{0}C and 50,70 & 90% RH was traced by Sadana and Kumari (1987a) in India and they

observed 25^0C in combination with 70% RH as the most suitable condition for the rapid development of the species. The same authors (1987b) further conducted studies on the comparative susceptibility of different grapevine cultivars to infestation by *B. phoenicis* and noted that resistant cultivars were more resistant against this mite than the susceptible ones.

Nakano *et al*. (1987) devised an experiment to trace the development of *B. phoenicis* on citrus fruits with and without scab and noted instances of mite population on fruits with scab. While surveying the acarine predators of *B. phoenicis* harbouring in the North eastern India, Borthakur and Das (1987) reported the occurrence of predatory mites of the genera *Agistemus* and *Cunaxa*. Flechtmann (1987) identified *B. phoenicis* on wild and cultivated plants in Ernando de Noronha Island of Brazil. Hatzinikolis (1987) made a revision of the family Tenuipalpidae of Greece and provided keys to the Greek species belonging to the genera *Aegyptobia, Brevipalpus, Cenopalpus, Pentamerisnus* and *Tenuipalpus*. Chiavegato and Mischan (1988) while studying the behaviour of *B. phoenicis* on the fruits of different citrus varieties observed that fruits of Valoncia oranage and Musscot orange were more favourable to development of mites.

New field tests for launching chemical control of the citrus leprosis mite, *B. phoenicis* were devised by Arashiro *et al*. (1988). Incidence of *B. phoenicis* in South Africa was first reported by Meyer and Ueckerman (1988).

The occurrence of *B. californicus* was recorded for the first time on cardamom in Costa Rica by Aguilar and Ochoa (1988). Nine species were described by Ochoa and Salas (1989) under the genus *Brevipalpus* along with data on their food plants in Costa Rica. A comparative analysis of the rate of reproduction in three species of *Brevipalpus* viz. *B. californicus*, *B. obovatus* and *B. phoenicis* infesting citrus fruits was made by Trinidade and Chiavegato (1990) and they observed that *B. phoenicis* had a higher reproductive rate than the other two species.

Incidence of *B. rica* and *T. decus* for the first time in India was reported by Sadana and Sindhu (1990). While making a survey on the phytophagous mites associated with mango crop in Costa Rica, Ochoa *et al*. (1990) noticed *B. phoenicis* as an important inhabitant. Misra *et al*. (1990) observed the infestation of *B. californicus* on brinjal in West Bengal. The host range of *B. phoenicis* was studied by Sadana and Kumari (1990) and the authors reported infestation of the species on 49 species of plants out of the 95 species surveyed.

Impact of various environmental factors on the distribution of *B. californicus* on citrus trees was studied by Halawary (1991). Kumar (1992) added a new plant, *Persimmon* to the existing list of host plants of *B. phoenicis* in Himachal Pradesh. Biological studies on *B. phoenicis* made by Gope and Das (1992) enabled to record the effect of some field management

practices on its seasonal abundance and the authors noticed considerable variation in mite population depending up on changes in season and cultural practices. A new phytophagous species of tenuipalpid mite, *B. nangalensis* was described by Sadana and Kaur (1992) from India. Grewal (1992) recorded seasonal fluctuation in the populations of various mite species including *B. californicus* and *B. phoenicis* infesting brinjal crop in Punjab. Kakoty *et al*. (1992) described the behaviour of *Oligonychus coffeae* and *B. phoenicis* with reference to the most suitable times for spraying acaricides on tea in India.

The behaviour of *B. phoenicis* on citrus was studied by Chiavegato and Kharfan (1993) in Brazil. Grewal (1993) conducted an experiment to analyse the bio-chemical factors present in the plants which were responsible for the development of resistance against *B. phoenicis* and the results of which revealed that plants containing amino acids like tryptophan, tyrosine and hydroxy proline did not support the development of *B. phoenicis*. Iskander *et al*. (1993) evaluated the effect of naturally derived miticides like abamectin and dicofol and three local mineral oils on different developmental stages of two phytophagous mite species, *viz. Eutetranychus orientalis* and *B. californicus*. The authors observed that abamectin and dicofol were highly effective against all developmental stages of both of the species.

Trinidade and Chiavegato (1994) studied the rate of development of *B. californicus*, *B. obovatus* and *B. phoenicis* on Azalea (*Rhododendron* sp.) and found that there was no significant difference in the developmental rates among the three *Brevipalpus* species at 23^0C and 27^0C. While studying the mite fauna infesting on summer vegetables in Punjab, Akbar and Aheer (1994) reported 10 phytophagous species including *B. inermis*, a new species found on tomatoes.

'Phase variation' (behavioral, morphological and physiological variations recorded within species ensuing in many cases of density effects during developmental stage), was reported as an adaptive quality associated with the species complex of *B. phoenicis* by Kennedy (1995). This phenomenon might explain the shortening of the developmental time of the mite under states of high population density. Attempts were made by Moraes *et al*. (1995) to control populations of *B. phoenicis* on oranges in Brazil through application of chemical pesticides and the authors estimated the mite population one day prior to spraying and subsequently on 3,23,26,53 and 72 days after spraying and observed that all the treatments gave effective control.

Sadana and Balpreet (1995) reported the incidence of *B. jambhiri*, on *Citrus jambhiri* from Northern India. An assessment of the population density of *B. phoenicis* on tea in Indonesia was made by Young *et al*. (1995) who provided information on the feeding and damage level of the species.

While studying the mechanical transmission and ultra-structural aspects of citrus leprosis disease, Colariccio *et al*. (1995) reported that non enveloped Rhabdo virus like particles were the causative agent of citrus leprosis. Sadana and Kumari (1995), while studying the influence of host plant leaves like lemon, guava and grapes on the development of *B. phoenicis* noticed that lemon leaves could exert a great influence on the development of the mite. Bozai and Brean (1995) described a new species of *Brevipalpus* viz. *B. tiliae* from Hungary.

Kitajima *et al.* (1996) pointed out that the major significant threat caused by the three *Brevipalpus* species on several different agricultural commodities was due to their direct involvement in vectoring a group of viruses belonging to an unassigned group of Rhabdoviriidae. Demecology of *B. phoenicis* was studied by Kennedy *et al*. (1996) and they provided data on the life and fecundity tables of this species. The association of *B. phoenicis* with ring spot injuries on leaves of *Ligustrum lucidum* in Brazil was observed by Rodrigues and Nogueira (1996). Sudoi *et al*. (1996) conducted studies through field trial application of nitrogenous fertilizers (NPKS 25:5:5:5) on the population build up of *B. phoenicis* on tea. The authors noticed that damage symptoms resulting from mite infestation got declined with increase in application of nitrogenous fertilizers.

The incidence of *Brevipalpus* sp. on weeds of Costa Rica was reported by Vargas *et al*. (1996). While studying the influence of citrus leprosis on the mineral composition of *C. sinensis* leaves, Nogueira *et al*. (1996) observed that leaves of infested plants had lower levels of nitrogen when compared to the uninfested leaves. Jadue *et al*. (1996) carried out observations on the effects of cold storage on the false grape mite, *B. chilensis* and pointed out that cold storage reduced the rate of oviposition in adult mites.

Neena *et al*. (1997) conducted detailed population studies on *B. phoenicis* on citrus lemons in relation to biotic and abiotic factors. Omoto (1998) described the factors affecting the evolution of resistance in *B. phoenicis* against acaricides. Cho *et al*. (1998) assessed the damages caused by *B. russulus* and *B. obovatus* and made a comparative study of the two species, using scanning electron micrographs. Laithy and Fouly (1998) provided an account on the distribution pattern of *B. pulcher* and its associated predatory mites in apple orchards. Domingues and Rodringues (1999) recorded the occurrence of citrus leprosis rhabdovirus and its mite vector, *B. phoenicis* in Brazil. Singh and Singh (1999) conducted a survey on the mites associated with summer vegetables in Manipur. A revision of the biology and behaviour of *B. phoenicis* was made by Raga *et al*. (1999) and they discussed the damage and the measures for its control. Fluctuations in population of *B. phoenicis* were studied by Moraes and Cruz (1999) on citrus

and they noticed that relative humidity and rainfall significantly affected the pest population.

Scarpellini and Santos (1999) studied the effect of acaricides against *B. phoenicis*. New species belonging to the genus *Brevipalpus* were described by Akbar and Khalid (1999) from Pakistan. Randeep Kaur *et al*. (1999) recorded new hosts and new species of tenuipalpid mites infesting deciduous fruit trees in Punjab. Rodrigues and Machado (1999) gave notes on the respiratory apparatus present in the eggs of *B. phoenicis*. The degree of feeding damage on guava fruit caused by *B. phoenicis* was evaluated by Guerere and Gonzalez (2000).

Jalaluddin and Sadakathulla (2000) studied the effect of botanicals, inorganic oils and plant growth regulators on *B. phoenicis*, infesting guava fruit. Albuquerque *et al*. (2000) evaluated the pathogenicity of fungi to *B. phoenicis*. Weeks and Breeuwer (2000) assessed intraspecific variation and genome mapping in mites by performing AFLP finger printing and the authors also studied genetic diversity and population structure of *B. phoenicis*. Effect of a mixture of acaricides like dicofol and fenpyroximate for managing resistance in *B. phoenicis* was evaluated by Alves *et al*. (2000). The predatory activity of *Euseius alatus* and *Iphiseiodes zuluagai* on the developmental stages of *B. phoenicis* was reported by Reis *et al*. (2000a) and they noticed that *I. zulugai* was a more aggressive predator than *E. alatus*.

Reis *et al*. (2000b) made observations on the spatial distribution of *B. phoenicis* on coffee plants and found that the mite preferred lower surface of leaves.Lehmanm and Danzinger (2000) conducted detailed studies on the diseases and pests of tea in Germany and provided an elaborate discussion on integrated pest and disease management of *B. phoenicis*. Possibilities of biological control of *Brevipalpus* sp. on *C. aurantifolia* were explored by Rosas and Sampedro (2000).

The occurrence of populations of *B. phoenicis* which carried the citrus leprosis virus (CiLV) in mandarin was reported by Rodrigues *et al.* (2000) and the authors successfully established transmission of leprosis to mandarins from symptomatic mandarin trees. Childers *et al.* (2001) could record incidence of 10 species of *Brevipalpus* and 5 species of *Tenuipalpus* on citrus worldwide. Fluctuations in the populations of *B. phoenicis* and *E. orientalis* on guava orchards were monitored by Neena and Singla (2001) and it was found that peak population of *B. phoenicis* (n=2.34/ leaf) occurred in April at MT (Maximum Temperature), RH (Relative Humidity), RF (Rain Fall), WV (Wind Velocity) and DL (Day Length) of 22.64^{o}C, 52.39%, 0.32 mm, 4.80 km/h and 12.00 respectively when there was no population of the predator, *A. delhiensis.* Based on the mobile immatures and adult stages of both sexes collected from the orchid, *Arundina graminifolia* De Moraes and Freire (2001) described a new species *viz. orchidofilo* from Brazil. Weeks *et al.*

(2001) found that antibiotics treated females of *B. phoenicis* eliminated feminizing bacteria and produced higher numbers of males.

Rodrigues *et al*. (2001) proposed a strategy to control citrus leprosis disease. While studying the relationship between the coffee quality and infestation by *B. phoenicis*, Ries and Chagas (2001) pointed out that mite infestation could induce a reduction in beverage quality of coffee. The effects of extracts of 17 plant species on the activity of *B. phoenicis* was evaluated by Guirado *et al*. (2001) and the authors found that the extract of *Allium sativum* acted as an antifeedant, while those of *Luffa cylindricai, Hedera helix* and *Datura metel* prevented inoculation of the virus on to the host plant.

Information on host related biology, seasonal abundance and control aspects of *B. obvotus* were provided by Rezk *et al*. (2001). A control strategy for inhibiting the virus vector cycle of *Brevipalpus* sp. and rhabdo virus disease was devised by Childers *et al*. (2001). The authors proposed a six-step programme comprising the use of quarantine, training education, monitoring and tree ravel to prevent spread of citrus leprosis. Chagas *et al*. (2001) supplemented information on several Rhabdo viruses or Rhabdo virus like diseases and their associated mite vectors belonging to the genus *Brevipalpus*.

Prevalence of haploidy in *B. phoenicis* was reviewed by Otto and Jarne (2001) and the authors discussed the significant role of feminizing bacteria of

the genus, *Wolbachia.* Feminization of haploid genetic males of *B. phoenicis* was discussed by Weeks *et al*. (2001) and they also reported variation at nine microsatellite loci in the mite and showed that it consisted of haploid female parthenogenesis and the above reproductive anomaly in *B. phoenicis* was caused by infection by an endosymbiotic bacterium. Studies concerning the diagnosis, agro ecology and phytosanitary importance of the citrus leprosis virus were made by Lovisolo (2001).

Fluctuations in the population of *B. phoenicis* in citrus orchards of the west of Santa Catrina were evaluated by Chiaradia and Souza (2001) and they observed lower populations during cold months and higher populations in warm months. Rodrigues and Nogueira (2001) reported the association of ring spot virus in *B. phoenicis* in Parana Brazil and showed the presence of the virus during frost conditions.

Mehrnejad *et al*. (2002) conducted a survey on mites infesting pistachio trees in Iran and showed that *Brevipalpus* species were the most injurious ones among the phytophagous mites present on the trees. Campos and Omoto (2002) studied the hexythiazox resistance in *B. phoenicis*. The damage caused by *B. phoenicis* to the apical tip of guava fruits was assessed by Quiroz *et al*. (2002). A survey on the insects and mites associated with guava was conducted by Camacho *et al*. (2002) and the results of which revealed *B. phoenicis* as the most common phytophagous species among the

mite fauna. An evaluation of the behavioural alterations in *B. phoenicis* on different plant species in citrus orchards was made by Ulian and Olivera (2002). The first report on incidence of coffee ring spot virus and infestation by *B. phoenicis* on coffee plants in Costa Rica was made by Rodrigues *et al*. (2002).

Association between Rhabdo virus – like particles and *Brevipalpus* mites on three ornamental plants which showed symptoms of local lesions was reported by Nogueira *et al*. (2003). Dragibe *et al*. (2003) successfully recorded a progressive reduction in citrus leprosis virus inoculation following the application of acaricides against *B. phoenicis*. A review on the feeding injury, biology and economic importance of four species of *Brevipalpus* viz. *B. obovatus*, *B. californicus*, *B. phoenicis* and *B. lewisi* was made by Childers *et al*. (2003a). The same authors (2003b) recorded a total of 928 plant species belonging to 513 genera and 139 families as hosts of these mites and established their potential to vectorise and spread viral diseases. Further, the authors (2003c) published an account on citrus leprosis and its status in Florida and Texas. Kitajima *et al*. (2003a) conducted studies on the role of *B. phoenicis* in the transmission of plant viruses and reported that a number of viral diseases could be transmitted by *Brevipalpus* species. The same authors (Kitajima *et al*., 2003b) provided information on the history of the etiology of citrus leprosis disease, host range, its geographical distribution, role of the mite vectors, viral structure and relationship with the infected cell and

presented data on the mite-virus-plant association, disease, damage and approaches for controlling disease spread. Rezendae *et al*. (2003a) also reported the occurrence of coffee ring spot virus and infestation by *B. phoenicis* on coffee plants, in Costa Rica.

Rezendae *et al*. (2003b) provided information on the occurrence of passion fruit green spot virus in Brazil and noticed that *B. phoenicis* vectored this virus. Kondo *et al*. (2003) made observation on the biological properties of the orchid fleck virus and its transmission by *B. californicus*. Transmission electron microscopic (TEM) examination of several hundred samples of mite damaged fruits from Texas citrus orchards by Childers *et al.* (2003d) could not indicate the presence of citrus leprosis virus or viral inclusion bodies and based on which, the authors concluded that this was due to feeding injury from *Brevipalpus* mites and not from citrus leprosis virus.

Ehara (2004) described a new species of *Dolichotetranychus, viz. D. zoysiae* from the lawn grasses, *Zoysia tenuifolia* Willd. (type host) and *Z. matrella* (L.) Merr. from the Okinawa Island of Japan. Welbourn *et al*. (2004) compared the morphological characters of *B. phoenicis* with those of *B. californicus* and *B. obvatus* and stated that the number of dorsal setae, number of solenidia on tarsus II and dorsal cuticular patterns were different. Mitochondrial DNA and RAPD polymorphism in *B. phoenicis* were studied by Rodrigues *et al*. (2004). Dispersal mechanisms of *B. phoenicis* in citrus

orchard were studied by Alves *et al*. (2005). Teodoro and Reis (2006) provided information on the reproductive performance of *B. phoenicis* on Citrus and Coffee. Groot *et al*. (2006) discovered a new endosymbiotic bacterium belonging to the genus *Cardinium* which induced haploid thelytoky in most clones of three closely related *Brevipalpus* species.

Carvalho *et al.* (2008) studied the population dynamics of *B. phoenicis* and predatory mites as well as the interactions among these mite species in Brazil. A general summary on the life cycle of false spider mites was given by Gerson (2008), based on his studies on *B. phoenicis* and he observed that the life cycle of these mites comprised of five stages viz. egg, larva, protonymph, deutonymph, and adult and it usually required about 3–4 weeks (dependent on temperature and host plant).

A detailed study on the breeding behavior and development of *D. cocos* infesting the perianth of coconut was performed by Santhosh *et al.* (2009) by successfully rearing the mite on nuts kept in a desiccator under laboratory conditions. The authors also provided a detailed data on mating, oviposition, hatching, duration of various developmental stages and total duration of life cycle of the species.

Peña *et al.,* (2009) identified and evaluated the potential biocontrol agents of the Red Palm Mite, *R. indica* in the Neotropical region. In order to develop an effective method to rear the Red Palm Mite in quarantine for a

classical biological control project, several banana and plantain varieties were tested by Cocco and Hoy (2009) in Florida as hosts for the RPM.

A review on the anatomy of *Brevipalpus* mites including histological and ultra-structural details was presented by Alberti and Kitajima (2010) with focus on the sensory system, gnathosoma, alimentary system, prosomal glands and genital organs. The sensilla on the gnathosoma as well as the eyes presenting well developed rhabdomeric microvilli were well studied by the authors and they compared the results of their studies with those obtained from other prostigmatid mites.

Considering the severe damage potential of *B. phoenicis* as well as its vector status on a multitude of crop plants, Prabheena and Ramani (2010) conducted studies on the reproductive behaviour and developmental biology of the species by rearing it on a common medicinal shrub, *Ocimum gratissimum*. The authors observed that *B. phoenicis* populations comprised entirely of female individuals and parthenogenesis was the sole mode of reproduction.

Through a survey made on natural vegetation, Ferragut and Navia (2010) could establish the association of 6 new species of false spider mites belonging to the genus *Tenuipalpus* with several endemic Velloziaceae species. The authors suggested that this genus was the most diverse of the

family Tenuipalpidae in the country and suspected the occurrence of many undescribed species on natural vegetation.

A series of field surveys were carried out by Taylor (2010) in Kerala, India between December 2008-April 2010 to investigate the ecology and natural enemies of *R. indica*. Temporal surveys on areca and coconut revealed that populations built up to significantly higher densities on areca than coconut when populations were at their peak, with evidence that females migrated down the stem of areca when densities were high.

Beard *et al.* (2010) described new characters and proposed a set of minimum requirements that should be adopted for future descriptions of species and/or genera within the family Tenuipalpidae and within the entire superfamily Tetranychiodea. Welbourn *et al.* (2010) used the techniques of Low Temperature Scanning Electron Microscopy and traditional light microscopy for studying the characters and character states for the segregation of *Brevipalpus* species and the authors illustrated morphological differences between six common pest species under the genus like *B. phoenicis*, *B. californicus*, *B. obovatus*, *B. lewisi*, *B. chilensis* and *B. trinidadensis*.

Biological observation on *R. indica* including its native predators in Florida, USA were studied by Carrillo and Peña (2010) and the authors recorded that *Amblyseius largoensis* had higher survival and reproductive

rates, and shorter developmental times when fed solely on *R. indica* when compared with other single test food sources. Hence this species could be considered as a potential species for controlling *R. indica* in Florida. Castro *et al.* (2010) conducted studies on the period of occurrence and the densities of three phytophagous mites, *Calacarus heveae* Feres, *T.heveae* Baker and *Eutetranychus banksi* on *H.brasiliensis* clones FX 2784, FX 3864, and MDF 180 and found that *T.heveae* reached the highest levels on clone FX 2784 (1.7 mite/cm2) in March and April, and was the most abundant mite species in the clone FX 3864 (1.4 mite/cm2).

Silva and Sato (2010) evaluated the influence of the phytoseiid predator, *Euseius concordis* on the movement and oviposition behaviour of *B. phoenicis* on citrus leaves by recording significant differences in the distribution of mites on areas exposed and non-exposed to the predator at an interval between 30 minutes and 48 hours after removing the predators. The highest contrast was observed during the evaluation made at 4 hours, during which the number of *B. phoenicis* on non exposed areas was 1.73 times greater than that on areas previously exposed to *E. concordis*. Significant differences in the number of *B. phoenicis* eggs on arenas exposed and non exposed to the predator were observed between 24 and 72 hours after removing the predators. The highest contrast was observed at 24 hours, with the number of eggs being 43% greater on non exposed arenas.

An evaluation of the efficiency of hexythiazox and lime sulfur mixture on the population of *B. phoenicis* in citrus orchard was made by Andrade *et al.* (2010) the results of which revealed that treatments with hexythiazox and lime sulfur mixture had prolonged effect than that of lime sulfur alone. The authors further revealed that the mixtures were more effective in the treatments with only hexythiazox due to the rapid reduction of mite population, therefore contributing directly to decrease the spread of citrus leprosis virus.

Novelli *et al.* (2010) reported the prevalence of *Cardinium* which induced genetic variability and feminization in *B. phoenicis* populations on different plant hosts in various geographic regions of Brazil. Presence of this bacterium was confirmed by PCR amplification and transmission electron microscopy, and its variability was evaluated by analysis of the 16S rDNA and gyrB gene region and the genetic variability of *B. phoenicis* was evaluated by mitochondrial COI sequences. Andrade *et al.* (2010) conducted a comparative study of the period of protection of citrus plants against *B.phoenicis* provided by sprays of spirodiclofen and that of other acaricides. The study revealed that spirodiclofen treatments provided a highly efficient control of *B. phoenicis* up to 98 days after application, reaching 99.6% and 100% efficiency at 20 and 25 mL c.p./100 L doses, respectively.

The mortality and the irritability of *B. phoenicis* subjected to different concentrations of agave juice were assessed by Barrêto *et al.* (2010). The number of live mites decreased with increasing concentrations of *A. sisalana* juice, but irritability was not observed. Oliveira *et al.* (2010) evaluated the efficiency of hexythiazox mixed with other acaricides on *B.phoenicis* in order to develop control strategy against *B.phoenicis*. This study showed that the hexythiazox mixed with fenbutatin oxide, dinocap, cyhexatin, chorfenapyr and propargite were the treatments that presented highest efficiency in controlling populations of *B. phoenicis*.

Carrillo *et al.* (2011), while reviewing the natural enemies associated with the red palm mite, *R. indica* reported 28 species of predatory arthropods, including mites and insects in Asia, Africa and the Neotropics. In addition, pathogenic fungi were also found associated with *R. indica* in the Caribbean islands.

High population levels of *R. indica* were found damaging coconut and banana in Cuba and Lima *et al.* (2011) estimated the potential of the mite as a pest in Cuba and evaluated the effectiveness of dicofol and *Bacillus thuringiensis* for its control. Twenty one plant species were found as hosts to RPM, of which 11 were under Arecaceae, 3 were under Musaceae, 2 were under Heliconiaceae, 2 were under Zingiberaceae, 1was under Strelitziaceae

and 2 were under Cycadaceae. *Mycrocycas calocoma* and *Cycas* species were reported as new hosts for this mite.

Taylor *et al*. (2011) studied the host range of *R. indica* in Kerala and they provided information on the number of RPM on coconut and *Musa* spp., on coconut and bananas grown as a mixed crop and the possible presence of RPM on palms and other selected plant species , especially on ornamentals which could serve as hosts of the RPM in the New World. Results of their study revealed extremely low numbers of RPM on *Musa* spp.and the pygmy date palm, *Phoenix roebelenii* O´Brien, could be detected as an additional breeding host in Kerala, as multi-generational colonies were found on this plant.

Replicated field experiment was demonstrated by Shivanna *et al.* (2012) at five different sites for two consecutive years (2008/2009 and 2009/2010) to circumvent the problems of conventional insecticides. Effects of two sprays each with the new molecules of diafenthiuran (50WP at 1.2 g/L) fenazaquin (10EC at 1.5 ml/L), and propargite (57EC at 0.5 ml/L) were evaluated with dicofol (20EC at 2.5 ml/L), wettable sulphur (80% WDG at 2.5 g/L), azadirachtin1300 ppm (0.03% at 3 ml/L) and untreated control. Results of this study reported that the new molecules, diafenthiuran (50WP at 1.2 g/L) or propargite (57EC at 0.5 ml/L) could be used for efficient

management of mites on areca. Further, fenazaquin (10EC at 1.5 ml/L) could also be used as a substitute to existing conventional insecticides.

Carrillo *et al*. (2012) evaluated the potential of the predator, *A. largoensis* by determining its likelihood of consuming eggs and larvae of *R. indica* and *T. gloveri* under no-choice and choice conditions. The possible implications of the observed differences in terms of biological control of *R. indica* were also discussed in the above study.

Prabheena and Ramani (2013) evaluated the damage potential of *B. phoenicis* on a common medicinal shrub of South India, namely *O. gratissimum*. The feeding activity of the mite on the leaves of *O. gratissimum* induced drastic reduction in the levels of chlorophyll *a* and *b* and the mite was found to exert adverse effect on the general health of the host plant thereby leading to reduction in the growth rate and biomass of the plant. Further, it was observed that the feeding activity of the mite resulted in the production of phoenicis blotch which would lead to the depreciation of the medicinal quality of the plant. The incidence, distribution and injurious status of *R. indica* on areca were studied by Prabheena and Ramani (2014) in Wayanadu and Malappuram districts of North Kerala. Their study revealed that, high population density of this mite was observed on areca plants and peak population in of *R. indica* was recorded in March/April.

Arabuli *et al*. (2015) were registered three flat mite species *viz. B. cuneatus*, *Aegyptobia tragardhi* and *A. beglarovi* for the first time for the Georgian fauna and Alatawi and Kamran (2015) reported two Tenuipalpid genera *Aegyptobia* and *Pentamerismus* from the Saudi Arabia for the first time on the basis of two species *A. arabica* and *P. bahaensis*. Prabheena and Ramani (2015) observed the incidence and the damage induced by *D. floridanus* on Areca of various localities of Kerala and various stages of this mite were found to inhabit inner side of the perianth of young nuts and cause significant damage to areca nuts.

CHAPTER III

MATERIALS AND METHODS

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The present study was mainly intended to gather information on the biological parameters of selected most injurious species of tenuipalpid mites associated with the fruit and plantation crops of Kerala. The study was also extended to collect information on the distribution pattern, host range, duration of development under different temperature-humidity parameters and also to elucidate the damage potential of selected most common and abundant species by adopting standard qualitative and quantitative methods. Accordingly, the various methods followed for the recovery of materials included in the present study and the techniques adopted for studying the feeding and breeding parameters of selected injurious species and measures for assessing the feeding damage either qualitatively or quantitatively or both are presented appropriately in this chapter.

A. SURVEY

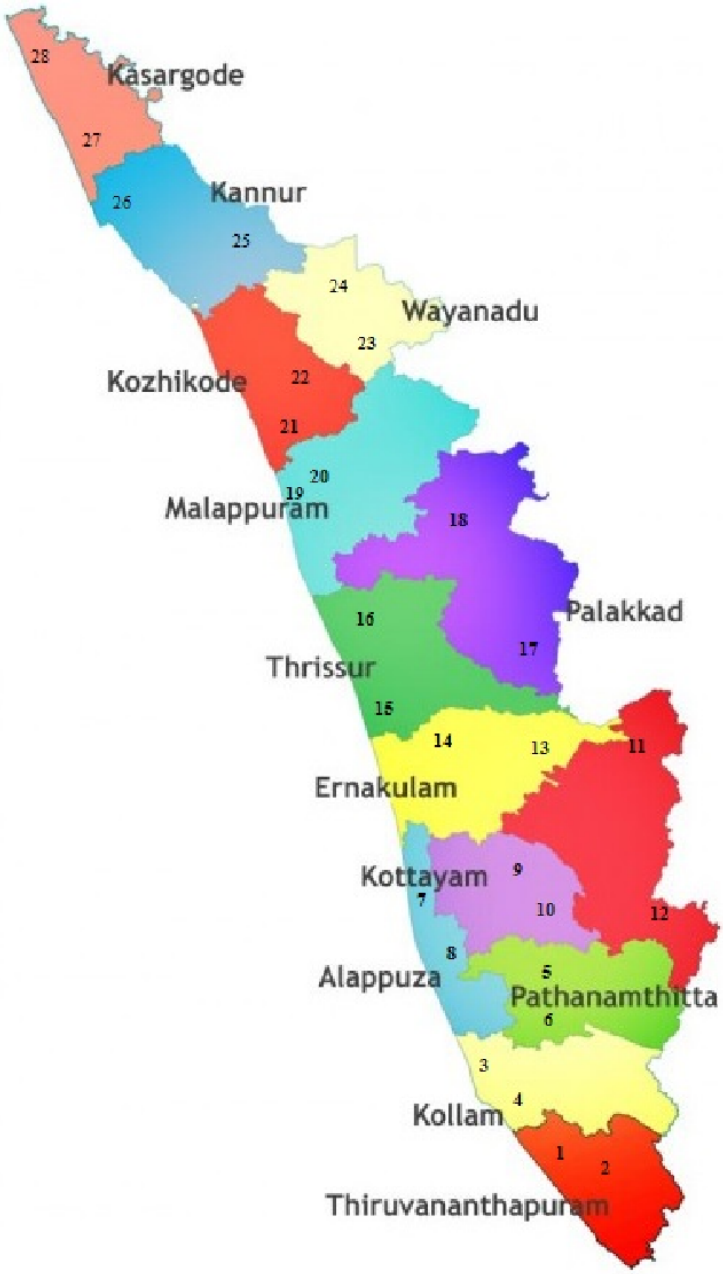
1. Study Sites

In the present study, collection of tenuipalpid mites infesting fruit and plantation crops was carried out by sampling mite infested leaves/leaflets/twigs/fruits of various host plants growing in various localities of Kerala. The state of Kerala occupies a unique position in India and it lies between the Arabian Sea to the west and the Western Ghats to the east with 8º.18'N and 12º.48'N latitude and 74º. 52'E and 77º. 24'E longitude. It has

38,863 km² total geographical area; *ie.*1.18% land mass of India. Physiogeographically, Kerala is divided in to three zones *viz*. coastal, midland and highland. The climate of Kerala is heavily influenced by the availability of seasonal heavy rains brought by the monsoon and the annual rain fall varies from 1520 mm to 4075 mm and the temperature changes from 19.8°C to 36.7°C. About 30% of the geographical area is occupied by forests which include Reserved forests and Protected forests. In the biodiversity scenario, Kerala is home to nearly 10035 plant species which is 22 % of the total number of plant species found in India, which includes many species of varying economic categories including fruit crops and plantation crops. Western Ghats is the main biodiversity site in Kerala and the entire State is blessed with year-round greenery. The mountain ranges of Western Ghats, south-western India have been considered as 'Hot spot' fostering a wide range of endemic genera, species and races, which mainly include higher plants, reptiles, fishes, birds, amphibians and mammals – all endemic to the Western Ghats. Agriculture in Kerala is one of the major sectors of the economy of the state since it contributes around 50 % of the gross income of the state.

In the present study, 28 sites distributed over 14 districts of Kerala were considered for the collection of tenuipalpid mites (Table.2 & 4). The districts covered during the present study were Malappuram, Kozhikkode, Kannur, Kasaragod, Wayanad, Palakkad, Thrissur, Eranakulam, Idukki, Kottayam, Alappuzha, Pathanamthitta, Kollam and Thiruvananthapuram. As

represented in the table, 2 collection sites were selected for sampling of host plants to explore the associated tenuipalpid mites.



1. Attingal, **2.** Palode, **3.** Karunagapalli, **4.** Kollam, **5.** Ranni, **6.** Konni, **7.** Cherthala, **8.** Moncompu, **9.** Pala, **10.** Mundakayam, **11.** Marayur, **12.** Thekkady, **13.** Kothamangalam, **14.** Aluva, **15.** Irinjalakuda, **16.** Kunnamkulam, **17.** Nelliyampathy, **18.** Mannarkkad, **19**. C.U. campus, **20.** Pallikkal, **21.** Pantheerankavu, **22.** Thamarasseri, **23.** Meppadi, **24**. Katikulam, **25.** Iritti, **26**. Payyannur, **27.** Kanhangad, **28.** Manjeswaram

2. Host Plants Surveyed:

In order to study the distribution pattern and host range of tenuipalpid mites considered during the study, an extensive survey on various species of fruit and plantation crops of Kerala was carried out during the present study from selected geographical locations, covering all seasons. Data on the various species of host plants surveyed with respect to collection localities are presented in Tables 1 & 2.

As represented in the table 1.a total of 52 species of plants comprising 16 species of plantation crops and 36 species of fruits plants were screened for the collection of tenuipalpid mites. Of these, 36 species belonging to 28 genera and 19 families represented fruit crops while 16 species under 16 genera and 15 families were plantation crops.

The fruit crops surveyed were *Annona reticulata* Linn., *Annona muricata* Linn., *Malus domestica* Borkh, *Passiflora edulis* Sims., *Psidium guajava* Linn., *Citrus sinensis* Linn., *Citrus limon* Linn., *Citrus maxima* Merr., *Pyrus pyrifolia* (Burm.f.) Nakai, *Litchi chinensis* Sonn., *Manilkara zapota* (L.) Van Royen, *Syzygium cumini* (L.) Skeels, *Syzygium samarangense* (Blume) Merr. & Perry, *Vitis vinifera* Linn., *Prunus avium* Linn., *Phyllanthus acidus* (L.) Skeels, *Averrhoa carambola* Linn., *Ficus carica* Linn., *Mangifera indica* Linn., *Artocarpus heterophyllus* Lam., *Nephelium lappaceum* Linn.,*Garcinia mangostana* Linn., *Fragaria ananassa*

Duchesne, *Persea americana* Mill., *Averrhoa bilimbi* Linn., *Carica papaya* Linn., *Garcinia gummi-gutta* (L.) Roxb., *Punica granatum* Linn., *Prunus persica* (L.) Stokes, *Artocarpus altilis* (Parkinson) Fosberg., *Pouteria campechiana* Baehni, *Durio kutejensis* Linn., *Nephelium mutabile* Blume, *Ziziphus jujube* Mill., *Phyllanthus emblica* Linn. and *Flacourtia inermis* (Burm.f.) Merr. The plantation crops surveyed were *Areca catechu* Linn., *Cocos nucifera* Linn., *Hevea brasiliensis* Mull.Arg., *Tectona grandis* Linn., *Piper nigrum* Linn., *Anacardium occidentale* Linn., *Musa acuminata* Linn., *Theobroma cacao* Linn., *Myristica fragrans* Hoult, *Ananas comosus* (L.) Merr., *Coffea Arabica* Linn., *Camellia sinensis* (L.) Kuntze, *Vannila planifolia* Jacks., *Cycas circinalis* Linn., *Swietenia mahagoni* (L.) Jacq and *Syzygium aromaticum*. (L.) Merrill & Perry. The survey on tenuipalpid mites was carried out from these host plants cultivated / grown in 2 localities from each district of Kerala mentioned above, covering different seasons. For further field studies, collection was restricted to selected plant species grown/cultivated in selected geographical locations only.

Duly considering the local availability, economic importance and intensity of mite infestation, collections were made from selected host plants in order to study the biological parameters of tenuipalpid mites under various temperature and humidity conditions and elucidation of nature and extent of damage caused by them. Accordingly, the following four species of plants

were considered for frequent surveys for the conduct of feeding and breeding biological studies of selected species of tenuipalpid mites.

1. *Areca catechu* Linn. (Arecanut palm)

The arecanut palm, *Areca catechu* L. (Palmae) is the source of arecanut commonly referred to as betelnut or supari in India and which is commonly used for masticatory (chewing) purposes as well as for various religious and social ceremonies (Murthy, 1968). Arecanut is largely cultivated in Karnataka, Kerala and Assam and accounts for over 90% of area and production. For the last two decades, farmers used to practice cultivation of improved varieties of areca palms, in the changed agro-climatic conditions. Although significant crop losses from pest attack were encountered on areca palms in the fields, lack of knowledge among the cultivators and farmers on the identity, distribution pattern and bionomics of the important pests hinders the formulation of suitable management practices to protect this commercial crop. An array of insect and non- insect pests are known to infest various parts such as stem, leaves, inflorescence, roots and nuts of areca palms, in one or other phases of growth. As many as 102 insect and non-insect pests have been reported to be associated with arecanut palms (Nair and Daniel, 1982). Among these, mites have been rated as the serious pests in young areca plantation, on leaves and which become active after the onset of hot weather.

2. *Manilkara zapota (L.)* (Sapodilla)

Manikara zapota commonly known as Sapodilla is the most economically important plant in the genus *Manikara* of the family Sapotaceae and it is distributed throughout the tropics. The genus *Manikara* is believed to be native of Mexico and Central America. The sapodilla trees are long lived, fairly slow growing and pyramidal at young. The adult trees are drought tolerant, evergreen and maintain thick canopy throughout the year. The sapodilla trees are primarily grown for fruits and which are edible when fully ripened. The fruit pulp of sapodilla is used in jams, juice, milkshakes and ice creams. In some countries, the gum or chicle is extracted from the bark of the sapodilla tree and is used as the principal component of chewing gum. Traditionally, young fruits are boiled and decoction is taken to stop diarrhea. Certain compounds extracted from the leaves of sapodilla exhibited anti-diabetic, antioxidant and hypocholesterolemic effects in laboratory animals.

3. *Syzygium cumini* (L.) (Jamun)

Syzygium cumini is commonly known as Java plum, jambolan, jamun, and duhat. This evergreen tall tree belongs to the flowering plant family Myrtaceae and is believed to be originated from the Southeast Asia. *S. cumini* is slow growing and it can grow up to 30 meters. This tree starts flowering from March to April and fruits develop by May or June which resemble large berries. According to Hindu belief, Lord Rama subsisted on the fruits of this

plant in the forest for 14 years during his exile from Ayodhya and therefore many Hindus, especially the Gujaratis consider the fruit of *S. cumini* as the fruit of the God. *S. cumini* is widely used in the Ayurveda and Indian folk medicines for the cure of diabetes mellitus. Several studies in experimental animals have proved the beneficial effects of *S. cumini* for the treatment of diabetes. This study also proved that the seed extract of *S. cumini* stimulated the secretion of insulin in the normal as well as from diabetic animals and also inhibited insulinase activity from liver and kidney.

4. *Psidium guajava* Linn. (Guava)

Psidium guajava is a low, evergreen small tree of the family Myrtaceae, with widely spreading branches reaching 6 - 25 feet high and square, downy twigs. This plant is a native of tropical America and cultivated throughout the tropical and subtropical areas of Africa, South East Asia, South Asia, The Caribbeans, North America, Australia and New Zealand and they can grow in both humid and dry tropical or subtropical climates. Guava fruits are rich in vitamin C, iron, calcium, phosphorus and dietary fiber, with moderate levels of folic acid and a single common guava fruit contains about four times the amount of vitamin C than that of an orange. The fruits and leaves of guava are widely used in traditional medicines for the treatment of gastroenteritis, diarrhea, dysentery, wounds and ulcers. The leaves are chewed

to relieve toothache and also used as remedy for coughs, throat, oral ulcers and inflamed gums, diarrhea and nephritis.

3. Sample Collection

During the first year of the study, attention was focussed to conduct mass collection of mite infested leaf/fruit/nut samples from the various sampling sites distributed in each district, covering different seasons, to gather information on the incidence, distribution pattern, seasonal abundance and host range of associated tenuipalpid mites. Collection was made based on visual symptoms of mite infestation and random sampling was performed from each species of host plant. Generally, newly sprout leaves and fruits were excluded from collection, owing to lack of visible symptoms of infestation. Similarly, old leaves which were about to shed were also not sampled. In the case of areca palm, fallen and fresh nut samples were collected from various arecanut plantations. The samples collected were carefully stored in polythene bags, labelled and transported to the laboratory, for following microscopic observation.

Based on the results of preliminary survey, regular sampling was carried out from selected fruit plants and plantation crops, which showed symptoms of tenuipalpid mite infestation, grown / cultivated in the various localities for further studies in the laboratory (Table.5). The collected plant samples were carefully screened under a stereomicroscope to record data on

the incidence, relative abundance, distribution pattern, host range, nature of damage induced etc. by individual species.

B. TAXONOMIC STUDIES

1. Collection and Preservation of mite specimens:

The samples of mite infested leaves/fruits/nuts collected from various host plants were carefully screened individually under a Stereomicroscope (MacroVis, MVNSZ-405). The mite specimens for taxonomic studies were carefully isolated with the aid of a moistened 'zero' point camel hair brush and preserved in 70% alcohol in a cavity block. All life stages namely the larva, proto, deuto and tritonymphal stages and the adult male and female specimens were segregated and preserved in alcohol. The preserved specimens were successively dehydrated in 80%, 90% and absolute grades of ethyl alcohol, before subjecting to subsequent clearing.

2. Clearing

As soon as the specimens were completely dehydrated, clearing of the specimens was carried out by transferring them in to a clearing medium, prepared by mixing absolute ethyl alcohol and lactic acid in 1:1 ratio. The time needed for clearing varied, depending up on the degree of sclerotization of the specimens.

3. Preparation of Permanent slides

The cleared specimens were subjected to permanent slide mounting in a drop of Hoyer's medium, prepared as given below:

Preparation of Hoyer's medium

Chloral hydrate : 200 gms

Gum arabic : 30 gms

Distilled water : 50 ml

Glycerine : 20 ml

The above ingredients were mixed thoroughly and the mixture was then filtered by using two folds of thin cloth or glass wool and stored in an amber coloured bottle and used for preparation of slides.

Slide mounting was performed by placing a very small drop of Hoyer's medium at the middle of a microscopic slide and spreading it out to a fairly thin layer, with the help of a micro needle. The cleared specimens representing the various life stages of individual species were placed in the Hoyer's medium, on the microslide. With the help of bristles of appropriate size, each specimen was positioned in the dorso-ventral axis, with the legs spread outward and the coverslip was mounted on top of the specimen on each microslide, without trapping any air bubbles under the cover glass.

Briefly dried the slide until the Hoyer's medium was set and the specimen was firmly stuck in position. The mounted slides were kept in an oven at 36□ C for 2-3 days to achieve adequate clearing. Properly dried slides were taken out and the position of specimen was marked with a marker pen and labeled giving data on collection locality, date of collection, name of host plant etc.

4. Identification of mites

The slide mounted specimens were identified under the high power of a Carl Zeiss Research microscope, following the relevant literature, keys etc. Quite often, help of experts was also sought, especially for confirmation of identity of the specimen and to avail relevant literature.

5. Morphological Studies

Permanent slide preparation was made in Hoyer's medium to study the morphological features of the various life stages of the mite species selected for detailed biological studies. Morphological features of the slide mounted life stages of each species selected for biological studies were studied by comparing with the species specific characters available in the identification keys, descriptions, monographs and other relevant literature. Drawings of the morphological details with taxonomic importance were drawn with the help of a Camera Lucida attached to a Meopta Research microscope. Measurements of the various life stages were taken under the high powers of

a Meopta Research microscope, calibrated with the stage and ocular micrometers.

6. Scanning Electron Microscopic studies

Scanning Electron Microscopic (SEM) studies of selected injurious species of tenuipalpid mites were performed to elucidate the fine structure of their morphological details. Adult male and female specimens of selected species were analyzed using Hitachi SU6600 Variable Pressure Field Emission Scanning Electron Microscope (FESEM) at the National Institute of Technology (NIT), Calicut, Kerala.

C. BIOLOGICAL STUDIES

1. Rearing of mites under Constant Temperature and Humidity

The mites were cultured in the Laboratory condition for observation on the feeding habits and life history parameters. Rearing was carried out under constant temperature and humidity parameters. The different developmental stages of mites were maintained on the host plant leaves in the laboratory condition and the leaves upon damage were replaced with fresh ones. Each culture set was maintained with two duplicates to confirm the observation and each culture set consisted of 1-3 mature leaves, kept in petridishes lined with a moistened cotton pads to maintain the water content of leaves up to maximum days.

Laboratory culturing was found essential for making observations on the biology of individual species and to record the impact of physical parameters like temperature, relative humidity, host plant etc. Regular observation on the feeding activity, nature of damage induced and other life history parameters of selected common and injurious species was carried out by raising sufficient cultures in the laboratory through rearing .

2. Raising of Stock Cultures through laboratory rearing

Along with the experimental set, stock cultures of the various species of mites were also maintained in the laboratory on the preferred host plants collected from the field to ensure constant supply of life stages.

3. Studies on Feeding biology

3.1. Qualitative Assessment of Damage Potential

Qualitative assessment of damage potential of selected most injurious species viz. *D. floridanus*, *T. micheli, T. chiclorum, R. indica* and *B. phoenicis* was made by making regular observation on the feeding activities of the various life stages and recording the damage symptoms induced on the host plant during progressive feeding. Qualitative assessment of feeding was made simultaneously through repeated field cum laboratory studies. Field collected mite infested and uninfested samples of host leaves were subjected to microscopic examination in order to record the nature of incidence,

severity of infestation, population density of the species, distribution pattern of the species, damage symptoms induced, qualitative difference in the morphology of the infested and uninfested leaves etc. Results of field studies were confirmed through simultaneous microscopic observation of leaves harbouring mites maintained in stock cultures in the laboratory. Observation of individual leaf was continued till the leaves got damaged, especially for recording the qualitative difference of the leaves and the damage potential of selected species. Renewal of damaged/decayed leaf discs was made in every 2 weeks and the observations were continued with fresh leaves.

3.2. Quantitative Assessment of Damage Potential

Quantitative assessment of damage potential of selected injurious species viz. *D. floridanus, T. micheli, T. chiclorum, R. indica* and *B. phoenicis* on leaves of respective host plants viz. *A. catechu, S. cumini*, *M. zapota* and *P. guajava* was carried out through biochemical analysis of various parameters given below:

3.2.1. Estimation of Chlorophyll Loss

The chlorophyll contents of mite infested and uninfested (control) leaf samples were estimated following the method of Arnon (1949). The exuviae, eggs, life stages and faecal matter of mites were carefully removed under a stereomicroscope from the infested leaves before subjecting these for subsequent chlorophyll analysis.

Procedure

Chlorophyll was extracted from 2g of the leaf sample using 20ml of 80% acetone. The supernatant was shifted to a volumetric flask after centrifugation at 5000 rpm for 5minutes. The extraction was repeated until the residue became colourless. The supernatant was pooled together and volume of the combined supernatant was noted. The absorbance of the solution was read in a Shimadzu UV-VIS spectrophotometer (Model UV – 1601) at 645 nm, 663 nm and 750 nm against the solvent blank of 80% acetone, for chlorophyll a, b and total chlorophyll.

The concentrations of chlorophyll ('a' , 'b' and 'total chlorophyll') present in the experimental and control samples were estimated as listed below, following the equation (Arnon, 1949).

Chlorophyll **a** (µg/ml) = [12.69 (A_{663}- A_{750}) -2.69(A_{645}- A_{750})/ Dry weight] x Volume

Chlorophyll **b** (µg/ml) = [22.9(A_{645}- A_{750}) - 4.68(A_{663}- A_{750})/ Dry weight] x Volume

Total chlorophyll (µg/ml) = [20.12(A_{645}-A_{750}) + 8.02(A_{663}-A_{750})/ Dry weight of Sample] x Volume

3. 2.2. Estimation of Nitrogen Loss

Quantitative assessment of feeding damage was made by estimating the total nitrogen content present in the mite infested and uninfested leaf samples. Estimation of total nitrogen content present in mite infested and uninfested leaf sample was made by following Kjeldahl method (1883) from Interfield Laboratories Pvt. Ltd., Cochin, Kerala.

Principle

Nitrogen in the protein or any organic substance is changed to ammonium suplhate by H_2SO_4 during digestion. This salt on steam distillation release ammonia, which is collected in boric acid solution and titrated against H_2SO_4.

Reagents

1. Potassium sulphate and copper sulphate (catalysts)
2. Sulphuric acid
3. Sodium hydroxide 50% solution
4. Indicator solution: Methylene blue 0.2g/100 ml ethanol, Methyl red 0.2g/100ml ethanol. For mixed indicator, two parts or methyl red solution were added to one part of methylene blue solution.
5. Boric acid 2% solution
6. Standard HCI or H_2SO_4, 0.02N

Procedure

Mite infested and uninfested (control) leaf samples collected from different localities were weighed (0.5 g each) and transferred to digestion flasks. Each of the catalyst (1 mg) was added and the samples were digested with 10 ml of concentrated sulphuric acid until the solution became colorless. After complete digestion, the volume was made up to 100 ml with distilled water and transferred 10 ml of which to the Kjeldahl flask. Then added 10 ml of 50% NaOH to the Kjeldahl flask and heated to liberate ammonia. The released ammonia was collected in a 100 ml conical flask containing 5 ml of boric acid solution with a few drops of mixed indicator. The flask was positioned with the tip of the condenser dipping beneath the surface of the solution and the solution was titrated against the standard acid until the first appearance of a violet color, which marked the end point. A reagent blank was run with an identical volume of distilled water and the titration volume was subtracted from that of sample titer volume.

The amount of nitrogen was calculated as follows::

$$\text{Nitrogen } (\%) = (A - B) \times \frac{C}{D} \times \frac{E}{(F \times G)} \times 100$$

where

A = Titer value for digested sample, ml

B = Titer value for blank, ml

C = Nitrogen equivalent of ammonium sulphate, mg

D = Titer value for ammonium sulphate, ml

E = Volume of digested sample, ml

F = Volume of sample taken for distillation, ml

G = Sample weight, mg

3. 2.3. Estimation of Proline

Proline contents present in the mite infested and uninfested samples were estimated by the method of Bates *et al*. (1973).

Principle

During choosy extraction with aqueous sulphosalicylic acid, proteins are precipitated as a complex. Other intrusive materials are also apparently removed by absorption to the protein sulphosalicylic acid complex. The extorted proline is ready to react with ninhydrin in acidic environment (pH 1) to form the chromophore (red colour) and the absorbency was read at 520nm.

Reagents

1. Aqueous Sulpho salicylic acid (3%): 3 gm of sulphosalicylic acid was dissolved in I00 ml of distilled water.

2. Acid Ninhydrin: 1.25 gm of Ninhydrin was suspended in a warm mixture of 30 ml of glacial acetic acid and 20 ml of Phosphoric acid (6 M) with agitation.

3. Standard Proline: 5 mg of proline was dissolved in 10 ml of 0.1 N Hydrochloric acid.

Procedure

Two hundred (200mg) milligrams of mite infested and uninfested fresh leaf samples were weighed separately and homogenised in 10 ml of 3% (w/v) aqueous sulfosalicylic acid, using a clear glass mortar and pestle. The homogenate was filtered by using Whatman No. 2 filter paper. From the filtrate, 2 ml aliquot was mixed with 2ml glacial acetic acid and acid nynhydrin (2ml). The tubes with mixture were heated in a boiling water bath for 1 hour and then the reaction was terminated by placing the tubes in an ice -bath. For colour development, toluene (4.0 ml) was added to the reaction mixture and stirred well for 20-30 seconds. Then the coloured toluene layer was separated and brought to room temperature. The colour intensity of the solution was measured at 520 nm using toluene as reagent blank in a

Spectrophotometer. L. Proline was used as the standard. The amount of proline in the test sample was calculated from the standard curve.

3.2.4. Estimation of Phenol

The effect of plants to mite attack in terms of concentration of total phenol content of each extract was determined, following Folin-Ciocalteu colorimetric method, on the basis of oxidation-reduction reaction (Waterhouse, 2002) method.

Principle

Phenols react with phosphomolybdic acid in Folin-Ciocalteau reagent to develop a blue-coloured complex in alkaline medium, which can be measured spectrophotometrically at 650nm.

Reagents

1. Ethanol (80%)
2. Folin-Ciocalteau reagent (1N)
3. Sodium carbonate (20%)
4. Galic acid (standard)

Procedure

The sample (0.5g) was homogenized in 10 times volume of 80% ethanol. The homogenate was centrifuged for 20 minutes at 10,000 rpm. The extraction was repeated with 80% ethanol. The supernatants were combined and evaporated to dryness. The residue was then suspended in a known volume of distilled water. Different aliquots were pipetted out and distilled water was added to make the volume 3.0ml in each tube. About (0.5ml) Folin-Ciocalteau reagent was added and the tubes were kept in a boiling water bath for exactly one minute. The tubes were allowed to cool and the absorbance was estimated at 650nm in a spectrophotometer against a reagent blank. Galic acid was used as the standard.

The concentration of phenols is expressed as mg/g tissue.

3.2.5. Estimation of Photosynthetic Efficiency

Photosynthetic efficiency of mite infested and uninfested leaves was analysed by using the Handy Photosynthetic Efficiency Analyser instrument, Handy PEA, Hansatech Ltd., Norfolk, U.K. Chlorophyll fluorescence transient was measured at room temperature on the fully expanded leaves and the following parameters were measured. Minimum fluorescence (F0) =the fluorescence level when the plastoquinone electron acceptor QA is fully oxidized), maximum fluorescence (Fm = the maximum fluorescence level measured, ideally when electron acceptor QA is fully reduced, variable

fluorescence (Fv = the variable component of fluorescence, obtained from Fm subtracted by F0), Fv/Fm (A ratio of the variable fluorescence divided by the maximal fluorescence. This is a ratio that has been shown to be proportional to the quantum yield of photochemistry, and shows a high degree of relationship with the quantum yield of net photosynthesis), P index (Performance Index reflects the functionality of both photosystems I and II) and Area (The area above the fluorescence curve between F0 and Fm i.e.Kautsky curve, is proportional to the pool size of the electron acceptors QA on the reducing side of Photosystem II).

4. Studies on Breeding Biology

Observation on the developmental parameters of selected species of mites was carried out in the laboratory by rearing the species on respective host plant leaves kept on moistened cotton pads lined in petridishes, to maintain adequate humidity requirements. Constant moisture levels were maintained in the petridishes by adding water as and when needed. Two duplicates were maintained for culture sets for each species. A pure culture set of each species was maintained in the laboratory by transferring mated females to a leaf/ leaf discs of respective host plant. The eggs laid by the transferred mated females were observed until they were hatched, to record the duration of incubation and subsequent hatching. The newly hatched larvae were transferred singly to fresh leaf discs for further observation on feeding.

Regular observation was made, twice in a day, one in the morning and the other in the evening to avoid frequent disturbance of the developing instars. Data on various developmental parameters like hatching, larval emergence, feeding activity, duration of developmental stages, moulting, mortality, longevity of males and females, sex ratio, oviposition periods etc. were recorded and presented. Microphotographs of the various developmental stages were also taken with the help of a Leica Stereo Zoom Microscope.

4.1. Maintenance of Constant Temperature and Humidity conditions

In order to study the impact of different temperature-humidity parameters on the duration of development of various instars as well as the total duration of development of the various species of mites selected during the present study, the culture sets were maintained at specific temperature-humidity conditions set in the laboratory. Constant humidity conditions were maintained for keeping the culture sets by preparing saturated salt solutions as specified below.

4.2. Preparation of Saturated Salt Solution to maintain Constant RH

Saturated salt solutions were prepared by dissolving salts in boiling water. The solution was then allowed to cool and more salt was added and the mixture was allowed to stand for a few days to 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). Relative

humidity of 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. The solution mixture containing equal volumes of saturated solution of LiCl and Mg(NO3)2 was used to set the relative humidity of 60 ± 5% at 35 ± 2°C.

CHAPTER IV

OBSERVATION

OBSERVATION

A. SURVEY

1. Incidence and distribution pattern of tenuipalpid mites recovered

Results of field survey carried out during the present study enabled to record the association of varied groups of phytophagous mites and predatory mites with the fruit and plantation crops of Kerala. Members of the families Tetranychidae and Tenuipalpidae were the major phytophagous groups recovered during the study period while the predatory mites were mainly represented by members of Phytoseiidae. Results of field studies enabled to record incidence of tenuipalpid mites on the fruit crops and plantation crops surveyed from most of the sampling localities (Table 2), distributed in the 14 districts of Kerala. Of the 36 species of fruit crops and 16 species of plantation crops surveyed during the period of the current study (Table 1), 14 species of fruit crops and 9 species of plantation crops (Table 1) disclosed evidences of tenuipalpid mite infestation. High incidence of these mites was observed on fruits trees like *A. reticulata, M. zapota, P. edulis, P. guajava, C. sinensis*, *C. maxima*, *S. cumini, C. papaya*, *P. granatum, M. domestica* and *A. altilis* and plantation crops like *A. catechu, C. nucifera*, *C. Arabica, C. sinensis* and *S. aromaticum.* All life stages of these mites viz. the egg, larva, nymphs and adults could be recorded on all the host plants screened. On all

the surveyed plants, mite infestation could be observed on the lower surface of leaves, especially on areas adjacent to midrib or veins (Table 5). Members of 5 genera of tenuipalpid mites viz. *Tenuipalus, Dolichotetranychus, Raoiella, Cenopalpus* and *Brevipalpus* were found predominating on the fruit and plantation crops surveyed from various localities of Kerala. The species recovered were *Tenuipalpus chiclorum* De Leon, *Tenuipalpus micheli* Lawrence, *Dolichotetranychus floridanus* Banks, *D. cocos* Flechtmann & Fernando, *Cenopalpus pulcher* Canestini & Fanzago, *Raoiella indica* Hirst, *R. macfarlanei* Pritchard & Baker, *Brevipalpus phoenics* Geijskes, *B. obovatus* Donnadieu and *B. californicus* Banks.

T. chiclorum was found associated with a single host plant, *M. zapota*. The occurrence of *T. chiclorum* was observed from Palode, Trivandrum district. The Incidence of *T. chiclorum* in Kollam district was recorded from Karunagapalli. In Pathanamthitta district, this mite was observed from Konni. In Kottayam district, distribution of *T. chiclorum* was recorded from Pala and in Idukki district this mite was observed from Thekkady. In Ernamkulam district, *T. chiclorum* infestation was observed in Aluva. Irinjalakuda and Kunnamkulam, were recorded as *T. chiclorum* distributed area in Thrissur district and Nelliyampathy was the area of infestation in Palakkad district. During the survey in Malappuram district, *T. chiclorum* was documented from the Calicut University campus and Pallikkal. From Kozhikode district, *T. chiclorum* was collected from Pantheerankavu and Thamarasseri. *T.*

chiclorum was also recovered from Kattikulam in Wayanadu district, Iritti and Manjeswaram in Kannur and Kasarkode districts respectively (Table 2). On the host plant, *S. cumini*, *T.micheli* showed infestation in the following localities of Trivandrum district *viz*. Attingal and Palode. The distribution of *T. micheli* was recorded in Karunagapalli and Ranni in Kollam and Pathanamthitta districts respectively. In Alappuzha district this mite was recorded from Cherthala and Moncompu. In the districts of Kottayam and Idukki, *T. micheli* showed infestation on host plants collected from Pala and Marayur respectively. Aluva was recorded as the distribution site of *T. micheli* in Ernamkulam district. In Thrissur district, this mite was observed in Irinjalakuda and Kunnamkulam and in Palakkad district, Mannarkkad was recorded as the distribution area of *T. micheli*. Calicut University Campus and Pallikkal showed the incidence of *T. micheli* in Malappuram district and in Kozhikode distric,t Pantheerankavu and Thamarasseri were documented as the distribution sites of this mite. In Wayanadu and Kannur districts, *T. micheli* was observed in Meppadi and Payyannur respectively (Table 4).

The presence of *B. phoenicis* could be recorded from 9 species of fruit crops and 5 species of plantation crops. The fruit crops which showed infestation by *B. phoenicis* were *P. edulis, P. guajava, C. sinensis*, *C. limon, C. maxima, V. vinifera, S. samarangense, C. papaya* and *A. altilis* while the plantation crops were *H. brasiliensis*, *T. grandis, A. catechu, C. arabica* and *C. sinensis*. The sampling localities from which the above mite species

recovered were Attingal and Palode in Trivandrum district, Karunagapalli in Kollam district, Ranni and Konni in Pathanamthitta district, Moncompu in Alappuzha district, Pala in Kottayam district, Marayur in Idukki district, Kothamangalam and Aluva in Ernamkulam district, Kunnamkulam in Thrissur district, Mannarkkad in Palakkad district, Calicut University Campus and Pallikkal in Malappuram district, Pantheerankavu and Thamarasseri in Kozhikode district, Meppadi and Kattikulam in Wayanadu district, Iritti and Payyannur in Kannur district and Kanhangad and Manjeswaram in Kasargod district.

The second species of the genus viz. *B. obovatus* showed its distribution on the fruit plant, *P. granatum* and plantation crops, *C. sinensis* and *S. aromaticum*. The sampling localities of *B. obovatus* were Palode in Trivandrum district, Ranni and Konni in Pathanamthitta district, Pala and Mundakayam in Kottayam district and Marayur in Iduki district. The occurrence of *B. obovatus* was also reported from the localities of Northern districts of Kerala *viz.* Nelliyampathy in Palakad district, Calicut University Campus and Pallikkal in Malappuram district, Thamarasseri in Kozhikode district, Meppadi and Kattikulam in Wayanadu district and Manjeswaram in Kasargode district. However, the results of the present study disclosed relatively less incidence of *B. obovatus* than that of *B. phoenicis*.

B. californicus was the third species of false spider mite recovered from the fruit and plantation crops of Kerala and the species was found inhabiting on 2 species of fruit plants viz. *C. maxima, A. reticulata* and 1 species of plantation crop, *T. cacao.* Its incidence was very low and its habitat included Palode in Trivandrum district, Kollam in Kollam district, Ranni in Pathanamthitta, Pala and Mundakayam in Kottayam district, Marayur in Iduki district. The occurrence of this mite also was recorded from Nelliyampathy in Palakkad district, Calicut University Campus and Pallikkal in Malappuram district, Thamarasseri in Kozhikode district and Meppadi and Kattikulam in Wayanadu district.

Two species of the genus *Dolichotetranychus* viz. *D. floridanus* and *D. cocos* could be detected in association with the plantation crops cultivated/grown in various places of Kerala. Of these, the former species showed its incidence on a single host plant viz *A. catechu*. The distribution of *D. floridanus* was recorded from the following localities *viz.* Attingal and Palode in Trivandrum district, Ranni in Pathanamthitta district, Cherthala and Moncompu in Alappuzha district, Pala and Mundakayam in Kottayam district, Thekkady in Idukki district, Kothamangalam in Ernamkulam district, Irinjalakuda and Kunnamkulam in Thrissur district, Nelliyampathy in Palakad district, Pallikkal in Malappuram district, Thamarasseri and Kattikulam in Wayanadu district, Iritti and Manjeswaram in Kannur and Kasargode districts

respectively. The latter species, *D. cocos* could be recovered from *C. nucifera*, the coconut trees cultivated in Pallikkal in Malappuram district.

The Red Palm mite *R. indica* was recognized as a serious pest of 3 plantation crops viz. *A. catechu, C. nucifera* and *M. acuminata* during the period of survey. The incidence of RPM was observed on the above host plants in almost all localities of Kerala except Moncompu and Changanassery. *R. macfarlanei* was another species collected under the genus *Raoiella* from a fruit cum medicinal plant viz. *S. cumini* grown in places like Palode in Trivandrum district, Pala and Mundakayam in Kottayam district, Marayur in Idukki district, Nelliyampathy in Palakkad district, Calicut University campus and Pallikkal in Malappuram district, Thamarasseri, Meppadi and Kattikulam in Kozhikode and Wayanadu district and Manjeswaram in Kasargode district.

C. pulcher was found associated with a single host plant *M.domestica* and the incidence of *C.pulcher* was very low and it was recorded in Calicut University campus from Malappuram district .

Of the various species of tenuipalpid mites seen in association with the fruit cum plantation crops of Kerala listed above, 5 species viz. *T .chiclorum*, *T. micheli, D. floridanus*, *R. indica* and *B. phoenics* were distributed widely and the abundance of these species was comparatively higher than that of the other species of tenuipalpid mites recovered and hence they were considered

as the dominant species of the tenuipalpid mites associated with fruit and plantation crops of Kerala exhibiting severe infestation and conspicuous damage symptoms on respective host plants.

The population density, distribution pattern and abundance of the various tenuipalpid species selected for detailed biological studies showed variation with respect to variations in sampling localities and host plants surveyed. Accordingly, *R. indica* was recognized as the most widely distributed species on host plants surveyed during the current study as it could be collected from 27 out of the 28 localities surveyed (Table 4). *D. floridanus* could be identified as the species with highly restricted distribution trend and its presence could be observed in 17 localities out of the total 28 surveyed. Infestation by *T. chiclorum*, *T. micheli* and *B. phoenics* was observed on plants collected from 16, 19 and 22 localities respectively, and variations could be noted in the intensities of these species.

Results of field studies enabled to locate variation in the seasonal distribution pattern of the various species of tenuipalpid mites collected during the present study (Table 3). Infestation by species like *T. chiclorum*, *T. micheli, R. indica* and *B. phoenicis* was evident throughout the year irrespective of seasonal variation. *D. floridanus* was found infesting on the host plant, *A. catechu,* during the period May- October in every year. The peak population density of *D. floridanus* on *A. catechu* was observed in

Kunnamkulam, Thrissur district during the period of May- July. Moderate populations of the species could be noted in August and then a decline could be observed and the population became scanty in September and October months. During the period of November to April, the species was found absent on the host plat, *A. catcheu*.

T. micheli produced highest population during the period of March – May, moderate population in the period of December to February and during the period of June- November the population documented was scanty on the host plant *S. cumini* in Pantheerankavu, Kozhikode district. During the time of February – May, *T. chiclorum* formed highest population density on the host plant, *M. zapota.* In the period of November – January *T. chiclorum* population was moderate and from June to October the population was scanty on host plant *M. zapota* in Calicut University campus, Malappuram District. *R. indica* showed peak population in the April and May; moderate population during the period of November –March and the population were scanty in the time of June – October on the host plant *A. catcheu* in the survey area Pallikkal, Malappuram district. The *B. phoenics* was recorded from Pantheerankavu, Kozhikode district with peak population during the period of February – May. Moderate population was observed during November – January and the population was scanty in the time of June – October on the host plant *P. guajava* (Table 3).

B. TAXONOMICAL STUDIES

1. Morphological description of life stages of *B. phoenicis*

Egg (Plate 50, Fig4)

Measurements: Length: 97- 101µm

Width: 70- 73 µm

Eggs when freshly laid appeared elliptical and bright orange – red in colour. The colour of the eggs then changed into dull red and a shiny coating became visible on the egg. Eye spots of the larva could be clearly visible through the egg case, one day prior to hatching.

Larva (Plate 2, Fig 1 &2; Plate 50, Figs 5&6)

Measurements: Length: 140 - 145 µm

Width:85 - 90 µm

Dorsal region

Almost rounded in shape, transparent; body with fine striations of varying nature at different regions; rostrum rounded and protruding anteriorly; stylets short and protruding beyond the rostral apex; 3 pairs of prodorsal setae, *v2, sc*1and *sc2; v*2 small and lanceolate; 9 pairs of dorsal opisthosomal setae, *c1,c3,d1,d3,e1,e3,f3,h1* and *h2*; *h* 2 smooth and small; *f3, h1* large and lanceolate; *c1, d1, e1* smooth and dorsocentral.

Ventral region

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

Protonymph (Plate 2, Figs. 3 &4 ; Plate 50, Figs 7)

Measurements: Length: 182 - 184 µm

Width:110 -115 µm

Dorsal region

Striations present; rostrum narrow and protruding; stylets long, parallel, running forward, extending far beyond the anterior margin of the rostrum; pedipalp 4 segmented; propodosoma broader posteriorly; 3 pairs of prodorsal setae, *v2,sc1,sc2;* 9 pairs of dorsal opisthosomal setae (as mentioned in larva), *h2* 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 with well developed anal plates; 4 pairs of legs, all terminating in well developed empodia.

Deutonymph (Plate 3, Figs. 3 &4; Plate 50, Figs. 9)

Measurements: Length: 260- 265 µm

Width: 140-144 µm

Dorsal region

Entire surface of body including legs reticulated; rostrum stout and broad; ; rostral shield poorly developed; stylets discernible; anterior region of propodosoma more straightened; dorsal setae larger than setae of ventral side; 9 pairs of dorsal opisthosomal setae.

Ventral region

1 pair of aggenital setae (*ag1*); genital plate (GP) developed with one pair of genital setae (*g1*); anal plate (AP) highly developed; 2 pairs of smooth pseudo anal setae, *ps1* and *ps2*.

Adult Female (Plate 1, Figs. 1-6; Plate 50, Fig. 1; Plate 3. Figs. 3 &4)

Measurements: Length:290 -295 µm

Width:160 – 162 µm

Dorsal region

Rostral shield well developed; stylets basally originate; pedipalp stout, four segmented; a pair of well developed eyes present; striations clearly

marked; ornamentation ranges from smooth to reticulate; verrucose, aerolate and colliculate; cuticular feature often present on the body surface; 9 pairs of dorsal opisthosomal setae, *f3 , h2,* and *h1* small and smooth.

Ventral region

Ventral setae smooth; ventral plate (V.P), anal plate (A.P.) and genital plate (G.P.) well developed; one more pair of genital setae (*g2*) added; 2 pairs of pseudo anal setae (*ps1* and *ps 2*); genital setae thicker than *ag* and *ps*; legs 6 segmented; tarsus 1 with a single solenidion (ω), tarsus II with two solenidia (ω 1 and ω 2).

2. Morphological description of life stages of *D. floridanus*

Egg (Plate 53, Fig. 2)

Measurements: Length: 140- 145µm

Width: 85 - 90 µm

Eggs were elliptical, orange -red in colour, smooth and sticky. Two days prior to hatching, the egg turned to opaque white. At this stage, two red to black coloured eye spots of the fully developed larva were clearly visible inside the egg case.

Larva (Plate 6, Figs 1&2; Plate 53, Fig. 3)

Measurements: Length: 160 - 165 µm

Width: 95 - 100 µm

Dorsal region

Body creamy white to pale yellow in colour, transparent with fine irregular striations on the hysterosoma and propodosoma; stylets protruding beyond the rostral apex; 3 pairs of longer and serrate dorsal propodosomal setae, *v2, sc1* and *sc2;* idiosoma elongate and slender; 2 pairs of dorso centrals *c1, d1,* 1pair of dorsal sublaterals *c2,* 6 pair lateral setae *c3, d2, e1, e2, f2* and *f1*; dorsal and lateral setae longer than those of the adult.

Ventral region

Ventral integument with weak, tuberculate striations; 2 pairs of ventral setae present, 1 pair of anterior medio ventral propodosomal setae, *1a*, 1 pair inter coxal setae *3a*, seta *1a* larger than *3a;* genital area feebly developed; 2 pairs of pseudoanal setae, *ps1* and ps_2 present, ps_1 larger than ps_2 ; legs 3 pairs, all 6 segmented.

Protonymph **(**Plate 6, Figs 3 & 4; Plate 53, Fig. 6)

Measurements: Length: 180 - 185 µm

Width: 110 - 115 µm

Dorsal region

Body creamy yellowish in colour; striations present on the body; stylets long ; propodosoma elongate posteriorly; 3 pairs of prodorsal setae, *v2, sc1,sc2* present; idiosoma with irregular transverse and longitudinal median lines; 9 pairs of dorsal hysterosomal setae (as mentioned in larva); protonymph differs from larva in having 4 pairs of legs; all legs six segmented.

Ventral region

3 pairs of ventral setae present, *1a*, *3a* and *4a*; *1a* longer than other two; 1 pair of aggenital setae (*ag*) present; genital area indistinct and without setae; anal area well demarcated with 2 pairs of pseudo anal setae ps_1 and ps_2.

Deutonymph (Plate 7, Figs 1 & 2; Plate 53, Fig. 1)

Measurements: Length: 300 - 310µm

Width: 120 - 130 µm

Dorsal region

The body of the deutonymph elongate, slender and orange red in colour ; stylets long; rostrum elongated and reaching base of femur I; rostral shield absent; pattern of dorsal chaetotaxy similar to that of protonymph; body with 3 pairs of dorsal setiform and serrate propodosomal setae; 9 pairs of hysterosomal setae; idiosoma with longitudinal and tansverse striations; hysterosoma with irregular transverse median lines.

Ventral region

Three pairs of ventral setae, *1a, 3a*, and *4a* present *,1a* long and flagelliform, *4a* shorter than *3a*; one pair of aggenital setae (*ag1*) present; genital area developed with one pair of seta, g_1; anal area developed; two pairs of smooth pseudo anal setae, *ps1* and *ps2* present; 4 pairs of legs present, all 6 segmented.

Adult Female (Plate 4, Figs 1-4; Plate 8, Figs.1 & 2)

Measurements: Length: 380 - 390 µm

Width: 130 -140µm

Dorsal region

Body dark red in colour, elongate- oval, without rostral shield; eyes 2 pairs, 1 pair on each side of the body; palp 3 segmented, palp tarsus with one solenidion (*ω*), one eupathidium and one seta, penultimate segment bears one seta; 3 pairs of propodosomal setae (*v*2*, sc1,sc2*) present, *v*2 half as long as the distance between their bases; hysterosoma with 9 pairs of setae , all sparsely serrate and setiform; 2 pairs of central setae (*c1, d1)*, 1 pair sub lateral setae (*c*2) and 6 pairs of dorsolateral setae(*c3, d2, e1, e2, f2,f1*) the 5th pair of dorsolateral seta (*f2)* strongest and longest than the other dorsal setae; longitudinal smooth striations on propodosoma and hysterosoma while transverse striations on anterior region of propodosoma and hysterosoma.

Ventral region

Irregular, longitudinal and tuberculate striations present on the entire ventral surface of the body ; 3 pairs of ventral setae present, *1a, 3a* and *4a*; *3a* longer than *4a*; *1a* the longest; reaching femur I; one pair aggenital setae (*ag*) present anterior to the genital flap; genital flap indistinct, genital area with 2 pairs of setae (g_1, g_2); aggential and genital setae hair like and

subequal in length; 2 pairs of pseudo anal setae (*ps1* and *ps 2*) inserted close to each other; pseudo anal setae shorter than the genital setae; legs 4 pairs, all six segmented, dorsal seta on femur- I very long while that of femur- 2 shorter , tarsus- I and tarsus-II with a single solenidion each; tarsal claws hooked and uncinate.

Adult Male (Plate 4, Figs. 5-6; Plate 8, Figs 3 &4 ; Plate 53 & Fig. 4)

Measurements: Length: 280 - 290 µm

Width: 110 - 115µm

Dorsal region

Body slender and elongate, hysterosoma tapering towards posterior end; rostrum extending to distal end of femur I; dorsal setal arrangement and striation pattern similar to those of the female; males smaller than the females and with a triangular posterior opisthosoma; aedeagus stylet like.

Ventral region

Microtuberculate striations present on the ventral surface; 3 pairs of ventral setae present, *1a, 3a* and *4a*; one pair aggenital setae present anterior to the genital plate; 2 pairs of genital setae (*g1* & *g2*) located; 2 pairs of pseudo anal setae (*ps1* and *ps 2*), *ps1* thicker than *ps 2*; legs 4 pairs , all six segmented; leg chaetotaxy same as that of the female, except that two solenidia present on tarsi I and II.

3. Morphological description of life stages of *R. indica*

Egg (Plate 56, Fig. 4)

Measurements: Length: 100 µm

Width: 90 µm

Freshly laid eggs were bright red in colour, smooth, sticky and with a long stipe. The stipe was found to carry a droplet of an unknown fluid at its tip. Eggs turned to opaque –white on the previous day of hatching.

Larva (Plate 9; Figs. 1 &2; Plate 56, Fig. 6)

Measurements: Length: 120 - 130 µm

Width: 100 - 110 µm

Dorsal region

Body bright orange red in colour, oval, with fine striations ; stylets short and protruding beyond the rostral apex; dorsal and lateral setae shorter than those of the adult; propodosoma with 3 pairs of setae, *v2, sc1* and *sc2;* 13 pairs of dorsal opisthosomal setae including 3 pairs of centrals (*c1, d1 ,e1)* 4 pairs of sublaterals (*c2, d2, e2,f2*), 6 pairs of laterals *(c3, d3,e3,f3,h1, h2), h2* very short.

Ventral region

Striations present; 2 pairs of ventral setae present, 1 pair medioventral propodosomal setae (*1a*), 1 pair inter coxal setae *(3a*), *1a* larger than *3a*; genital area indistinct, 2 pairs of pseudoanal setae (*ps1* and *ps2)* detected; 3 pairs of legs, all 6 segments present.

Protonymph (Plate 9, Figs 3&4; Plate 56, Fig. 5)

Measurements: Length: 170 - 190 µm

Width: 130 - 140 µm

Dorsal region

Striations present on the body; stylets long; pedipalp 2 segmented; propodosoma broader posteriorly; 3 pairs of prodorsal setae (*v2, sc1, sc2)* seen; 13 pairs of opisthosomal setae (as mentioned in larva), 1st and 2nd laterals longer than the sublaterals; protonymph differs from larva in having 4 pairs of legs, all legs six segmented.

Ventral region

Three pairs of ventral setae present, *1a, 3a* and *4a*; *1a* longer than the other two; 1pair of aggenital setae (*ag);* anal area well demarcated with 2 pairs of pseudo anal setae, *ps1* and *ps2;*

Deutonymph (Plate 10, Fig 1 & 2; Plate 56, Fig. 5)

Measurements: Length: 230 - 240µm

Width: 170 - 180 µm

Dorsal region

Body broadly oval and dark red in colour; broadly oval; entire surface with black patches; stylets long and basally originate; dorsal chaetotaxy pattern same as that of protonymph and adult; 13 pairs of dorsal opisthosomal setae; droplets of unknown fluid present on dorsal setae, when alive or frozen.

Ventral region

Gnital plate (GP) developed with one pair of genital setae (*g1*); 1 pair of aggenital setae (*ag1*) present; anal plate (AP) developed; 2 pairs of smooth pseudo anal setae, *ps1* and *ps2* observed.

Adult Female (Plate 8, Figs 1-6; Plate 11, Figs 1&2; Plate 56, Figs. 1 &2)

Measurements: Length: 250 - 270 µm

Width: 200 - 210µm

Dorsal region

Body dark red with prominent black patches, oval in outline and without rostral shield; palp 2 segmented, one solenidion (ω), one eupathidium

and one companion seta detected dorsally; eyes 2 pairs, 1 pair on each side of the body; anterior margin of prodorsum smoothly rounded with a notch; dorsal setae spatulate and arise from tubercles; propodosomal setae 3 pairs; humeral setae one pair; hysterosomal setae 12 pairs; central setae, *c1, d1* weakly spatulate and *e1* tapered, *e1* smaller than that of the nymphal stages; lateral setae(*h2*) setiform, with finely tapering tip; seta *f2* shorter than *f3*; legs 4 pairs, all 6 segmented, 1st & 2nd with 4 setae, genu 1st & IInd with 3 setae, each tarsi 1st & IInd with companion setae, longer than solenidion.

Ventral region

Striations present on entire body surface, which often transverse medially; 3 pairs of ventral setae present, *1a, 3a* and *4a*; one pair of aggenital setae present anterior to the genital plate; genital plate (GP.) well developed, bearing 2 pairs of setae (*g*1, *g2*); 2 pairs of pseudo anal setae (*ps1* and *ps 2*) inserted distant to each other, minutely serrate, all other ventral setae simple.

Adult Male (Plate 8, Figs. 7 & 8; Plate 12, Figs 1&2; Plate 56; Figs. 9)

Measurements: Length: 220 - 230 µm

Width: 150 - 160µm

Dorsal region

Males smaller than the females, with a triangular posterior opisthosoma; dorsal setae spatulate and arise from tubercles, dorsal setal pattern resembles that of the female; aedeagus stylet like.

Ventral region

Three pairs of ventral setae present, *1a, 3a* and *4a*; one pair aggenital setae present anterior to the genital plate; 2 pairs of genital setae (*g*1 & *g2*) located; 2 pairs of pseudo anal setae (*ps1* and *ps 2*) inserted distant to each other, *ps1* short and thicker than *ps 2*.

4. Morphological description of life stages of *T. micheli*

Egg (Plate 59, Figs. 3 &4)

Measurements: Length: 95- 98µm

Width: 70 - 73 µm

Eggs when freshly laid appeared as elliptical and bright orange- red in colour. Two days prior to hatching, colour of eggs changed into dull red and

a silvery white coating appeared on the egg surface. Eye spots of the larva could be clearly visible through the egg case, one day prior to hatching.

Larva (Plate 14, Figs 1&2; Plate 59, Fig. 5)

Measurements: Length: 125 - 130 μm

Width:90 - 100 μm

Dorsal region

Body more or less oval in appearance, red coloured and transparent with fine striations of varying nature at different regions; rostrum oval and protruding anteriorly; stylets short; 3 pairs of propodosomal setae, *v2, sc1* and *sc2*, *sc2* long, *sc1* small; 1 pair of smooth and long humeral setae (*c3),* 3 pairs of dorsocentral setae (*c1, d1,e1),* 6 pairs of caudolateral setae (*d3*,*e3*,*f2*,*f3*, *h2* and *h1)* present, *h2* flagelliform and smooth.

Ventral region

1pair of short anterior medioventral seta *3a*; genital area indistinct, 2 pairs of smooth, pseudo anal setae present (*ps1* and *ps2)*; 3 pairs of legs, each terminates in an empodium.

Protonymph (Plate 14, Figs. 3 &4; Plate 59, Figs. 6&7)

Measurements: Length: 200 - 204 µm

Width:130 -135 µm

Dorsal region

Striations poorly developed; rostrum narrow and protruding; stylets long, extending beyond the anterior margin of the rostrum; propodosoma broader anteriorly; pedipalp 3 segmented; 3 pairs of propodosomal setae, *v2, sc1* and *sc2.* body setae setiform, serrate;10 pairs of dorsal hysterosomal setae (as mentioned in larva) present, *h2* long, smooth, flagelliform.

Ventral region

One pair of short anterior medioventral setae *3a*; single pair of longer posterior medioventral setae *4a*; 1 pair of plumose aggenital setae (*ag*1) and 2 pairs of smooth pseudo anal setae(*ps1* and *ps2)*; anal area demarcated; 4 pairs of legs, all 6 segmented with tarsi terminating in well developed empodia.

Deutonymph (Plate 15, Figs. 1&2; Plate 59, Fig. 8)

Measurements: Length: 260- 265 µm

Width: 140-150 µm

Dorsal region

Entire surface of body including legs reticulated; dorsal medial area possess wide transverse striations; rostrum conical and notched; rostral shield poorly developed; stylets discernible; anterior region of propodosoma more broad; 13 pairs of dorsal idiosomal setae (as mentioned in earlier stages).

Ventral region

Ventral and genital plates fused together; venter with a single pair of short anterior medioventral setae, *3a* and a single pair of longer posterior medioventral setae *4a*; 1 pair of aggenital setae (*ag1*) and 1 pair of genital (*g1*) present, both plumose; anal plate (AP) poorly developed; 2 pairs of pseudo anal setae(*ps1* and *ps2)* visible.

Adult Female (Plate 15, Figs. 3 &4; Plate 59, Fig. 1; Plate 13, Figs. 1-4)

Measurements: Length:280 -290 µm

Width:150 – 160 µm

Dorsal region

Striations clearly marked; one pair of well developed eyes present; rostral shield well developed; dorsal surface rugose with a series of longitudinal oblique folds; broad flat projection of prodorsum over gnathosoma; stylets basally originate; pedipalp 3 segmented,1 pair of pectinate seta on 2nd segment and a solenidion on 3rd palpal segment; 3 pairs of propodosomal setae (*v*2*, sc*1 and *sc*2) present*, v*2 and *sc*2 lanceolate and serrate while *sc*1 setiform and serrate; 3 pairs of dorsocentral setae (*c1,d1,e1)* located*, c1* lanceolate and serrate, *e1* short and simple; 6 pairs of caudolateral setae (*d3*, *e3*, *f2* ,*f3* , *h2* and *h1)* present, *h2* long and flagelliform , *d3*, *e3*, *f2* ,*f3* and *h1* nonflagellate, lanceolate and serrate caudolateral setae.

Ventral region

Gnathosoma bears 1 pair of plumose setae; 2 pairs smooth ventral setae *3a* and *4a* seen, *4a* long smooth, single pair of posterior medioventral setae; ventral and genital plates fused together; 1 pair of plumose aggenital setae (*ag1*); one more pair of plumose genital setae (*g2*) added; anal plate (A.P.)

well developed; 2 pairs of smooth pseudo anal setae (*ps1* and *ps2*) visible; genital setae thicker than aggenital and pseudoanal setae.

Legs

Legs 4 pairs, all terminating in well developed empodium with tenent hairs, all legs 6 segmented, tarsi I & II with a single solenidion (ω) each ; serrate sub spatulate dorsal setae and lanceolate, serrate distal setae on femur I; short lanceolate, serrate inner setae and longer serrate outer setae on femur II.

Adult Male (Plate 16, Figs. 1 &2; Plate 13, Figs. 5-7; Plate 59, Fig. 2)

Measurements: Length: 240 - 250 µm

Width: 130 - 140µm

Dorsal region

Males similar but smaller than females; opisthosoma narrower posteriorly; dorsal setal and striation patterns resemble those of the female; hysterosoma divided into 2 parts; serrate dorsal body setae present; aedeagus stylet like.

Ventral region

Three pairs of ventral setae *1a*, *3a* and *4a* present; one pair of plumose aggenital setae (*ag*) present anterior to the genital setae; 2 pairs of

smooth genital setae (*g*1 & *g2*) seen; 2 pairs of smooth pseudo anal setae (*ps1* and *ps 2*), inserted posterior to genital setae.

Legs

Legs 4 pairs, all 6 segmented; leg chaetotaxy same as that of female.

5. Morphological description of life stages of *T. chiclorum*

Egg (Plate 62, Fig. 3)

Measurements: Length: 90- 95µm

Width: 70 - 75 µm

Freshly laid eggs appeared elliptical, flat and bright yellowish-orange in colour. A few days before to hatching, the colour of the eggs became faded and a silvery white coating developed on the egg surface. Two days prior to hatching, the red eye spots of the developing larva were clearly visible through the egg case.

Larva (Plate 18, Figs. 1-2; Plate 62, Fig. 5)

Measurements: Length: -115 - 120 µm

Width: 80 - 85 µm

Dorsal region

Body cream coloured, transparent with fine transverse striations dorsally; rostrum oval in appearance and protruded anteriorly; stylets short ; 3 pairs of long, slender propodosomal setae, *v2, sc1* and *sc2* present; 1 pair of smooth, long humeral setae (*c3)* present; 3 pairs of dorsocentral setae (*c1, d1, e1)* detected, *c1*and *d1* long and slender, *e1* short; 6 pairs of lateral setae (*d3,e3,f2,f3,h2* and *h1)* seen, *h2* flagelliform and smooth.

Ventral region

Two pairs of ventral setae (*1a* and *3a)* present , *1a* larger than *3a*; genital area indistinct, 2 pairs of smooth pseudo anal setae *ps1* and *ps2* visible.

Legs.

Three pairs of legs present, each terminates with an empodium and claw, all legs 6 segmented.

Protonymph (Plate 18, Figs. 3&4; Plate 62, Fig. 5)

Measurements: Length: -145- 150 µm

Width: - 95-100 µm

Dorsal region

Rostrum small, protruding anteriorad; stylets long, extending beyond the anterior margin of rostrum; transverse striations present dorsally; propodosoma broader anteriorly; pedipalp 1 segmented; body setae long, slender,serrate;10 pairs of dorsal hysterosomal setae (as mentioned in larva), *h2* long, smooth, flagelliform; 3 pairs of long, slender propodosomal setae *(v2, sc1* and *sc2)* present.

Ventral region

One pair of smooth pregenital setae *ag*1 present ; 2 pairs of smooth pseudo anal setae *ps1* and *ps2* detected, anal area well demarcated; 1 pair of posterior medioventral seta, *4a* and 2 pairs of anterior medioventral setae, *3a* seen.

Legs

Four pairs of legs, all terminating in well developed empodia and claws.

Deutonymph (Plate 19, Figs 1&2; Plate 62, Fig. 6)

Measurements: Length: 255 - 260 µm

Width: 130- 140µm

Dorsal region

Dorsal medial area with wide transverse, rugose striations ; rostrum conical and bifurcated; rostral shield poorly developed; stylets discernible; anterior propodosoma more broad; 3 pairs of slender, long, dorsal propodosomal setae (*v2, sc1* and *sc2)* located; 3 pairs of dorsocentral setae (*c1, d1, e1), c1*and *d1* long and slender, *e1* small and serrate; 7 pairs of caudolateral setae (c3,*d3,e3,f2,f3*, *h2* and *h1), h2* flagelliform and smooth, *c3* and *e3* long and slender .

Ventral region

Ventral and genital plates fused together. Three pairs of smooth ventral setae (*1a*, *3a* and *4a*) ; 1pair of long, 1 pair of small anterior medioventral setae *3a* ; 2 pairs of pseudo anal setae (*ps1* and *ps2)* present; one pair of plumose genital setae (*g1*) added; one pair of smooth, pregenital setae (*ag1*) detected.

Adult Male (Plate 17, Figs. 5-7; Plate 20, Figs 1&2; Plate 62, Fig. 2)

Measurements: Length: 210 – 220 µm

Width: 105-110 µm

Dorsal region

Males smaller than the females with narrow posterior opisthosoma; dorsal setal and striation patterns resemble those of the female, body setae smaller than those of the female; hysterosoma divided into 2 parts; dorsal body setae setiform, serrate.

Ventral region

3 pairs of ventral setae *1a, 3a* and *4a* present; 2 pairs of smooth genital setae (*g*1 & *g2*) present; one pair of smooth pregenital setae (*ag*) located anterior to the genital setae; 2 pairs of smooth pseudo anal setae (*ps1* and *ps 2*) inserted posterior to genital setae; aedeagus stylet like.

Legs

Four pairs of legs present, all legs six segmented; leg chaetotaxy same as in female; genu I & II each with a single solenidion (ω); stout, ensiform dorsal setae on femur I and rod like setae on femur II located.

Adult Female (Plate 17; Figs. 1-4; Plate 19, Figs 3&4; Plate 62, Fig. 1)

Measurements: Length: 300 - 310 µm

Width: 170 - 175µm

Dorsal region

Striations clearly marked; rugose honey comb design seen on the dorsocentral area; strong ridges present at the dorsolateral areas; cuticular feature often located on the body surface; rostral shield well developed and notched medially; stylets basally originate; flat projection of prodorsum over gnathosoma; pedipalp one segmented with a single setae; 3 pairs lanceolate and serrate propodosomal setae (*v2, sc1* and *sc2)* present*, sc1* smaller than *v2* and *sc2* ; 3 pairs of dorsocentral setae (*c1,d1,e1)* seen*, c1*and *d1* lanceolate and serrate, *e1* short, simple; 7 pairs lateral setae (*c3,d3*, *e3*, *f2* ,*f3* , *h2* and *h1)* located; *h2* long and flagelliform; non flagellateate lateral setae leaf like and of varying size; 1 pair of well developed eyes present.

Ventral region

Ventral plate weakly developed; transverse striations present ;ventral and genital plates fused together, anal plate (A.P.) well developed; one more pair of plumose genital setae (*g2*) added; 1 pair of smooth pre genital setae (*ag1*) seen; 2 pairs of smooth pseudo anal setae (*ps1* and *ps2*) present,

*ps1*smaller than *ps2* ; anal setae shorter than the genital setae; 4pairs smooth ventral setae (*1a, 3a* and *4a*) present.

Legs

Legs 4 pairs, all 6 segmented and terminating in well developed empodia, with tenent hairs; genua I & II each with a single solenidion (ω); stout, ensiform dorsal setae on femur I and rod like setae on femur II located.

C. FEEDING BIOLOGY

1. Assessment of damage induced by *B. phoenicis*

1.1. Qualitative assessment of damage

B. phoenicis was found to infest both surfaces of the leaves of *P. guajava*, in field and laboratory conditions. The entire colony of *B. phoenicis* was found to comprise females and all life stages of the species were reddish orange in colour, flat and elliptical in appearance. Generally, the mites showed a preference to inhabit leaves of plants grown in shaded areas. Lower surface of the leaves of *P. guajava* was found more preferred by the mite rather than the upper surface. Feeding was found more confined to the lower leaf surface, at the base of the lamina and leaf petiole, along the midrib and often edges of the leaf. All the active life stages of *B. phoenicis* were observed on the lower surface of the leaf and the adult mites were rarely observed on the upper surface when the mite population was high.

All life stages were found to display voracious feeding activity by sucking the leaf sap. The epidermal cells of the leaves were found pierced by the mites with 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 yellow or brown coloured patches (Plate 21). Generally, the infestation was observed along the mid rib of the leaves. The fully damaged leaves were yellow or brown in colour. The completely damaged leaves were found subjected to premature aging and eventually shed down.

1.2. Quantitative assessment of damage

Feeding by *B. phoenicis* was found to induce drastic changes in the different biochemical parameters studied. Photosynthetic efficiency of the leaves was also found severely affected by mite infestation.

1.2.1. Estimation of Chlorophyll

The uninfested, healthy leaves of *P. guajava* were found to contain a mean concentration of 0.81±0.03 mg/gm of chlorophyll 'a' and 0.91±0.03mg/gm of chlorophyll 'b' (Table 6; Plate 22.). In leaf samples infested by *B. phoenicis*, the amounts of both chlorophyll 'a 'and 'b' pigments were found reduced, and which could be recorded as 0.51±0.02 mg/gm and 0.71±0.02 mg /gm respectively (Table 6). Therefore, the per cent reductions in chlorophyll 'a' and 'b' pigments observed during the study were

36.75 ± 0.82 and 21.95 ± 0.62 respectively. The total chlorophyll content was also found to be decreased (29.12%) in mite infested samples (Plate 23). The results were analysed statistically and were found significant ($p<0.05$).

1.2.2. Estimation of Nitrogen

Results of comparative estimation of the total nitrogen content of uninfested and mite infested leaf samples of *P. guajava* leaf samples are presented in table (Table 10 & Plate 24). Mite infestation was found to lead to a drastic decrease in the nitrogen content. The uninfested *P. guajava* leaves showed an average amount of 20.77 ± 0.13 mg of nitrogen/gm where as infested leaf samples contained 9.89 ± 0.15 mg /gm. Thus the nitrogen content was found reduced by 52.25 ± 0.73% as a result of infestation by *B. phoenicis*. The results were analysed statistically and were found significant ($p<0.05$).

1.2.3. Estimation of Proline

Feeding by *B. phoenicis* was found to stimulate the production of proline by the leaves of *P. guajava* . This was proved quantitatively by recording an increased amount of proline in the mite infested leaves, the amount of which was averaged to 1.78 ±0.02 mg/gm (Table 14; Plate 25). The uninfested leaves presented a lower quantity of proline which could be recorded as 0.80 ±0.01 mg/ gm. The results were analysed statistically and were found significant ($p<0.05$).

1.2.4. Estimation of Phenol

The concentration of phenol was also found elevated owing to mite infestation. This was clearly evident in leaf samples of *P. guajava* infested by *B. phoenicis,* which revealed a mean quantity of 0.81±0.03 mg phenol/gram leaf tissue (Table 18; Plate 26). The uninfested leaves showed a reduced amount of phenol which could be recorded as 0.48±0.02 mg phenol/gram leaf tissue during the present study. The per cent elevation of phenol due to *B. phoenicis* was estimated as 69.90±2.76 (Table). The results were analysed statistically and were found significant ($p<0.05$).

1.2.5. Estimation of Photosynthetic Efficiency

A major decrease in chlorophyll fluorescence could be recorded in the leaves of *P. guajava* owing to infestation by *B. phoenicis*. The mean values of the photosynthetic parameters like Minimum fluorescence (F0), maximum fluorescence (Fm), variable fluorescence (Fv) , performance index (PI) and the area above the fluorescence curve between F0 and Fm (Kautsky curve) were found reduced in the mite infested leaf samples when compared to those of uninfested samples (Table 22; Plate 27). This clearly indicated that *B. phoenicis* infestation could affect the photosynthetic efficiency of the plant. The results were analysed statistically and were found significant ($p<0.05$).

2. Qualitative assessment of damage induced by *D. floridanus*

The habitat of *D. floridanus* was quite different from the other foliage dwelling species of tenuipalpid mites described above. The species, instead of the foliage of the host plant was found to colonize the inner concealed niches available under the perianth of tender nuts of areca palms. Each blotch of the tepals of tender arecanut harboured a large number of adults and immature stages of the species. All life stages were slender, reddish and delicate and on exposure to bright light were found died because of desiccation. Mite infested nuts were found to harbor varying number of colonies comprised of large number of individuals of *D. floridanus*. All active life stages exhibited voracious feeding habit by sucking the sap from the epicarp, around the point of attachment of the nut.

The shed nuts in most cases displayed a characteristic reddish discolouration at the area adjacent to the perianth. As a result of feeding activity of the life stages of the mites, the inner surface of the tepals showed the presence of longitudinal reddish, blister like, deformed corky tissue, in the form of irregular and small cracks. The initial symptom of damage by the species was the appearance of a brown patch at the base of young nuts, at the level of the perianth (Plate 28) At this stage, several aggregates of orange coloured life stages of the mite could be seen under the perianth, which were easily visible when the perianth was lifted up and observed under the

microscope. Later, the brown patches got enlarged and the epidermis was found cracked and occasionally, deep fissures were also developed (Plate 28). In many occasions, malformation of nuts was also observed and in severe cases of infestation, immature nut fall also occurred.

3. Assessment of damage induced by *R. indica*

3.1. Qualitative assessment of damage

Results of microscopic observation on the infested leaves of areca palm collected from different sampling localities enabled to understand the details of the nature and extent of infestation induced by the Red Palm mite (RPM). Infestation by this species was found confined to the lower surface of the foliage where colonies of different size in varying numbers could be located. Mite incidence was highest on the bottom frond leaflets of areca palm when compared to the top and middle frond leaflets. The number of mites recovered from a single leaflet was found to range from 50–100, during April which ensured easy detection of the mites even with unaided eyes in the field. All stages of the RPM were present in each colony and several such colonies could be located on the lower surface of individual leaflet. In the productive colony remnants of exuviae (cast skins) were more when compared to the live mites and these remnants were white in colour (Plate 29). All life stages of the RPM were reddish in colour as soon as they got moulted, whereas the adult females often had dark coloured areas on their body. Both the juvenile stages

and the adults of *R. indica* occurred in colonies on the lower surface of leaves and they actively sucked the leaf sap of the foliage of areca palms.

Feeding activity of large numbers of the different life stages of RPM resulted in the development of localised yellow patches at the feeding sites on the leaf lamina. On progressive feeding, these yellow patches coalesced and turned to bronze coloured (Plate 29) areas. Such leaves with large number of brown cloured leprotic patches and lesions were found dried, imparting a withered appearance to the plant.

3.2. Quantitative assessment of damage

Results of quantitative studies clearly established that infestation by *R. indica* on areca palms could induce the drastic alterations in various biochemical parameters. The photosynthetic efficiency of the leaves when measured using Handy Photosynthetic Efficiency Analyzer Instrument revealed that, the mite infested leaves had lowered photosynthetic efficiency.

3.2.1. Estimation of Chlorophyll

The amount of chlorophyll present in the mite infested and uninfested areca leaf samples on estimation revealed a drastic decline in both 'a' and 'b' pigments (Table 7; Plate 30). As shown in table 7, the mean amounts of chlorophyll 'a' in the uninfested and infested leaf samples recorded during the study were 1.25 ± 0.01 and 0.47 ± 0.01mg/gm tissue respectively. This

showed that the mite infested leaf samples had a loss of 62.21 ± 0.63 % of Chlorophyll 'a' pigment when compared to the uninfested leaves of areca . The amount of chlorophyll 'b' pigments recorded in the mite infested and uninfested areca leaves were 1.71 ± 0.02 and 0.72 ± 0.01mg respectively which showed a loss of 57.67 ± 0.73% chlorophyll 'b' owing to infestation by RPM. Total chlorophyll content was also recorded to be decreased due to the mite infestation (Plate 31). The results were analysed statistically and were found significant ($p<0.05$).

3.2.2. Estimation of Nitrogen

Similar to chlorophyll 'a' and 'b' pigments, RPM infestation was also found leading to loss in nitrogen content also. This was evident when the nitrogen contents of mite infested and uninfested leaf samples were estimated following Kjeldahl method. The results of nitrogen estimation in the mite infested and uninfested leaf samples are shown in table 11; Plate 32. As presented in the table, the mean amounts of total nitrogen in the uninfested and infested areca leaf samples were 23.31± 0.20 and 11.14 ± 0.14 mg per gram leaf tissue respectively. Thus the mite infestation was found to induce 51.92 ± 0.72 % loss of total nitrogen content in areca leaves. The results were analysed statistically and were found significant ($p<0.05$).

3.2.3. Estimation of Proline

The amount of proline in the mite infested and uninfested samples when estimated following the method of Bates *et al*. (1973) showed an increase in mite infested leaves (Table 15; Plate 33). The mean proline content of mite infested leaf sample recorded during the study was about 3 times that of the uninfested sample. Thus the RPM infestation was found to induce an increased production of proline, which could be accounted to 190.8% in the present study. The results were analysed statistically and were found significant ($p<0.05$).

3.2.4. Estimation of Phenol

Similar to proline content, the phenolic content of areca leaves also showed an increase owing to infestation by the RPM. The uninfested and infested areca leaves contained 1.40 ± 0.01 and 2.65 ± 0.02 mg of phenol/gram tissue respectively (Table 19; Plate 34). The per cent increase in phenol content due to *R. indica* was recorded as 91.18 ± 1.77%. The results were analysed statistically and were found significant ($p<0.05$).

3.2.5. Estimation of Photosynthetic Efficiency

Results of quantitative estimation of leaf damage induced by RPM infestation to the areca palm by measuring chlorophyll fluorescence using the Handy Photosynthetic Efficiency Analyzer Instrument revealed a major

reduction in the chlorophyll fluorescence. The mean values of various photosynthetic parameters like the Minimum fluorescence (F0), maximum fluorescence (Fm), variable fluorescence (Fv), performance index (PI) and the area above the fluorescence curve between F0 and Fm (Kautsky curve) showed reduction in the RPM infested areca leaves when compared to the uninfested samples (Table 23; Plate 35). The results were analysed statistically and were found significant ($p<0.05$).

4. Assessment of damage induced by *T. micheli*

4.1. Qualitative assessment of damage

The adult mites were observed on both surfaces of the leaves of *S. cumini* whereas the immature stages were more confined on the lower surface. Very seldom, presence of immature stages of *T. micheli* could be observed on the upper surface of leaves of *S. cumin*i. The individuals of *T. micheli* though were found actively feeding on both surfaces of *S. cumini* leaves, more preference was shown to the lower surface. All active life stages were found voraciously sucking the leaf sap, especially on the lower surface. The feeding activity was extended for 1-2 minutes at each feeding spot. Most of the mites were present on the leaves of bottom branches and the number of mites was lesser on the leaves of top. All life stages of *T. micheli* were reddish in colour and the adult females were dark red coloured.

The damage induced by *T. micheli* was predominantly concentrated near the mid rib of the host plant leaves where most of the adults were present. Microscopic observation on the feeding activity of these mites revealed that they could successfully pierce the leaf epidermis for sucking the leaf sap and which consequently led to silvering of the leaf tissue. The damaged portions of the infested leaves appeared as dark spots. In the initial stages of infestation, slight colour changes were observed, which later got converted in to light yellow patches and finally the damaged area became dark coloured (Plate 36). When the feeding spots were completely damages, the mites moved to adjacent areas in search of fresh areas of the leaves and initiated their feeding activity. The exuviae, egg cases and eggs were often found at the damaged area (Plate 36). The fully damaged leaves showed premature abscission.

4.2. Quantitative assessment of damage

The extent of damage induced by *T. micheli* was estimated quantitatively in several ways and the results of which are presented below.

4.2.1. Estimation of Chlorophyll

The chlorophyll 'a' and 'b' contents of uninfested and mite infested leaves of *S. cumini* were estimated following Arnon's method and compared to know the chlorophyll loss induced by the feeding activity of the mite. It was found that the average amount of chlorophyll 'a' content of uninfested

healthy leaves of *S. cumini* was 1.07 ± 0.02 mg/gm leaf tissue while that of the mite infested leaves was 0.72 ± 0.01mg (Table 8; Plate 37). The mean concentration of chlorophyll 'b' in uninfested leaves was 0.94 ± 0.02 mg/gm while the infested leaves contained a lower concentration (0.72 ± 0.01 mg /gm). Thus, in the present study, *T. micheli* was found to cause depletion of both chlorophyll 'a' and 'b' pigments, the percent of which were recorded as 32.31 ± 0.51 and 23.52 ± 0.40 respectively. The total chlorophyll content of mite uninfested and infested saples were recorded as 2.014 and 1.440 mg/gm respectively (Plate 38). The results were analysed statistically and were found significant ($p<0.05$).

4.2.2. Estimation of Nitrogen

A reduction in the total nitrogen content was also observed in the leaves of *S. cumini* as a result of infestation by *T. micheli*. As presented in table 12; Plate 39, the uninfested leaf contained an average amount of 10.81 ± 0.11 mg of nitrogen/gm of leaf sample where as the infested leaf samples contained 7.02 ± 0.06 mg of nitrogen/gm. Thus the infested leaves showed 34.38 % reduction in the total nitrogen content when compared to the uninfested leaves. The results were analysed statistically and were found significant ($p<0.05$).

4.2.3. Estimation of Proline

Unlike the earlier biochemical parameters**,** the amount of proline showed an increasing trend owing to mite infestation, as observed during the present study. The mean concentration of proline in uninfested and mite infested leaf samples of *S, cumini* could be recorded as 1.04 ± 0.01 and 1.74 ± 0.01 mg / 1gm of leaf sample respectively (Table 16; Plate 40). This indicated that *T. micheli* infestation caused an increase in proline production in the leaves of *S. cumini*, the per cent of which could be recorded as 68.33 ± 2.114 during the present study. The results were analysed statistically and were found significant ($p<0.05$).

4.2.4. Estimation of Phenol

Resembling the proline production, the phenol content also was found enhanced owing to infestation by *T. micheli*. As presented in table 20, Plate 48, the mean concentration of phenol in the uninfested leaf sample of *S. cumini* was 0.49±0.02 while that of the infested leaves was 1.05±0.03 mg /gram tissue. Thus the per cent increase in phenol recorded during the present study owing to infestation by *T. micheli* was 115.46±11.36**.** The results were analysed statistically and were found significant ($p<0.05$).

4.2.5. Estimation of Photosynthetic Efficiency

Infestation by *T. micheli* on *S. cumini* resulted in a significant reduction in chlorophyll fluorescence also. The mean values of various photosynthetic parameters like the Minimum fluorescence (F0), maximum fluorescence (Fm), variable fluorescence (Fv), performance index (PI) and the area above the fluorescence curve between F0 and Fm (Kautsky curve) were found reduced in the infested leaf samples when compared to those of uninfested leaves of *S. cumini* (Table 26). The results of the study indicated that *T. micheli* infestation would drastically affect the photosynthetic efficiency of the leaves of *S. cumini*. The results were analysed statistically and were found significant ($p<0.05$).

5. Assessment of damage induced by *T. chiclorum*

5.1. Qualitative assessment damage

In the present study, *T. chiclorum* was found predominantly infesting the bottom branches of *M.zapota*. The adults of *T. chiclorum* were brown in colour while the immature stages were whitish brown (Plate 43). All life stages of the species were present on the leaves where active feeding was observed. Immature stages were often found on the upper surface of the leaves while the adults showed more preference to the lower surface of the leaves. However, feeding by adults was observed on both surfaces of the leaf lamina. The adults were mostly found associated with the mid rib of the

leaves and maximum damage symptoms were found near the mid rib of the leaves. The feeding activity was found extended for 1-2 minutes at each feeding spot and the adults were recognized as voracious sap feeders when compared to the immature stages.

On microscopic observation, the various life stages of *T. chiclorum* were found to suck the leaf sap by piercing the epidermal cells of the leaves of *M. zapota*. As a result of piercing, light yellow spots were developed initially on the leaf surface, which on progressive feeding, turned to grey coloured areas. With the appearance of these grey to brown coloured patches, the infested leaves were found completely damaged which further were turned to black in colour. On exhaustion of green coloured sap and with the development of brown colouration, the active life stages of the mite were found migrating to fresh areas of the leaf in search of new feeding sites. Moulting skins, egg cases and eggs were seen left behind at the fed areas of the leaves.

5.2. Quantitative assessment of damage

Significant variations were observed in the various biochemical parameters of the leaves of *M. zapota* as a result of infestation by *T. chiclorum*. The feeding activity of *T. chiclorum* was found to result in significant reductions in chlorophyll pigments and photosynthetic efficiency of the leaves, nitrogen and protein contents of the plant etc. However, mite

infestation was found to lead to an enhanced production of proline, phenol etc. as observed during the study. The results of the various biochemical estimations are presented below.

5.2.1. Estimation of Chlorophyll

Results of quantitative assessment of chlorophyll 'a' and 'b' pigments present in the uninfested, healthy leaves and mite infested leaves of *M. zapota* are illustrated in Table 19. As presented in table 19; Plate 44, the uninfested leaves showed an average amount of 1.19±0.01mg/gm leaf tissues of chlorophyll 'a' while that of chlorophyll 'b' was recorded as 1.47±0.02 mg/gm. A reduced amount of both chlorophyll 'a' and 'b' pigments could be recorded in mite infested leaves. As shown in the table, the mean amount of chlorophyll 'a' was noted as 0.69 ± 0.02 mg/gm and that of chlorophyll 'b' was 0.79±0.01mg/gm of leaf tissue. The per cent reductions in chlorophyll 'a' and 'b' observed during the study were 42.67±1.16 and 46.45±1.03 respectively. The total chlorophyll content was also decreased by 43.67% due to the mite infestation (Plate 45). The results were analysed statistically and were found significant ($p<0.05$).

5.2.2. Estimation of Nitrogen

Result of quantitative studies on the total nitrogen content of mite infested and uninfested leaves of *M. zapota* revealed a drastic decrease in the nitrogen content due to mite infestation. The uninfested leaf samples

presented a mean concentration of 19.36 ± 0.15 mg of nitrogen/gm of leaf tissue where as the infested leaf samples contained 9.73 ± 0.11 mg /gm of total nitrogen. Mite infested leaf samples showed 49.43 ± 0.72% reduction in the total nitrogen content when compared to the uninfested leaves of *M. zapota* (Table 13; Plate 46). The results were analysed statistically and were found significant ($p<0.05$).

5.2.3. Estimation of Proline

A quantitative increase in proline was observed during the present study in the leaves of *M. zapota* owing to infestation by *T. chiclorum.* The proline content of uninfested leaves was 0.58 ± 0.01 mg / 1gm of leaf tissue whereas that of infested leaf was 1.57 ± 0.04 mg / 1gm (Table 17; Plate 47). The results were analysed statistically and were found significant ($p<0.05$).

5.2.4. Estimation of Phenol

An increase in phenol was observed in the mite infested leaves of *M. zapota.* The respective concentrations of phenol in uninfested and mite infested leaves were 0.48±0.02 and 0.69±0.29 mg phenol/gram tissue (Table 21). The per cent elevation of phenol due to infestation by *T. chiclorum* was estimated to be 46.27±3.87 (Table 21; Plate 48). The results were analysed statistically and were found significant ($p<0.05$).

5.2.5. Estimation of Photosynthetic Efficiency

Quantitative assessment of photosynthetic efficiency of *T. chiclorum* infested and uninfested leaves of *M. zapota* revealed a decrease in the mean values of the photosynthetic parameters like the Minimum fluorescence (F0), maximum fluorescence (Fm), variable fluorescence (Fv), performance index (PI) and the area above the fluorescence curve between F0 and Fm (Kitschy curve) (Table 25; Plate 49). Thus all photosynthetic parameters were found reduced as a result of mite infestation. The results were analysed statistically and were found significant ($p<0.05$).

D. BREEDING BIOLOGY

1. Breeding biology of *B. phoenicis*

1.1. Oviposition

Results of the field survey clearly revealed that the entire population of *B. phoenicis* was comprised of females. The pre-oviposition, oviposition and post-ovipositioin periods were found varied with respect to the temperature-humidity conditions. The mean duration of pre-oviposition period recorded on the host plant, P. *guajava* was 9 ± 0.05 days at 25 ± 2ºC & 80± 5% RH, 8.6 ± 0.05 days at 30 ± 2ºC & 70 ± 5% RH and 7.4 ± 0.08 days at 35 ± 2ºC & 60 ± 5% RH (Table 26; Plate 51).

The process of oviposition was initiated by the females from 7-9 days after their emergence. Generally, the females preferred the lower surface of the leaf lamina for oviposition. However, when the population density was high, the female mites laid eggs on the upper surface of the leaf also. Prior to oviposition, the females assumed a stationary posture and at the time of oviposition, lowered the hysterosoma to extrude the eggs. The eggs were laid singly normally, but often appeared in clusters as several eggs were laid side by side. Several such egg clusters were observed on the leaf surface, usually in the cracks, cervices and other protected areas on the leaves. The eggs were sticky, and firmly adhered to the leaf surface.

The oviposition period was also found varied depending up on the temperature and humidity conditions. At 25 ± 2°C & 80 ± 5% RH, the oviposition period could be recorded as 11.9 ± 0.12 days, while it was 10.6 ± 0.08 days at 30 ± 2°C & 70 ± 5% RH and 9 ± 0.08 days at 35± 2°C & 60 ± 5% RH (Table 26, Plate 51). The period of oviposition of *B. phoenicis* on the host plant, *P. guajava* was slightly high at low temperature and high RH. Subsequent to the oviposition period, the females became highly lethargic, and their feeding activity got diminished. The dark red colour of the body was found faded. This was recognized as the post-oviposition period, the end of which was marked by the death of the individuals. The mean durations of post -oviposition period were recorded as 8.9 ± 0.07 days at 25 ± 2°C & 80 + 5% RH, 8 ± 0.05 days at 30 ± 2°C & 70 + 5% RH and 6.9 ± 0.11 days at 35 ± 2°C & 60 ± 5% RH.

The rate of egg production per individual female was found varied with respect to the temperature-humidity conditions provided during the study period. The number of eggs laid by a single female during its oviposition period was 9-10 at 25 ± 2°C & 80 ± 5% RH, 10-12 at 30 ± 2°C & 70 ± 5% RH and 10-14 at 35 ± 2°C & 60 ± 5% RH (Table 27, 28, 29). The maximum number of eggs was laid on the 5th or 6th days of oviposition. The daily production of eggs by a single female was also found varying and was recorded as 2 at 25 ± 2°C & 80 ± 5% RH, 2 at 30 ± 2°C & 70 ± 5% RH and 3 at 35 ± 2°C & 60 ± 5% RH. The rate of egg production was found to decline from the 7th day onwards and quite often, the females did not lay any eggs on some days of the oviposition period.

The longevity of females of *B. phoenicis* was also subjected to variation according to the prevailing temperature - humidity conditions. The longevity was found maximum at 25 2°C & 80 5% RH. The longevity was recorded as 30 days at 25 ± 2°C & 80 ± 5% RH, 27 days at 30 ± 2°C & 70 ± 5% RH and 23 days at 35 ± 2°C & 60 ± 5% RH.

1.2. Eggs, Incubation and Hatching

Newly laid eggs were reddish in colour, elliptical and slightly broader at one pole (Plate 50). Two days prior to hatching, each egg was turned to opaque-white in colour and the red eyes of the larvae were clearly visible inside the egg case. Hatching was initiated after 3-6 days of incubation.

Duration of incubation showed variation with respect to altered temperature-humidity conditions (Table 30, 31,32; Plate 52). Initiation of hatching was marked by the appearance of a semicircular slit at the broader end of egg. Then the slit extended to either sides owing to the wriggling movements of the emerging larvae. As the slit got widened, the emerging larva protruded its first two pairs of legs through the slit. This was followed by the thrashing action of the larval propodosoma and movement of the legs. Later the larva was struggled out of the egg shell, leaving behind the egg case. The whole process of hatching was found completed within 20-25 minutes.

1.3. Duration of Developmental Stages

1.3.1. Larval Period

The newly hatched larva was small, six legged and bright orange-red in colour (Plate 50). It initiated feeding activity immediately after hatching. While feeding, the larva inserted its cheliceral stylets in to the leaf tissue and actively sucked the tissue fluid. As the feeding activity proceeded, the colour of the larva was found to change and it developed black and orange patches on the body. The duration of active larval stage was found to range from 4-6 days at 25 ± 2°C & 80 ± 5% RH, 4-5 days at 30 ± 2°C & 70 ± 5% RH and 3.5-5 days at 35 ± 2°C & 60 ± 5% RH (Plate 52). At the end of the active period, the feeding activity of the larva got diminished, and it became lethargic and gradually settled at a suitable spot on the leaf surface. This was distinguished

as the first quiescent stage and it lasted for 1 to 2.5 days. The end of I quiescence was marked by moulting which resulted in subsequent emergence of the I nymphal instar, the so called protonymph.

1.3.2. Nymphal stages

1.3.2.1. Protonymph

Protonymph resembled the larva in general appearance, but was larger in size and characterized by the presence of 4 pairs of legs. The integument appeared transparent with orange and black patches. It initiated feeding activity after a short interval of its moulting. With progressive feeding activity, the colour of the protonymph became more intense and the active period of the protonymph lasted for 5-6 days at 25 ± 2°C & 80 ± 5% RH, 5-6 days at 30 ± 2°C & 70 ± 5% RH and 4-5 days at 35 ± 2°C & 60 ± 5% RH (Table 30,31,32; Plate 52). At the end of the active period the feeding activity of the protonymph was found decreased and it entered in to the second quiescent phase and subsequent moulting resulted in the emergence of the deotoonymph.

1.3.2.2. Deutonymph

The newly emerged deutonymph was slightly larger in size and was pale in colour (Plate 50). It was found actively engaged in feeding and duration of feeding period was found varied depending upon the temperature-

humidity variations. At 25 ± 2ºC & 80 ± 5% RH, the active feeding period of *B. phoenicis* lasted for 5-6 days and it was 5-6 days at 30 ± 2ºC & 70 ± 5% RH and 3-5 days at 35 ± 2ºC & 60 ± 5% RH. Then the deutonymph entered in to the third quiescent phase and subsequent moulting of which resulted in the adult emergence.

1.3.3. Quiescent periods

At the end of each of the active stage of *B. phoenicis*, an inactive or quiescent phase was observed. Prior to the initiation of the quiescent phase, the feeding activity of the active instar got decreased and it became lethargic. Gradually the feeding activity was found completely arrested and the instar became immobile. Simultaneously, the body of the instar became turgid and shiny in appearance and the body assumed a characteristic posture, with its stylets penetrated into the plant tissue and legs stretched outwards. In the life cycle of *B. phoenicis*, three quiescent phases were observed viz. the first, second and third quiescent stages, at the end of the larval, protonymphal and deutonymphal stages respectively. The durations of quiescent stages recorded after each active period under different temperature humidity conditions provided during the current study are given in table 30,31,32. After the larval stage, 1.5-2.5 days at 25 ± 2ºC & 80 ± 5% RH, 1-2 days at 30 ± 2ºC & 70 ± 5% RH and 1-2 days at 35 ± 2ºC & 60 ± 5% RH. After the protonymph, 1.5-2 days at 25 ± 2ºC & 80 ± 5% RH, 1.5-2 days at 30 ± 2ºC & 70 ± 5% RH and

1-2 days at 35 ± 2°C & 60 ± 5% RH and after the deutonymph it was recorded as 1.5-2.5 days at 25 ± 2°C & 80 ± 5% RH, 1-2 days at 30 ± 2°C & 70 ± 5% RH and 1-2 days at 35 ± 2°C & 60 ± 5% RH (Plate 52).

1.3.4.Moulting

Removal of the outer cuticle of preceding instar was achieved through moulting and the process occurred at the end of each of the quiescent phase of *B. phoenicis*. The process of moulting was found lasted for 15-20 minutes. Prior to moulting, the outer cuticle of the quiescent instar became silvery white in colour and a horizontal slit was developed at the mid dorsal region of the body, between the 2nd and 3rd pairs of legs. The slit was further extended along either sides of the body and finally met ventrally. The backward thrust exerted by the moulting individual helped to widen the slit and emergence of anterior part of the body. The cuticle at the ventral region of the moulting individual remained intact for some time and then it was discarded by slow, sliding movements of the particular stage. The moulting skin was found glued to the leaf surface after the emergence of the particular instar.

1.3.5. Adult

In the present study, the entire population of *B. phoenicis* was found to comprise females alone and hence description of only females is included:

1.3.6. Female

The newly emerged body of the adult female appeared elliptical, flat and light red in colour (Plate 50). The newly emerged female remained in a resting posture for a while and then slowly started movement. It initiated feeding on the leaf sap of *P. guajava* and as feeding progressed, its body colour got changed into reddish black. The newly emerged females initiated oviposition with in 6-10 days depending up on the temperature-humidity conditions. The durations of pre-oviposition period recorded at different temperature and humidity conditions were 9 days at 25 ± 2°C & 80± 5% RH, 8.6 days at 30 ± 2°C & 70 ± 5% RH and 7.4 days at 35 ± 2°C & 60 ± 5% RH. The oviposition and post- oviposition periods also showed slight alterations with respect to variations in temperature –humidity conditions and which are presented in table 26.

1.3.7. Breeding pattern

In both laboratory and field conditions, the population of *B. phoenicis* was found to comprise only females. Thus the species was found to reproduce solely through parthenogenetic mode, giving rise to female progenies alone.

1.3.8. Duration of life cycle

The average durations of development under parthenogenetic mode of the species, from egg to adult on the host plant*, P. guajava* also showed slight

variations, according to the temperature-humidity conditions. The duration of development was recorded as 25-27 days at 25 ± 2°C & 80 ± 5% RH, 23-25 days at 30 ± 2°C & 70 ± 5% RH and 19-23 days at 35 ± 2°C & 60 ± 5% RH. The newly emerged females started laying eggs within 6 – 10 days at three different temperature and humidity conditions. Thus, the duration of F_1 generation was found completed within 52 – 59 days at 25 ± 2°C & 80 ± 5% RH, 49 – 53 days at 30 ± 2°C & 70 ± 5% RH and 42- 49 days at 35 ± 2°C & 60 ± 5% RH.

2. Breeding biology of *D. floridanus*

2.1. Oviposition

The adult females of *D. floridanus* were found to lay eggs on the inner part of the tepals of the nuts of areca palm (Plate 53). Resembling the adult mites, the eggs also were orange –red in colour and were commonly seen in groups, in close association. During oviposition, the female mites remained in a stationary posture and slightly lowered the posterior region of the hysterosoma for extruding the egg.

The pre-oviposition period of *D. floridanus* was found subjected to variation depending up on the changes in the humidity-temperature conditions. On the present host areca palm, the pre-oviposition period of the species was recorded as 2.45± 0.05 days at 25 ± 2°C & 80 ± 5% RH, 1.75 ± 0.03 days at 30 ± 2°C & 70 ± 5% RH and 1.45 ± 0.05 days at 35 ± 2°C &

60 ± 5% RH. The period of oviposition of *D. floridanus* was also found dependent on temperature and humidity conditions. It was observed that the mean duration of oviposition was 8.3 0.08 days at 25 ± 2°C & 80 ± 5% RH, 7.1 0 ±.03 days at 30 ± 2°C & 70 ± 5% RH and 6 ± 0.07 days at 35 ± 2°C & 60 ± 5% RH (Table 33; Plate 54).

The oviposition period was followed by a period marked by reduced feeding activity and sluggish behavior of the mites and this was distinguished as the post-oviposition period. Like the pre-oviposition and oviposition periods, the post-oviposition period of *D. floridanus* was also dependent on the prevailing temperature and humidity conditions. The average duration of post-oviposition period observed during the current study was 6.2 ± 0.08 days at 25 ± 2°C & 80 ± 5% RH, 4.5 ± 0.08 days at 30 ± 2°C & 70 ± 5% RH and 3.45 ± 0.05 days at 35 ± 2°C & 60 ± 5% RH (Table 33). As the days progressed, the mites became more and more inactive, and the feeding activity was found completely arrested. The normal orange-red colour of the body of the adult mites got faded and ultimately they were died.

The fecundity of mated and virgin females also got varied in accordance with the temperature-humidity variations. Results of the present study enabled to record comparatively lower rate of egg production during the initial days of oviposition and a progressive increase was observed in egg production to reach the peak level on the 3rd, 4th and 5th days of oviposition. A

subsequent decrease was noticed from the 7th day onwards. The rate of egg production recorded during the study was comparatively greater for the mated females than that of virgin females. The mated females laid more number of eggs when compared to the unmated virgin mites. The average rate of egg production by mated females at the varied temperature –humidity parameters was observed as 11.57 ± 0.11 at 25 ± 2°C & 80 ± 5% RH, 13.29 ± 0.11 at 30 ± 2°C & 70 ± 5% RH and 11.50 ±0.07 at 35 ± 2°C & 60 ± 5% RH. The rate of egg production by virgin females was still lower and averaged to 10±00 at 25 ± 2°C & 80 ± 5% RH, 12.33±0.19 at 30 ± 2°C & 70 ± 5% RH and 9.5±0.35 at 35 ± 2°C & 60 ± 5% RH (Table 34,35,36).

The longevity of the mated and virgin females of *D. floridanus* also showed variation. The longevity of mated females was comparatively greater than that of the virgin females. The longevity of the females of the species at the different temperature and humidity conditions was found averaged to 17.64± 0.17days (mated) and 16± 0.33 days (virgin) at 25 ± 2°C & 80± 5% RH , 13.64± 0.12 days (mated) and 12.67± 0.19days day (virgin) days at 30 ± 2°C & 70 ± 5% RH and 11.37± 0.12 days (mated) and 9± 0.00 days (virgin) at 35 ± 2°C & 60 ± 5% RH (Table 34,35,36;Plate 54) .

2.2. Egg, Incubation and Hatching

The eggs of *D. floridanus* were orange red in colour, and apparently oval (Plate 53). The eggs were found adhered to the lower surface of the

tepals of arecanut. Eggs measured 140 µm approximately reaching 1/3 of the size of the adult mite and were turned to opaque prior to hatching.

The incubation period was found varied depending up on the difference in the temperature and humidity conditions. The period of incubation under different temperature and humidity conditions was recorded as 8.55 ± 0.07 days at 25± 2°C & 80 ± 5% RH , 6.75 ± 0.11 days at 30 ± 2°C & 70 ± 5% RH and 6 ± 0.06 days at 35 ± 2°C & 60 ± 5% RH (Table 37,38,39& Plate 55). The end of incubation period was marked by the process of hatching and the latter was found initiated within 5.5-10 days of incubation.

Prior to hatching, presence of two black eye-spots was very evident through the egg case, and which corresponded to the head region of the developing larva. The process of hatching was initiated with the appearance of a semicircular slit at the broader end of the egg and the slit proceeded to either sides. Widening of the slit was intensified by the rhythmic movement of the hatching larva inside the egg case. When the slit got widened, the emerging larva protruded its first two pairs of legs through the slit and this was followed by the thrashing action of the larval propodosoma and subsequent movement of the basal leg segments. Soon after, the larva struggled out of the egg case and the hatching process was completed within 15-20 minutes.

2.3. Duration of Developmental Stages

2.3.1. Larval Period

The newly hatched larva of *D. floridanus* was a hexapod with a pale-cream coloured body and the posterior end was more or less oval (Plate 53). The larva measured approximately 160µm and it initiated feeding activity immediately after hatching. The mean durations of the active larval period under the different temperature-humidity conditions were recorded as 4.4 ± 0.07days at 25 ± 2°C & 80 ± 5% RH, 4.25±0.11 days at 30 ± 2°C & 70 ± 5% RH and 2.75±0.09 days at 35 ± 2°C & 60 ± 5% RH (Table 37,38,39; Plate 55). At the end of active period, the feeding activity of the larva was found diminished and it became indolent and gradually settled at a suitable spot on the leaf surface. This stage was manifested as the first quiescence stage and which lasted for 2 to 3 days. At the end of this quiescence phase, moulting occurred, leading to the emergence of protonymph.

2.3.2. Nymphal stages

2.3.2.1. Protonymph

The protonymph greatly resembled the preceding stage in general appearance but was slightly larger and characterized by the possession of 8 legs (Plate 53). The protonymph of *D. floridanus* was yellow in colour and was quite motile. After a short interval of moulting, it started to suck the plant

sap. Its feeding activity was more intense than that of the larva and the feeding period varied depending up on the temperature – humidity variation. The protonymphal period was found to last for an average of 3.65 0.08 days at 25 ± 2°C & 80 ± 5% RH, 3.05± 0.08 days at 30 ± 2°C & 70 ± 5% RH and 2.50 ± 0.07 days at 35 ± 2°C & 60 ± 5% RH (Table 37,38,39 & Plate 55). Gradually, the feeding activity was found decreased and the protonymph entered in to the second quiescent phase which on subsequent moulting led to the emergence of the deutonymph.

2.3.2.2. Deutonymph

The colour of the newly moulted deutonymph was bright orange and it was relatively more motile and exhibited active leaf sucking habit (Plate 53). The deutonymph was comparatively larger than the protonymph and its active feeding period was relatively more. The average deutonymphal periods recorded during the current study at the various temperature-humidity conditions tested were 5.6± 0.08 days at 25 ±2°C & 80 ± 5% RH, 4.75± 0.11 days at 30 ± 2°C & 70± 5% RH and 3.80 ± 0.04 days at 35 ± 2°C & 60 ± 5% RH (Table 37,38,39 & Plate 55). The deutonymph later became sluggish and lethargic and stopped feeding activity to enter in to the third quiescent phase which up on subsequent moulting, gave rise to the emergence of the adult.

2.3.3. Quiescent periods

The life cycle of *D. floridanus* was found to comprise three quiescent phases *viz*. the first, second and third quiescent stages, each at the end of the larval, protonymphal and deutonymphal stages respectively. Prior to the initiation of each quiescent phase, the instar became sluggish, highly lethargic with decreased feeding activity. Up on quiescence, the instar became completely immotile and non-feeding. The durations of the first and second quiescent phases recorded during the study at the varied temperature-humidity parameters were the same and were 2-3 days at 25 ± 2°C & 80 ± 5% RH, 2-2.5 days at 30 ± 2°C & 70 ± 5% RH and 1.5-2 days at 35 ± 2°C & 60 ± 5% RH. The durations of third quiescent phase was comparatively greater for all the three temperature-humidity conditions tested and were recorded as 3-7 days at 25 ± 2°C & 80 ± 5% RH, 2-4 days at 30 ± 2°C & 70 ± 5% RH and 2-5 days at 35 ± 2°C & 60 5% RH (Table 37,38,39 & Plate 55)

2.3.4. Moulting

Each quiescent phase was followed by the occurrence of moulting which resulted in the emergence of the succeeding in star after discarding the exuvia of the preceding instar. The molting process in *D. floridanus* was found to require 10-25 minutes for completion. During moulting, the outer cuticle became silvery white in colour and a horizontal slit appeared at the mid dorsal region of the body, between the 2nd and 3rd pairs of the legs. Then

the slit was further progressed to either sides and finally met ventrally. The backward thrust exerted by the moulting instar helped in the widening of the split and emergence of the posterior part of the body. The ventral region of the cuticle remained intact for some time and then it was discarded by the slow sliding movements of the instar. The discarded exuviae were visible on the tepal's surface.

2.3.5. Adult

The newly moulted adult of *D. floridanus* was bright red in colour (Plate 53). The female was comparatively larger than the male. The body of the female was relatively oval where as that of the male was pointed posteriorly. Feeding was initiated by the adult mites immediately after moulting and at this stage, their colour appeared as light red to bright orange red.

2.3.6. Breeding pattern

The results of the present study enabled to record both sexual and parthenogenetic modes of reproduction in *D. floridanus* and the sequence of events from egg to adult development was similar in both types of reproduction. However, all the progeny comprised of males in the case of parthenogenetic development and in the sexual mode of reproduction, females were produced. In the laboratory cultures, males emerged earlier than the females and soon after emergence, they were found moving in search of

the quiescent female deutonymphs The males were observed to help the female quiescent deutonymphs for moulting, by removing the cuticular covering. The females copulated only once in their life time. During mating, the male was found to crawl over the female hysterosoma. Posterior tip of the male hysterosoma was then held in a characteristic bent position, protruding the stylet like aedeagus to the vagina of the female. Mating lasted for 4 to 5 minutes. At the end of copulation, the male retracted the aedeagus and moved backwards in search of a new female. The durations of the various developmental stages under both modes of reproduction showed slight variations and were found influenced by prevailing temperature-humidity conditions.

2.3.7. Duration of life cycle

Thus, the developmental durations of *D. floridanus* under the sexual and parthenogenetic modes were recorded as 28- 33 days at 25 ± 2°C & 80 ± 5% RH, 21-30 days at 30 ± 2°C & 70 ± 5% RH and 19- 24 days at 35 ± 2°C & 60 ± 5% RH (Tables 34,35,36; Plate). However, parthenogenetic development required relatively shorter duration when compared to the sexual development.

A comparison of the total duration of development from egg to adults of *D. floridanus* on *A. catecheu* under different temperature-humidity conditions enabled to record a shorter duration of development at 35 ± 2°C &

60 ± 5% RH and a longer duration at 25 ± 2°C & 80 ± 5% RH (Plate 55). At the same time, *D. floridanus* produced more generations at 30 ± 2°C & 70± 5% RH than that of 25 ± 2°C & 80 ± 5% RH and 35 ± 2°C & 60 ± 5% RH . Results of life history studies also revealed that the number of males was lesser than that of the females.

3. Breeding biology of *R. indica*

3.1. Oviposition

Mature females of *R. indica* were found laying eggs, mostly on the lower surface of the leaves of *A. catechu*. Rarely, the upper leaf surface was also found preferred by the females, especially when the population was high. During oviposition, the females assumed an immobile posture with the hysterosoma lowered slightly to extrude the eggs. Freshly laid eggs were ovoid, reddish in colour, smooth and appeared sticky. The eggs were attached to the lower surface of the leaf lamina by a white, slender hair like structure (white stipe), which was as long as or longer than the eggs.

During the present study, the period prior to the initiation of oviposition *i.e.,* pre-oviposition period of *R. indica* on the host plant *A. catechu* was found varied depending up on the temperature –humidity conditions. The mean period of pre-oviposition was 5.9 ± 0.07 days at 25 ± 2°C & 80 ± 5% RH, while it was 3.85 ± 0.07 days at 30 ± 2°C & 70 ± 5% RH and 3.15 ± 0.08 days at 35 ± 2°C & 60 ± 5% RH (Table 40). Similar

variations could be observed in oviposition period also as presented in table 40. At 25 ± 2°C & 80 ± 5% RH, the average duration of oviposition period was 23 ± 0.22 days while it was 21.7 ± 0.18 days at 30 ± 2°C & 70± 5% RH and 19.90 ± 0.17 days at 35 ± 2°C & 60 ± 5% RH.

The feeding activity of the female mites got diminished during the final days of oviposition and the mites became lethargic. This inactive period was recorded as the post-oviposition period and which also was found varied depending up on the variations in temperature and humidity conditions. The mean durations of post-oviposition period could be recorded as 7.5 ± 0.09 days at 25 ± 2°C & 80± 5% RH, 5.60 ± 0.11 days at 30 ± 2°C & 70 ± 5% RH and 1.6 ± 0.05 days at 35 ± 2°C & 60 ± 5% RH. Subsequently, the colour of the females got faded and finally death occurred after 2-6days. Fecundity was less during the early days of oviposition, which then gradually increased to reach the peak level on the 3rd day of oviposition and continued for 16 days. The number of eggs laid by the female got declined from the 20th day onwards. Quite often, the female mites didn't lay any eggs, on some days of the oviposition period.

The mated gravid females laid more number of eggs when compared to the unmated virgin females. The mean rate of egg production by mated female was recorded as 21.74 ± 0.09 at 25 ± 2°C & 80 ± 5% RH, 43 ± 0.25 at 30 ± 2°C & 70 ± 5% RH and 38.14 ± 0.23 at 35 ± 2°C & 60 ± 5% RH (Table

41,42,43). The fecundity of parthenogenetic females was comparatively lower under all temperature-humidity parameters. As presented in table 41,42,43,the range of egg production by parthenogenetic females was 17- 18 at 25 ± 2°C & 80 ± 5% RH, 33 - 34 at 30 ± 2°C & 70 ± 5% RH and 29-34 at 35 ± 2°C & 60 ± 5% RH. Thus the optimum temperature humidity conditions which supported the maximum rate of egg production under sexual and parthenogenetic conditions were 30 ± 2°C & 70 ± 5% .

Longevity of *R. indica* under different temperature and humidity conditions also showed variation. As presented in table 41, 42,43; Plate 57, the longevity of mated and virgin females at different temperature and humidity could be recorded as 38.0 ± 0.23 days (mated) and 32.67 ± 0.19 days (virgin) at 25 ± 2°C & 80 ± 5% RH , 33.67 ± 0.12 days (mated) and 27.38 ± 0.08 day (virgin) days at 30 ± 2°C & 70 ± 5% RH and 26.33± 0.26 days (mated) and 22.13 ± 0.18 days (virgin) at 35 ± 2°C & 60 ± 5% RH.

3.2. Eggs, Incubation and Hatching

The nature of eggs got changed on progressive days of incubation. Period of incubation also was found varied in accordance with the variations in temperature-humidity conditions. The shortest incubation period recorded during the present study was at 35 ± 2°C & 60 ± 5% RH. The incubation periods at different temperature-humidity parameters were found to range from 6-9 days at 25 ± 2°C & 80 ± 5% RH , 5-7 days at 30 ± 2°C & 70± 5%

RH and 4-6 days at 35 ± 2°C & 60 ± 5% RH (Table 44,45,46). One day prior to moulting the eggs turned to opaque.

Initiation of hatching could be manifested with the appearance of a semicircular slit at the broader end of the egg. Then the slit got widened along either sides, by the wriggling movements of the emerging larva. When the slit got widened, the emerging larva protruded its first two pairs of legs through the slit, followed by the thrashing action of the larval propodosoma and movement of the first pair of legs. The larva was found struggling out of the egg shell and the process of hatching was completed within 20-30 minutes.

3.3. Duration of Developmental Stages

3.3.1. Larval Period

Newly hatched larva was small, dark red in colour with three pairs of legs and a broadly oval body (Plate 56). It initiated feeding activity immediately after hatching. The colour of the larva got changed on progressive feeding. The active larval period extended for 4-7 days at 25 ± 2°C & 80 ± 5% RH, 4-6 days at 30 ± 2°C & 70 ± 5% RH and 3-5 days at 35 ± 2°C & 60 ± 5% RH. The feeding activity of the larva was found reduced at the end of the active period and it gradually became lethargic and subsequently found settled at a suitable spot on the leaf surface. This stage was recognized as the I^{st} quiescent stage, which lasted for 1-2.5 days. At the end of this quiescent phase, moulting occurred, resulting in the emergence of the protonymph.

3.3.2. Nymphal stages

3.3.2.1. Protonymph

The protonymph was slightly larger than the larva, dark red in colour, nearly rounded in appearance and characterized by the presence of 4 pairs of legs (Plate 56). The protonymph commenced feeding activity after a short interval subsequent to moulting. On progressive feeding on the plant sap, the colour of the body became more dark. The active feeding period of the protonymph was 3-5 days at 25 ± 2°C & 80 ± 5% RH, 3-5 days at 30 ± 2°C & 70 ± 5% RH and 3-4 days at 35 ± 2°C & 60 ± 5% RH. A gradual decrease in feeding trend was observed at the end of protonymphal stage and it entered into an inactive/quiescent phase, the so called second quiescent phase. The quiescent phase lasted for 1-3 days and at the end of which moulting occurred and the deutonymph emerged, leaving behind the exuviae.

3.3.2.2. Deutonymph

The newly emerged deutonymph was larger than the protonymph and displayed more vigorous feeding activity (Plate 56). Depending up on the variations in the temperature-humidity conditions offered in the laboratory, the active feeding period of the deutonymph also was found to vary. The average durations of the deutonymphal period recorded during the study were 3-6 days at 25 ± 2°C & 80 ± 5% RH, 3-5 days at 30 ± 2°C & 70 ± 5% RH and 3-4 days at 35 ± 2°C & 60 ± 5% RH (Table 44,45,46; Plate 58).The

deutonymph gradually became lethargic with arrested feeding activity and entered in to the third quiescent phase. After 1- 2.5 days, moulting occurred and the adult mite emerged.

3.3.3. Quiescent periods

The life history of *R. indica*, resembling all other species studied was found to include an inactive or quiescent period of zero activity, at the end of each of the active instar. The initiation of this quiescent phase was marked by reduced feeding activity and movement of the instar and the body of instar became turgid and shiny. The instar turned to be highly lethargic and immobile and its feeding activity was found completely arrested. During this phase, the instar assumed a characteristic posture, with its stylets penetrated into the plant tissue and the legs were stretched out. In the life cycle of *R. indica,* three quiescent phases *viz*. first, second and third quiescent stages were recognized, each at the end of the larval, protonymphal and deutonymphal stages respectively. The durations of quiescent phases after each of the active stage were recorded as 1.5-2.5 days at 25 ± 2°C & 80 ± 5% RH, 1-2 days at 30 ± 2°C & 70 ± 5% RH and 1-2 days at 35 ± 2°C & 60 ± 5% RH for the I quiescent phase, 1-2.5 days at 25 ± 2°C & 80 ± 5% RH, 1-2 days at 30 ± 2°C & 70 ± 5% RH and 1-2 days at 35 ± 2°C & 60 ± 5% RH for the second quiescent phase, and 1.5-2.5 days at 25 ± 2°C & 80 ± 5% RH, 1-2 days at 30 ± 2°C & 70 ± 5% RH and 1-2 days at 35 ± 2°C & 60 ± 5% RH for the third quiescent phase (Plate.57).

3.3.4. Moulting

The red palm mite, *R. indica* was found to discard its exuvia during the process of moulting and this was found completed within 15-25 minutes. The process of moulting was similar in all species of tenuipalpid mites studied. At the time of moulting, the outer cuticle became silvery white in colour and a horizontal slit was found developed at the mid dorsal region of the body, between the 2nd and 3rd pairs of legs. The slit was further proceeded to either sides and finally met ventrally. The emerging individual exerted a backward thrust, which helped to widen the slit and subsequent protrusion of the anterior part of the body. Ventral region of the cuticle remained intact for some time and then it was discarded by slow sliding movements. After the emergence of the moulting instar, the exuviae were seen as flaking patches on the leaf surface.

3.3.5. Adults

Sexually mature adult males and females of *R. indica* were bright red in colour (Plate 56). The adult females of *R. indica* measured 250 - 270 µm in length and 200-210 µm in width. Newly emerged RPM females were oval in shape and reddish in color and after feeding, the females developed prominent dark markings on the dorsum of the body. The female remained immobile for a while and slowly started movement and feeding. The males of *R. indica* were smaller than the females, but resembled the females in features, except

in having a distinctly triangular body. Dorsal setae of males and females were spatulate and with a droplet of liquid at the end of setae.

3.3.6. Breeding pattern

R. indica was found capable of undergoing both sexual and parthenogenetic modes of reproduction in both laboratory and field conditions and the sequence of events from egg to adult were similar in both types of reproduction. However, under parthenogenetic mode, the resulting progeny was found to comprise males alone while in sexual reproduction, only females were produced. The durations of the various developmental stages showed slight variations in both types of reproduction. The durations of individual instars also showed variations with respect to changes in the temperature-humidity conditions.

3.3.7. Duration of life cycle

Thus, the duration of development of *R. indica* from egg to adult stages at 25 ± 2°C & 80 ± 5% RH was 22-30 days (Sexual – 29.35 ± 0.05 & Parthenogenetic – 23 ± 0.17 days), at 30 ± 2°C & 70 ± 5% RH was 20-27 days (Sexual – 25.33 ± 0.11 & Parthenogenetic 20.38 ± 0.12 days) and at 35 ± 2°C & 60 ± 5% RH, 16 - 22 days (Sexual - 20.25 ± 0.21 days & Parthenogenetic - 16.75 ± 0.13 days) (Tables 44,45,46; Plate 58). However, parthenogenetic development required relatively shorter duration when compared to the sexual development.

A comparison of total duration of the life cycle of *R. indica* on *A. catecheu* under different temperature-humidity conditions enabled to record a shorter duration of development at 35 ± 2°C & 60 ± 5% RH and a longer duration at 25 ± 2°C & 80 ± 5% RH . At the same time, *R. indica* gave rise to more generations at 30 ± 2°C & 70 ± 5% RH than that of 25 ± 2°C & 80± 5% RH and 35 ± 2°C & 60 ± 5% RH .

Results of life history studies showed that males were usually lesser in number when compared to the females. The observed sex ratio of the species at all the 3 sets of temperature-humidity conditions tested in the laboratory was 3- 4.

4. Breeding biology of *T. micheli*

4.1. Oviposition

Under field and laboratory conditions, the females of *T. micheli* exhibited a general preference to the lower surface of leaves of *S. cumini* for oviposition. The eggs were found laid mostly along the midrib on the lower surface of the leaves and were firmly adhered by a sticky substance. Eggs were laid singly, but appeared in clusters, as several eggs were laid side by side. Freshly laid eggs were elongate and reddish in colour. The process of oviposition was similar to that of other tenuipalpid mites studied.

Oviposition in *T. micheli* was found initiated within 6-10 days after the emergence of the adult female. The pre-oviposition period was of shortest duration at 35 ± 2°C & 60 ± 5% RH and the maximum duration was recorded at 25 ± 2°C & 80 ± 5% RH. The average durations of pre-oviposition period recorded for *T. micheli* on the host plant, *S. cumini* were 6.6 ± 0.09 days at 25 ± 2°C & 80 ± 5% RH, 5.55 ± 0.06 days at 30 ± 2°C & 70 ± 5% RH and 4.55± 0.07 days at 35 ± 2°C & 60 ± 5% RH (Table 47).

The oviposition period in *T. micheli* was also found variable depending up on the temperature-humidity variations. The maximum duration was recorded at 25 ± 2°C & 80 ± 5% RH and the minimum duration could be observed at 35 ± 2°C & 60 ± 5% RH (Table 47). The mean durations of oviposition period recorded during the study were 12.5 ±7 days at 25± 2°C & 80 ± 5% RH, 11.7 ± 0.05 days at 30 ± 2°C & 70 ± 5% RH and 9.6 ± 0.07 days at 35 ± 2°C & 60 ± 5% RH (Table 47; Plate 60). When the process of oviposition was completed, the female mites gradually became lethargic with minimized feeding activity. This was identified as the post-oviposition period and the duration of which also was found subjected to variation, depending up on the prevailing temperature-humidity conditions. The mean durations of post oviposition period recorded for *T. micheli* were 6.7 0.09 days at 25 ± 2°C & 80 ± 5% RH, 5.5 ± 0.09 days at 30 ± 2°C & 70 ± 5% RH and 4.40 ± 0.05 days at 35 ± 2°C & 60 ± 5% RH (Plate 60). During this period, the normal dark red colour of the adult females got faded and finally the females were died.

The number of eggs laid by a mated female of *T. micheli* during its oviposition period was found minimum on the 1st, 2nd and 3rd days of oviposition. The mated females laid relatively large number of eggs than that of the unmated virgin females. The average fecundity recorded for mated females was 12.43 ± 0.22 at 25 ± 2ºC & 80 ± 5% RH, 16.75 ± 0.07 at 30 ± 2ºC & 70± 5% RH and 14.63 ± 0.06 at 35 ± 2ºC & 60 ± 5% RH (Table 48,49,50). The mean fecundity of virgin females was relatively lower, reaching 9.67 ± 0.14 at 25 ± 2ºC & 80 ± 5% RH, 13.50 ± 0.25 at 30 ± 2ºC & 70 ± 5% RH and 11.50 ± 0.25 at 35 ± 2ºC & 60 ± 5% RH (Table 48,49,50).

The longevity of adult females of *T. micheli* recorded at different temperature -humidity conditions averaged to 25.80 ± 0.21 days at 25 ± 2ºC & 80 ± 5% RH, 22.80 ± 0.13days at 30 ± 2ºC & 70 ± 5% RH and 18.55 ± 0.11 days at 35 ± 2ºC & 60 ± 5% RH. Thus, 25 ± 2ºC & 80 ± 5% RH supported the maximum life span of the species (Plate 60).

4.2. Egg, Incubation and Hatching

Freshly laid eggs were orange coloured and elliptical in appearance (Plate 59). Two days prior to hatching, the colour of the eggs turned to silvery-white and the red eyes of the larvae were clearly visible within. Hatching was initiated within 7-11 days of incubation. The periods of incubation was found to vary under different temperature -humidity conditions and were recorded as 9-11 days at 25 ± 2ºC & 80 ± 5% RH, 8-9

days at 30 ± 2°C & 70 ± 5% RH and 7-9 days at 35 ± 2°C & 60 ± 5% RH (Table 51,52,53). Hatching was initiated by the appearance of a semicircular slit at the apical portion of egg. Later, the slit continued to both sides and the developing larva was found wriggling inside. As the slit got widened, the emerging larva protruded its first two pairs of legs through the slit. This was followed by the thrashing action of the larval propodosoma. Later, the larva struggled out of the egg shell within 20-25 minutes.

4.3. Duration of Developmental Stages

4.3.1. Larval Period

Newly hatched larva was small, six legged and bright orange in colour. It initiated feeding activity immediately after hatching (Plate 59). As the feeding progressed, the colour of the larva got changed and black and red coloured patches were developed on the body. The active feeding period of the larva extended for 8-9 days at 25 ± 2°C & 80 ± 5% RH, 6-7 days at 30 ± 2°C & 70 ± 5% RH and 5-7 days at 35 ± 2°C & 60 ± 5% RH (Plate 61). At the end of the active period, the feeding activity of the larva got decreased and it became sluggish and finally settled at a suitable site on the leaf surface to enter in to the first quiescent phase, which lasted for 2-4 days. Subsequent moulting resulted in the emergence of the protonymph.

4.3.2. Nymphal stages

4.3.2.1. Protonymph

The newly emerged protonymph greatly resembled the larva but was larger and characterized by the possession of 4 pairs of legs (Plate 59). The integument was red with orange and black patches. It initiated sucking the plant sap a short interval after moulting and as feeding advanced, the colour of the protonymph became more intense. The feeding period of the protonymph varied and it lasted for 6-8 days at 25 ± 2°C & 80 ± 5% RH, 5-7 days at 30 ± 2°C & 70 ± 5% RH and 5-6 days at 35 ± 2°C & 60 ± 5% RH. At the end of this active period, the feeding activity of the protonymph was found decreased and it became immobile and entered in to the second quiescent phase. Further moulting resulted in the emergence of the deutonymph.

4.3.2.2. Deutonymph

The newly emerged deutonymph was similar to the protonymph, except in having an increased size (Plate 59). The mean duration of the active period of the deutonymph lasted for 6.10 ± 0.07days at 25 ± 2°C & 80 ± 5% RH, 5.85 ± 0.05 days at 30 ± 2°C & 70 ± 5% RH and 5.80 ± 0.06 days at 35± 2°C & 60 ± 5% RH. Subsequent to the active feeding period, the deutonymph became lethargic with arrested feeding activity and entered into the third quiescent phase. The adult mite emerged as a result of the moulting of the third quiescent instar.

4.3.3. Quiescent periods

Resembling all other tenuipalpid species studied so far, a quiescent/inactive phase was observed at the end of each of the active stage of *T. micheli*. During this period, the instar stopped feeding, became lethargic, immobile and its body developed a turgid and shiny appearance. The instar assumed a characteristic posture, with its stylets penetrated into the plant tissue and legs stretched outwards. Three quiescent phases viz. first, second and third quiescent phases each at the end of the larval, protonymphal and deutonymphal stages respectively were observed in *T. micheli* also. The range of duration of the first quiescent phase was 3-4 days at 25 ± 2°C & 80 ± 5% RH, 2.5-3.5 days at 30 ± 2°C & 70 ± 5% RH and 2-2.5 days at 35 ± 2°C & 60 ± 5% RH. The second quiescent phase was found ranged between 3-4 days at 25 ± 2°C & 80 ± 5% RH, 2-3 days at 30 ± 2°C & 70 ± 5% RH and 2-2.5 at 35 ± 2°C & 60 ± 5% RH. The duration of third quiescent showed a range of 2-3 days at 25 ± 2°C & 80 ± 5% RH, 2-3 days at 30 ± 2°C & 70 ± 5% RH and 1.5-2.5 days at 35 ± 2°C & 60 ± 5% RH (Plate 61).

4.3.4. Moulting

The duration of moulting process in *T. micheli* was found to last for 15-25 minutes. During moulting, the outer cuticle became silvery-white in colour and a horizontal slit developed at the mid dorsal region of the body of the moulting instar, between the 2nd and 3rd pairs of legs. The slit further

proceeded to either sides and finally met ventrally. As a result of the backward thrust exerted by the moulting instar, the slit got widened and aiding in the emergence of anterior part of the body. The ventral region of the cuticle remained intact for some time and then it was discarded by slow sliding movements. The discarded exuviae were found glued to the leaf surface, on completion of the moulting process.

4.3.5. Adult

The newly emerged adult of *T. micheli* was orange red in colour and later turned in to maroon -red with black patches (Plate 59).The female was comparatively larger in size than the male and its body was relatively ovoid than that of the male. The males could be easily identified based on their smaller size and narrower body. The adult mites initiated feeding immediately after moulting.

4.3.6. Breeding pattern

Both sexual and parthenogenetic modes of reproduction were observed in *T. micheli* and the developmental pattern was similar in both types of reproduction. In sexual mode, only females were produced while in parthenogenetic mode, the progeny was found to comprise only males. Males were emerged earlier than the females, and soon after emergence, they wandered on the leaf surface, in search of the females. The males were observed to hasten the moulting of quiescent female deutonymph by helping

in the removal of the cuticular covering, for subsequent mating. During moulting, the male crawled over the female hysterosoma and lifted up the posterior end of his hysterosoma. The posterior tip of the male hysterosoma was then held in a characteristic bent position and the stylet like aedeagus was protruded to reach the genital orifice of the female. Mating lasted for 4 to 5 minutes and at its end, the male retracted his aedeagus and moved backwards in search of a new female. The female mite was found to copulate only once in her life time. The durations of the various instars were found influenced by variations in temperature-humidity conditions, in both types of reproduction.

4.3.7. Duration of life cycle

The duration of development of *T. micheli* from egg to adult on *S. cumini* was recorded as 37-43 days at 25 ± 2°C & 80 ± 5% RH (Sexual – 41.79 ± 0.08 & Parthenogenetic – 38.33 ± 0.28 days), 33-38 days at 30 ± 2°C & 70 ± 5% RH (Sexual – 35.63 ± 0.16 & Parthenogenetic- 33 ± 0.00 days) and 30-35 days at 35 ± 2°C & 60 ± 5% RH (Sexual – 33.06 ± 0.08 days & Parthenogenetic - 30 ± 0.00 days) (Tables 51,52,53 ; Plate 61). However, duration of development from egg to adult under parthenogenetic mode was relatively shorter when compared to that of the sexual development.

Results of life history studies showed that the number of males was generally lesser in *T. micheli* when compared to that of females. A comparison of the total duration of life cycle from egg to adults of

T. micheli on *S. cumini* under different temperature-humidity conditions enabled to record a shorter duration of development at 35 ± 2°C & 60 ± 5% RH and a longer duration at 25 ± 2°C & 80 ± 5% RH. *T. micheli* produced more generations at 30 ± 2°C & 70 ± 5% RH than that of 25 ± 2°C & 80 ± 5% RH and 35 ± 2°C & 60 ± 5% RH .

5. Breeding biology of *T. chiclorum*

5.1. Oviposition

Adult females of *T. chiclorum* exhibited a general preference to the lower surface of leaves of the host plant, *M. zappota* for egg deposition. Rarely, eggs were also found laid on the upper surface of the leaves, especially when the mite population was high. The female was found to be stationary while laying eggs. Eggs were usually seen laid closely adhered along the mid rib of the leaves by a sticky fluid and were easily recognized by their orange hue and elongated appearance.

The process of oviposition was found initiated among the females of *T. chiclorum* from 5-8 days after emergence as adults. The mean duration of pre-oviposition period was observed as 7.3±0.05 days at 25± 2°C & 80 ± 5% RH, 6.5±0.05 days at 30 ± 2°C & 70 ± 5% RH and 5.45±0.06 days at 35± 2°C & 60 ± 5% RH (Table 54).

The period of oviposition was also found influenced by alterations in temperature-humidity parameters. Accordingly, at 25 ± 2°C & 80 ± 5% RH, the average duration of oviposition period was recorded as 11.2±0.08 days. At 30 ± 2°C & 70 ± 5% RH, the oviposition period was of still lower duration and it was 10.1±0.07 . At 35± 2°C & 60 ± 5% RH, the oviposition period was found averaged to 8.8±0.06 days (Table 54). The oviposition period was found followed by the post-oviposition period which was also found subjected to variation by the prevailing temperature and RH. During post-oviposition period, the mites became highly inactive and their feeding activity was found minimized. The dark brown colour of the females also found faded. The mean durations of post ovipostion period at the three different temperature and humidity conditions studied were 7.0±0.07 days at 25 ± 2°C & 80 ± 5% RH, 6.1±0.09 days at 30 ± 2°C & 70 ± 5% RH and 5.4±0.07 days at 35 ± 2°C & 60 5± % RH (Plate 63). The post oviposition period was found culminated in the death of the females.

The number of eggs laid by the virgin as well as mated females showed variation, as observed during the present study. The mated females laid more eggs when compared to the unmated virgin females. The mean number of eggs laid by mated females was 12.85 ± 0.09 at 25 ± 2°C & 80 ± 5% RH, 16.57 ± 0.09 at 30 ± 2°C & 70 ± 5% RH and 15.75 ± 0.09 at 35 ± 2°C & 60 ± 5% RH. The virgin females on the other hand laid still lower number of eggs and which was found averaged to 10.33 ± 0.08 at 25± 2°C & 80 ± 5%

RH, 13.0±0.08 at 30 ± 2°C & 70 ± 5% RH and 12.5±0.08 at 35 ± 2°C & 60 ± 5% RH (Table 55,56,57).

5.2. Egg, Incubation and Hatching

The newly laid eggs were elliptical and light yellow orange in colour. Later, the colour got changed to orange (Plate 62). Two days prior to hatching, the eggs turned to silvery-white in colour and the red eyes of the larvae were clearly visible within. The duration of incubation period was found altered owing to variations in temperature-humidity parameters and the minimum duration was recorded at 35 ± 2°C & 60 ± 5% RH. The mean durations of incubation observed under the different temperature-humidity parameters were 7.80±0.06 days at 25 ± 2°C & 80 ± 5% RH, 7.0±0.07 days at 30 ± 2°C & 70 ± 5% RH and 6.6±0.07days at 35 ± 2°C & 60 ± 5% RH (Table 58,59,60; Plate 64). The incubation period was found ended with the process of hatching and it was found initiated by the appearance of a semicircular slit on the surface of the egg and the slit progressed to either side owing to the wriggling movements of the larva inside. As the slit got widened, the emerging larva protruded its first two pairs of legs through the slit and subsequently exhibited vigorous movements of the body and the larva finally struggled out of the egg shell. The entire process of hatching was found completed within 15-25 minutes.

5.3. Duration of Developmental Stages

5.3.1. Larval Period

The pale yellow coloured, hexapodous larvae initiated feeding activity immediately after hatching (Plate 62). As feeding progressed, the larva changed to orange in colour. Variations in the prevailing temperature-humidity conditions were found to influence the duration of larval instar and the shortest duration could be recorded when the temperature was high and the RH was low. Thus the average duration of active larval period was recorded as 6.70±0.07 days at 25 ± 2°C & 80 ± 5% RH, 6.35 ± 0.08 days at 30 2°C & 70 ± 5% RH and 6.1 ± 0.08 days at 35 ± 2°C & 60 ± 5% RH (Plate 64). The feeding activity of the larvae got decreased at the end of the active period and gradually the larva became highly lethargic and got gradually settled and immobile at a suitable site on the leaf surface. This was recognized as the first quiescent phase and it extended for 2-4 days. The end of this phase was marked by the moulting process which led to the emergence of the subsequent instar, the protonymph.

5.3.2. Nymphal stages

5.3.2.1. Protonymph

Protonymph exhibited high morphological similarity with the larva, but was slightly larger in size and characterized by the presence of 4 pairs of

legs (Plate 62). The protonymph initiated feeding after a short interval of moulting and on progressive feeding, the colour of the protonymph became deeper. The protonymphal period was found to be of maximum duration at higher temperature and low RH. The mean durations of the active period of the protonymph recorded during the study were 6.40±0.07 days at 25 ± 2°C & 80 ± 5% RH, 6.5±0.05 days at 30 ± 2°C & 70 ± 5% RH and 6.6±0.05 days at 35 ± 2°C & 60 ± 5% RH (Table 58,59,60; Plate 64). At the end of the active period, the protonymph also arrested the feeding activity, assumed an immobile posture and settled on a suitable spot on the leaf to enter into the second quiescent phase. On subsequent moulting, the deutonymph got emerged.

5.3.2.2. Deutonymph

The deutonymph was similar to the protonymph in many features, but its size was comparatively larger. The active feeding period of the deutonymph was found maximum at the higher temperature and lower RH selected during the study. The average durations of deutonymphal period under the different temperature-humidity combinations selected during the study were 6.55±0.05 days at 25 ± 2°C & 80 ± 5% RH, 6.4±0.06days at 30 ± 2°C & 70 ± 5% RH and 6.1±0.06days at 35 ± 2°C & 60 ± 5% RH. Resembling the preceding instars, the deutonymph also exhibited a reduced feeding activity and gradually entered into the third quiescent phase which lasted for 2-4 days. On subsequent moulting, the adult mite got emerged.

5.3.3. Quiescent periods

Prior to entry into this zero activity period, the instars completely arrested their feeding activity and became lethargic and immobile. Simultaneously, the body of the instars assumed a turgid and shiny appearance. The quiescent instars were easily recognized by their characteristic posture, with the stylets penetrated into the plant tissue and legs stretched outwards. In the development of *T. chiclorum*, three quiescent phases were observed viz first, second and third quiescent stages, each at the end of the larval, protonymphal and deutonymphal stages respectively. The durations of the quiescent phases were slightly altered by changes in temperature and RH. The durations recorded for the first and second quiescent phases were 2-3 days for all temperature-humidity combinations selected during the study viz. 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH. The duration of third quiescent phase was found to range from 2-4 days at 25 ± 2°C & 80 ± 5% RH, 2-3 days at 30 ± 2°C & 70 ± 5% RH and 2-3 days at 35 ± 2°C & 60 ± 5% RH (Plate 64).

5.3.4. Moulting

Moulting, the process of emergence of an instar from the outer cuticle of preceding instar was observed to last for 20-25 minutes in *T. chiclorum*. Initially, the outer cuticle became silvery- white in colour and a horizontal slit appeared at the mid-dorsal region of the body, between the 2nd and 3rd pairs of

the legs of the moulting instar. The slit further proceeded to either sides and finally met ventrally. Simultaneously, the moulting instar exerted a backward thrust, which helped in the further widening of the slit and emergence of the anterior part of the moulting individual. Ventral region of the cuticle remained intact for some time and then it was discarded by the slow sliding movements of the moulting instar. The moulted skin was found glued to the leaf surface after the emergence of the particular stage.

5.3.5. Adult

The newly emerged adults of *T. chiclorum* were cream in colour and which later turned into cream to dark brown in colour (Plate 62). The adult males and females of *T. chiclorum* were easily distinguishable based on the size and shape of their body. The males were comparatively smaller than the females and with a narrow body. The females were ovoid in appearance and they were larger in size. Both males and females initiated feeding on plant sap immediately after the final moulting.

5.3.6. Breeding pattern

T. chiclorum possessed a dual mode pattern of reproduction comprising both sexual and parthenogenetic modes. The sequence of development from egg to adult was similar under both modes of reproduction. In sexual mode of reproduction, only female progeny was resulted while in the parthenogenetic development, the progeny produced was found to

comprise only males. Males emerged earlier than the females, and soon after the emergence, they moved in search of the female quiescent deutonymphs. On detection of female quiescent duetonymphs, the males were found to position themselves near them and often helped in their moulting by removing the cuticular covering. After removing the cuticle completely, the male was found to climb over the female hysterosoma and initiated the mating activity by lifting up the posterior part of his hysterosoma. When the posterior tip of the male hysterosoma was held in a bent position, the aedeagus was protruded and it was inserted into the vagina of the female. The process of mating lasted for 8 to 10 minutes and at the end of copulation, the male retracted his aedeagus and moved backwards in search of another newly emerged female. The males were observed to mate with several females while the females copulated only once in her life time. The durations of the individual developmental stages from egg to adult showed slight variations and were also found influenced by alterations in the temperature-humidity conditions, under both modes of reproduction.

5.3.7. Duration of life cycle

The life cycle of *T. chiclorum* was found to require comparatively shorter duration under parthenogenetic mode of development. In the present study, at 25 ± 2°C & 80 ± 5% RH the average duration was 35.6 ± 0.12 days (Sexual – 36.21 ± 0.11 & Parthenogenetic – 34.16 ± 0.02 days), at 30 ± 2°C &

70 ± 5% RH duration was 34.05 ± 0.08 days (Sexual – 34.78 ± 0.17 & Parthenogenetic- 32.33 ± 0.10 days) and at 35 ± 2°C & 60 ± 5% RH duration was 32.95±0.08 days (Sexual – 33.44± 0.17 days & Parthenogenetic – 31.0 ± 0.10 days) (Tables 58,59,60; Plate 64). However, parthenogenetic development required relatively shorter duration compared to sexual development.

Results of life history studies carried out under laboratory conditions revealed that the population of *T. chiclorum* comprised of a lower number of males when compared to the females. A comparison of the total duration of life cycle of the species on the host, *M. zapota* under the different temperature-humidity conditions selected during the study enabled to record the minimum duration at 35 ± 2°C & 60 ± 5% RH and the maximum duration at 25 ± 2°C & 80 ± 5% RH . *T. chiclorum* was found to produce more number of generations at 30 ± 2°C & 70 ± 5% RH than that of 25 ± 2°C & 80 ± 5% RH and 35 ± 2°C & 60± 5% RH.

CHAPTER V

DISCUSSION

DISCUSSION

Tenuipalpid mites , the commonly called 'False spidermites' or 'Flat mites' are worldwide in distribution and represent an exclusively phytophagous group on plants of all economic categories. The false spider mites belong to the family Tenuipalpidae and which in general are found adapted to survive in the tropical to subtropical climates (Jepson *et al*., 1975; Baker and Tuttle, 1987). These mites usually feed directly from the epidermal and sub mesodermal tissues of the leaves, stems and fruits (Beard *et al*., 2012). Apart from the direct damage, many species successfully serve as vectors, transmitting various phytopathogenic plant viruses to the host plants on which they feed. Despite their important roles as pests cum vectors, tenuipalpid mites have received relatively very little recognition in a state like Kerala which is blessed with extremely rich plant diversity of different economic utility.

Fruit plants and Plantation crops on which the present investigation is concentrated, have attracted the attention of man since the dawn of human civilization owing to the huge demand in the international market for such plant based products. Fruits and plantation crop products have a major role in the export sector of the nation, serving to fetch a high amount of foreign

exchange. Therefore, they are important to the Indian economy and constitute one of the rich source of our national income.

Due to the attack of several pests, especially the arthropod pests like the phytophagous insects and mites, the annual production of fruits and Plantation crops have been severely dwindled. Among the phytophagous mites, the false spider mites form one of the major group, which exhibit very intimate association with diverse types of crop plants including the fruit and plantation crops (Kitajima *et al*., 1972; Rice and Weinberger, 1981, 1997; Oomen, 1982; Chagas *et al*., 2000). Considering the extent of damage induced by tenuipalpid mites on different host plants, the present project was undertaken to understand the common species of these mites inhabiting the fruit plants and plantation crops of Kerala and also to record data on the host range, geographical and seasonal patterns of distribution, nature and extent of damage induced on respective 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.

During the present study, members of two families viz. Tetranychidae and Tenuipalpidae were recognized as the major groups of phytophagous mites and among the predatory mites, members of the family Phytoseiidae formed the dominant group. The results of the general survey disclosed the incidence and quite often the abundance of tenuipalpid mites on all the fruit

plants and plantation crops screened from the various localities, thereby making a clear evidence of infestation by this group of mites in Kerala. In most instances, the these mites were found confined mostly to the lower surface of the leaves /leaflets of the host plants thereby supporting the earlier findings (Feres, 2000; Pontier *et al.,* 2001; Feres *et al*., 2002; Ferla & Moraes, 2002).

In the present study, 36 species of fruit crops and 16 species of plantation crops were screened to analyse the symptoms of tenuipalpid mite infestation in Kerala conditions. The results of the study showed that 14 species of fruit crops and 9 species of plantation crops harboured members of 5 genera of these mites viz. *Tenuipalus, Dolichotetranychus, Cenopalpus, Raoiella* and *Brevipalpus* and the species recovered were *T. chiclorum*, *T. micheli, C.pulcher, D. floridanus*, *D. cocos, R. indica*, *R. macfarlanei, B. phoenics, B. obovatus* and *B. californicus.* In the present study, these species were recognized to cause economic damage on diverse types of crops. Visible symptoms of high incidence of these mites were observed on fruits plants like *C. maxima, C. sinensis*, *P. guajava, C. papaya, A.reticulata, P. edulis, M.domestica, S. cumini, P.granatum* and *A. altilis* and plantation crops like *A. catechu, C. nucifera*, *C. arabica, C. sinensis* and *S. aromaticum*. All life stages of these species were also found harbouring in high populations on respective host plants, inducing considerable damage and hence were selected for detailed studies on the nature and extend of feeding damage as well as

breeding pattern, duration of life cycle, morphological features of developmental stages etc.

In the present study, the distribution pattern and population density of the different species of tenuipaplpid mites showed variation with respect to geographic variation. The population density of *D. floridanus* was relatively lower in many surveyed districts and its incidence could not be recorded on the host plants screened from Kollam district. Generally, plant mites are highly sensitive to fluctuations in miroclimatic conditions (Jeppson *et al*., 1957; Perring *et al*., 1984) and accordingly their population density also is found variable. Hence the variation in the density of *D. floridanus* in the different localities surveyed can be correlated with the alterations in the environmental factors such as temperature and humidity and also the varietal difference of the host plant, *A. catechu.*

Similarly, the incidence of *T. micheli* could not be recorded from the Kasarakode district and all other species were recorded from all districts. Generally, the occurrence and abundance of plant mites can be related to the intensity of solar radiation and consequential variations in leaf temperature or can be due to the differences in predator abundance (Hanna *et al.*, 1996). Variations in the physical factors like temperature, humidity and air movement can affect the profusion of mites greatly (Perring *et al.,* 1984).

The genus *Brevipalpus* represents the largest genus of Tenuipalpidae and it comprises around 300 species, distributed worldwide (Welbourn *et al*., 2003). The members of this genus have attracted the attention of acarologists for the last few decades owing to their tremendous economic status as pests of a multitude of agricultural crops and ornamental plants of the tropics as well as vectors of various plant pathogens (Ochoa *et al*., 1994; Childers and Rodrigues, 2011). Among the species of the genus Brevipalpus*, B. phoenicis* has been reported as a highly polyphagous species inducing considerable economic damage to many host plants. The species is known to enjoy wide host range, extending its distribution on 65 species of host plants (Pritchard and Baker, 1958) or even on a higher number like 114 species (Ochoa *et al*., 1994). The species is known to infest and induce diseases to fruit and plantation crops in Brazil and the hosts include citrus, coffee, passion fruit (Musumeci and Rossetti, 1963; Chagas, 1978; Kitajima *et al.,* 1997). In the present study, *B. phoenicis* could be recorded from 9 species of fruit crops and 5 species of plantation crops, thereby supporting its wide distribution pattern on these economic crops. The polyphagous habit of this mite would be the determining factor for its wide distribution pattern and the species has been reported in all zoogeographical regions (Arabuli *et al.,* 2015). The results of the present study enabled to recover two more species of *Brevipalpus* viz. *B. obovatus* and *B. californicus* also along with *B. phoenicis* from same host plants, growing in similar geographical vicinities of Kerala,

which supports the earlier findings on the wide distribution of the genus (Childers *et al*., 2003). The above three species were reported as the major pests of tea in Sri Lanka (Cranham, 1966). However, variations in species wise infestation were also reported from different localities. Accordingly, *B. californicus* was reported to be the most common species on tea in Sri Lanka (Cranham, 1966). In the present study, *B. phoenicis* was the only species recovered from tea and its population was high. The results of the present study clearly confirmed that the abundance and distribution of *B. phoenicis* was high when compared to that of *B. obovatus* and *B. californicus* in Kerala. The distribution of *B. obovatus* was recorded both from fruit crops and plantation crop like *C. sinensis*, *P. granatum* and *S. aromaticum*. *B. californicus* was found to infest on host plants like *C. maxima, A. reticulata* and *T. cacao*. Citrus plants were recognized as the common hosts for three species of *Brevipalpus* viz. *B. phoenicis, B. obovatus* and *B. californicus*. These three species were reported as the greatest economically important species distributed on citrus plants as pests worldwide (Mayer, 1979; Denmark, 1984; Evans *et al.,* 1993; Ochoa *et al.,* 1994; Childers *et al*., 2003) inducing leprotic symptoms. The present study were also in line with the previous observations and the results of this study clearly established that, the genus *Brevipalpus* has wide distribution in Kerala and it induces serious damages like leprotic symptoms on the host plants .

The distribution and development of *Brevipalpus* species are generally influenced by the physical factors of the environment apart from the nature of host plants (Morishita, 1954; Haramoto, 1969; Chandra and Channa Basavanna, 1974; Lal, 1978; Goyal *et al.*, 1985). Dry conditions usually favour population build up of these mites and their presence is mostly confined to shaded areas on their host plants, in more humid environments. In the present study also, infestation by these mites was observed on the lower surface of leaves of respective host plants where they showed preference to regions adjacent to midrib or veins. The selection of concealed microhabitats would ensure protection to the delicate life stages like the eggs and immature stages and also help to avoid elevated temperature conditions on sun-exposed plant surfaces (Childers and Rodrigues, 2011).

In the present study, infestation of *D. floridanus* was detected on areca nuts and which caused severe damage culminating in nut fall in areca plantations of different localities of Kerala. This observation seems to extend the host range of the species by adding a new host like the areca palm. Infestation by this mite was first reported on pineapple from Florida (Banks, 1900). Subsequent studies could successfully establish this species as a monospecific and gregarious one associated with pineapples alone (Poli, 1991) and it was known to inhabit in all pineapple growing regions of the world (Baker and Pritchard,1956; Elder, 1988). Despite, this the results of the present study clearly disclosed the alteration in the habitat preference of *D.*

floridanus and further showed that it is not a monospecific species infesting pineapple alone, but has the potential to enjoy multiple infestation , especially by invading plantation crops like the areca palm.

The species of *Tenuipalpus* considered for detailed studies in the present investigation viz. *T. micheli* was recognized to have a cosmopolitan distribution (Lawrence, 1940; Prichard and Baker, 1958; Meyer and Ryke, 1959) and the species was found to infest the host plant, *Chaetaeme aristata*. Earlier studies performed in India enabled to extend the host range of *T. micheli* by recording its presence on new host plants like peach and pear from Punjab (Randeep and Sadana, 1999). Results of the present study helped to add another new host plant viz. *S. cumini* for the species. The second species of genus *Tenuipalpus* viz. *T.chiclorum* was first recorded from plants belonging to the family Sapotaceae (De Leon, 1957). During the present study, presence of *T. chiclorum* was detected on *M. zapota*, another member of the same family Sapotaceae. This clearly indicates the preference of the species to the members of this family of plants.

The results of field studies carried out during the present investigation disclosed the high incidence of the Red Palm Mite, *R. indica* on 3 species of plantation crops viz. *A. catechu, C. nucifera* and *M. acuminata* in almost all localities of Kerala. The mite was first reported in 1924 from Tamil Nadu, India (Hirst, 1924) from coconut leaves and it was reported to feed on the

underside of palm fronds of various hosts in the orders Arecales and Zingiberales. The mite attained economic significance when it was first reported as an invasive species in the Caribbeans (Flechtmann and Etienne, 2004). It was reported as a very serious pest of economically important crops like the coconut, (*C. nucifera*) and banana (*Musa acuminata*) in India and abroad (Nagesha-Chandra and Channabasavanna,1984; Welbourn, 2006). The species was reported as polyphagous with extensive host range, mainly infesting the palms of the family Arecaceae, and quite often plants belonging to other families like Zingiberaceae, Pandanaceae, Strelitziaceae, Musaceae and Heliconiaceae (Carillo *et al*., 2011). Subsequent studies could establish the species as a multivoltine and gregarious one with the potential to build up its population in high densities and causing considerable damage to a variety of host plants (Carrillo *et al*., 2012). The results of the present study disclosed the mite as a serious pest of areca palms and which built up its population in very high density to spread rapidly to most of the areca plantations distributed over most of the collection localities of Kerala. Symptoms of infestation by the RPM were very prominent on the leaves and fruits and which comprised of formation of yellow patches, bronzing and subsequent withering of the leaves.

The incidence and distribution of tenuipalpid mites to a great extend are under the operation of various climatic factors prevaling in the ecosystem, of which rainfall and temperature were reported to exert great impact on their

population density (Castro *et al*., 2013). In the present study, the seasonal distribution of *T. micheli* and *T. chiclorum* also showed great variation depending upon the temperature and rainfall. The population density of both the species was scanty during the monsoon periods and subsequently with the gradual increase in atmospheric temperature, both the species built up their population to moderate levels and which attained peak levels during the period from the last week of February to the last week of May when there was no rain fall. The washing effect of rain would be the probable reason for the population decline observed under field conditions. Thus the populations of both *T. micheli* and *T. chiclorum* were under the regulation of temperature and rainfall, of which the former exerted a positive impact while the latter showed a negative impact.

During the present study, the species of *Brevipalpus* also showed a more or less similar trend of population distribution. The population of *B. phoenicis* attained the peak levels in the dry season, from February to May. The mite population was scanty during the monsoon season, from June-October and then it increased to moderate levels during the period of November- January. This observation is in support of the earlier findings on the species (Childers and Rodrigues, 2011) in Texas and California where dry summer period supported huge populations of *B. phoenicis* on well irrigated citrus trees. The species was recorded as the most abundant one during the dry season in Florida and Brazil also. The rate of development of

Brevipalpus spp. was found strongly influenced by various factors like temperature, relative humidity, and host plant (Morishita, 1954; Haramoto, 1969; Lal, 1978).

The population density of the Red Palm Mite, *R. indica* could be observed as the maximum during April- May and then it followed a declining trend to reach moderate and scanty levels during November- March and June-October periods respectively. This is in accordance with the earlier reports (Yadav Babu and Manjunatha, 2007) on *R. indica* which showed the peak population of the mite from March – to the first week of May and then a decline in population from June onwards. Thus the population density of the Red palm mite also was found positively correlated with temperature and negatively correlated with relative humidity and rainfall.

Generally, the seasonal or periodic variation in the numbers of mites (Bengston, 1965; Goodwin, 1990) can be resulted from climatic factors (Jeppson *et. al*., 1957; Bengston, 1965) or from limited resources (Hamstead and Gould, 1957). Therefore , resources like food, mates and environmental parameters such as the photoperiod, rainfall or humidity can cause fluctuation in mite population (Van Houten, 1989). The population of *D. floridanus* on pine apple, was reported (Poli,1991) to follow distinctive seasonal fluctuation, attaining the maximum density in late summer and lowest population in the cooler months. On areca palms, as observed during the present study, the

seasonal pattern of distribution of *D. floridanus* followed a different trend than that of pineapple. The population of this species was at the peak level during the rainy season (May last – July), moderate in August and scanty in September and the presence of this mite could not be recorded in summer. Despite this, on pineapple, the peak population of this mite was reported during summer. In the present study, the presence of *D. floridanus* was mainly recorded on the young, tender (green coloured) nuts of Areca palms in Kerala, during the period of last week of May to July. This variation in the seasonal distribution pattern of the same species on different hosts may be accounted owing the availability of resources in tender nuts of Areca palms which are available only during the months of May to July. Since these mites were found confined to the area underneath of tepals of the nut, the delicate stages are excluded from the washing out effect of rain, and provide concealed niche to ensure maximum protection for their development and build up of population.

Tenuipalpid mites being exclusively plant parasitic, induce various types of abnormalities on their host plants. However, the direct feeding symptoms of these mites are less intense when compared to tetranychid and eriophyid mites. Quite often, apart from direct feeding injuries, these mites induce extreme yield loss through their efficient role as vectors, transmitting various phytopathogenic microbes and affecting the plant vigour and yield (Kitajima *et al.*, 2003 b; Kondo *et al.*, 2003). While feeding, these mites inject

toxic saliva into the fruits/leaves/ stem and bud tissues of their host plants (Childers *et al.,* 2003b). Species like *B. lewisi* feeds on different parts of plants such as stems, nut cluster and petioles and induces the formation of dark, irregular and roughened scab-like blotches at the feeding sites (Rice and Weinberger, 1981). Mite infested fruits develop lesions, which initially appear as very light yellowish circular areas in depressions as seen on the grape and citrus fruit surfaces (Dean and Maxwell, 1967; French and Rakha, 1994). These injuries gradually develop into centrally brown necrotic spots and which finally become darker with corky texture. Thus, the observations made during the present study are in line with the previous studies, revealing the severity of the damage induced by the species.

Feeding activity of the Red Palm Mite was found to induce development of localised yellow patches on the leaf lets of areca palms and these patches on continued feeding by the life stages of the mite coalesced and turned to bronze coloured areas. Infested leaves bearing large numbers of brown coloured leprotic patches were easily dried and such plants appeared withered. Stunted growth and withering of leaves in RPM infested palms were already observed in South Indian conditions (Puttarudraiah and Channabasavanna, 1956). The species was recognized as a very serious pest of palms worldwide (Flechtmann and Etienne, 2004; Vàsquez *et al*., 2008 ; Estrada and Venegas *et al*., 2010) and in which feeding through the stomata of host plants was reported for the first time (Ochoa *et al.,* 2011). This

specialized feeding habit of the species would interfere with the photosynthetic and respiratory processes of affected plants.

Tenuipalpid mite infestation was reported to cause accountable tissue damage on the leaves, nuts, stem and fruits of host plants and feeding activity of these mites on the epidermal tissue often would lead to the drying up and development of cracks. The feeding punctures and cracks would lead to secondary infection by fungal and bacterial pathogens to promote subsequent tissue decay (Jeppson *et al.*, 1975). On drying up of these lesions, scarring and tissue deformation would result (Sanches and Zem, 1978). *D. floridanus* was reported to invade pineapple farms and was known to cause greater harm to young plants and they voraciously feed on the soft white tissue of the leaf's base and would lead to the formation of rust like lesions in turn leading to microbial infestation and subsequent tissue rot (Poli, 1991). Rigorously infested pineapple plants often exhibit a stunted appearance, without any fruits (Singh and Raghuram, 2011). In the present investigation also similar types of feeding injury could be observed on arecanuts infested by *D. floridanus*. The life stages of *D. floridanus* were found to feed on the soft white tissue lying under the perianth and adjacent area of arecanuts, imparting a distinct discolouration of the injured area. Formation of deformed corky tissue in the form of irregular and small cracks also could be observed on mite infested areca nuts, leading to nut abnormalities and ultimately resulting in nut fall (Prabheena and Ramani, 2015).

The Red Palm Mite , *R. indica* infestation could be observed on 3 plants viz. *A. catechu, C. nucifera* and *M. acuminata*, during the present study. Heavy infestation by this mite was observed on areca palms of the nursery stage and younger leaves, which resulted in the yellowing of leaves and development of brown patches. Mite infestation on areca palms was reported to show symptoms like withering of leaves and diminution of growth (Puttarudraiah and Channabasavanna, 1956). Intensive feeding by large numbers of the various life stages of this species on areca palms was reported to induce formation of localised yellow colouration on leaf lamina which gradually developed yellow patches and later turned to bronze coloured areas and ultimately led to withering of the leaves (Prabheena and Ramani, 2014). The present results could clearly support the previous findings and would serve to detect stunted growth in infested areca palm.

On coconut, RPM infestation was reported to affect yield loss and often would adversely interfere in the esthetic quality of the trees and in Brazil, this species was reported to cause a particular form of damage (Moraes *et al.,* 2004). *R. indica* was the mite species which was documented to feed through the stomata of host leaves (Ochoa *et al*., 2011) and this particular feeding habit possibly would obstruct the physiological activities of its host plants like photosynthesis and respiration. The feeding of *R. indica* on coconut plant was found to initiate at the base of leaflets, leading to bronzing of the leaflets and subsequent conversion to necrotic tissues. The

infestation of *R. indica* on banana also was found to cause considerable loss to banana farmers (Moraes *et al.,* 2014).

The damage symptoms induced by species of *Tenuipalpus* viz. *T. micheli* and *T. chiclorum* on their respective host plants were more or less in agreement with those induced by other species of tenuipalpids studied. Both *T. micheli* and *T. chiclorum* were observed to feed on both surfaces of the leaves of *S. cumini* and *M.sappota,* though more preference was shown to the lower surface in both cases. *T. micheli* induced more damage on areas adjacent to the mid rib where the epidemis was pierced by the various life stages of the mite, leading to the development of silvery coloration of the affected leaf tissue. In the initial stages of infestation, slight colour changes were observed, and later the leaves developed light yellow patches and finally the damaged area became dark in colour. All life stages of *T. chiclorum* also were found to pierce the leaf epidermal tissue of the host plant, leading to formation of light yellow spots initially and which on progressive feeding turned to yellow or grey coloured. Completely damaged leaves appeared as black coloured. Similar types of damage symptoms were reported in other tenuipalpid species like *T. bakeri* which also led to formation of patches on the underside of leaves of *Trichilia havanensis* and the infested leaves showed irregular chlorosis and yellowing and infestation on fruits led to the formation of characteristic fine cracks (Ochoa *et al.,* 1994). *T. bakeri* infestation on *Chamaedorea* spp. was reported to cause intervenal yellowing of leaves

(Ochoa *et al.,* 1994). Similar intervenal yellowing was reported in leaves of *Cedrela sp.* infested by *T. costerricansis* (Salas and Ochoa, 1986). The feeding activity of *T. pacificus* induced the formation of reddish brown colouration at the base and along the principal vein of affected leaves which in some cases would lead to yellowing of leaves also. On severe infestation the species induced foliar necrosis (Ochoa *et al.,* 1994).

Feeding activity of *B. phoenicis* on different host plant also disclosed the preference of the mite to the lower surface of the leaf lamina, adjacent to the midrib or veins (Reis and Chagas, 2001; Prabheena and Ramani, 2013). On citrus plant, the species was found to aggregate on the lower leaf surface, next to the mid-vein or lateral veins and through feeding induced formation of yellow blistering on the leaf surface (Childers *et al.*, 2003). The injured parts gradually became necrotic, ensuring leaf drop, particularly when large numbers of mites were present (Childers *et al*., 1994). On the medicinal plant *O. gratissimum*, *B. phoenicis* exhibited more preference to the middle-aged leaves on which the species produced large number of white coloured chlorotic spots owing to its feeding activity (Prabheena and Ramani, 2010). Such feeding wounds induced by the species were found combined to form light brown coloured spots (Akbar and Aheer, 1994; Carvalho *et al*., 2008; Prabheena and Ramani, 2013). Severely infested leaves, mainly the middle-aged leaves, demonstrated the existence of diffused chlorotic spots on the leaf lamina and frequently on the veins and midribs, generally called as the

'phoenicis blotch' (Jeppson *et al*., 1975; Knorr *et al*., 1968; Prabheena and Ramani, 2013). The damage induced by this species on *P. guajava* during the present study was also in line with the earlier findings. On *P. guajava,* the damage symptoms initially appeared as white coloured chlorotic spots and which ultimately turned yellow and brown coloured patches. The species while feeding pierced the epidermal tissue, thereby leading to the formation of light yellow colouration. The completely damaged leaves turned to yellow or brown in colour and showed signs of premature aging and in due course shed down. These observations were in support of the eartlier findings mentioned above on the damage symptoms induced by *B. phoenicis* on various host plants.

Apart from the physical damage, the feeding activities of tenuipalpid mites induce alterations in the biochemical constituents of the host plants. Mite invasion routes to various biochemical alterations, leading to changes in inorganic and organic compounds and also the mineral composition of affected plants. The changes in the biochemical components in turn would result in alterations in the physiology and morphology of host plants (Golek, 1975; Kolodoziej *et al.,* 1979; Shree and Nataraja, 1993; Prabheena and Ramani, 2013).

Among plants, chlorophyll pigments are responsible for absorbing light energy from the sun for its subsequent conversion to chemical energy (Yakar

and Bilge, 1998) through photosynthesis which is highly essential for the synthesis of various organic compounds. Therefore, chlorophyll content is considered as a key experimental parameter in plant biology and agronomy (Lamb *et al*., 2012). Apart from the correlation to photosynthetic potential, the chlorophyll concentration provides wealth information also on the physiological status of the plants (Gamon and Surfus, 1999). Results of the present study very clearly demonstrated the feeding impact of 4 species of tenuipalpid mites viz. *T. micheli*, *T. chiclorum, B. phoenicis* and *R. indica* on the chlorophyll contents of their respective host plan*s* such as *S. cumini, M. zapota, P. guajava* and *A. catechu.* Feeding activity of all the 4 species were found to cause significant reduction in the chlorophyll contents of their host plants thereby supporting earlier findings (Ghoshal, 2013; Prabheena and Ramani, 2013). The reduced chlorophyll level in mite infested leaves could have resulted either from the mechanical damage of chloroplasts in the leaf tissue owing to mite feeding or from alterations in chlorophyll metabolism resulted due to the water stress induced by the feeding activity of the mite (Tomezynsk and Kropzynska, 1985). Infestation by *Tetranychus ludeni* was found to induce chlorophyll loss of 33.62% in *Luffa acutangula* (Chatterjee and Gupta, 1997) and 13.45 % loss of chlorophyll in *Corchorus capsularis* due to the infestation by *Polyphagotarsonemus latus* (Ghoshal *et al.,* 2005). It may be concluded that, the infestation of *B. phoenicis, T. micheli*, *T. chiclorum* and *R. indica* would significantly affect the concentration of

chlorophyll in respective host plants, and thus interfere with their photosynthetic efficiency and reduce the fabrication of organic compounds, which in turn would result in stunted growth and immature senescence of plants and leaves.

Nitrogen is one of the vital elements in plants and which plays a key role in chlorophyll production and forms part of the various proteins that have major roles in many metabolic processes associated with plant growth (Sinfield *et al*., 2010). In addition, this element is essential for the assembly of chemical components that defend against parasites and plant diseases (Hoffland *et al*., 2000). Demonstration of the concentration of nitrogen in mite infested and uninfested leaves enabled to understand the feeding effect of tenuipalpid mites. Leaves o respective plants infested with *B. phoenicis, R. indica, T. micheli* and *T. chiclorum* disclosed significant reduction in the total nitrogen composition. Nitrogen loss induced by *B. phoenicis* and *R. indica* was comparatively higher than that of *T. micheli* and *T. chiclorum as* evidenced during the current study. Similar results were reported by earlier workers (Ghoshal *et al*., 2005) also by accounting the percent loss of Nitrogen in *Corchorus capsularis* owing to feeding by *P. latus*. Feeding activity of *T. ludeni* on *Luffa acutangula* also was recorded to bring loss of nitrate and nitrite (Chatterjee and Gupta, 1997). Nitrogen loss due to the infestation by mites in the leaves of *O. sanctum* (Ghoshal, 2013). Further support on the impact of infestation of two spotted spider mite on cucumber

also exists (Park and Lee, 2002) which resulted in changes in the physiological and biochemical components, including loss of nitrogen. The loss of Nitrogen in the infested plant leaves would be due to the penetration of leaf cells by the cheliceral stylets of mites and subsequent introduction of saliva would lead to mechanical damage, alteration in cell cytology, physiological and biochemical processes of stabbed as well as non-stabbed nearby cells (Tomczyk and Kropczynska, 1985). Another probable reason for nitrogen reduction is the increased production of reactive oxygen species (ROS) due to mite infestation. The increased ROS leads to the destruction of membrane permeability there by leading to declined levels of minerals (Farouk and Osman, 2011).

The amino acid, proline is believed to be a compatible solute and the accumulation of proline was noticed in plants, produced when unfavorable conditions prevailed (Aspinall and Paleg, 1981). Many plant species were reported to produce increased nitrogen content on exposure to extensive range of stress conditions like salinity, high light intensity, extreme temperatures and water shortage (Aspinall and Paleg, 1981; Delauney and Verna, 1993; Mansour, 2000). In addition to abiotic stress, plants accumulate proline under biotic stress also to overcome the stress. During the microbial infection, the proline contents of certain plants become raised many folds in sensitive and resistant cultivators (Raj *et al*., 1983 ; Gupta, 2001). In the present investigation, the amount of proline was found increased significantly on all

host plants owing all the 4 species of mites studied, thereby supporting the earlier observations showing the impact of mite feeding on eucalyptus (Khattab, 2005; Kielkiewicz, 2005) and bean (Farouk and Osman, 2012) and the population density of mites was also found to be correlated with the amount of proline accumulated in leaves (Sivritepe *et al*., 2009). The percentage increase in proline content was higher in plants infested by *R. indica* and *T. chiclorum* when compared to *T. micheli* and *B. phoenicis* infested plants. The accumulation of proline in plants under stress would be due to the ability of proline to move between tissues to defend the plant from stress by performing as a storage compound for carbon and nitrogen, thereby guarding the enzymes and cellular structures (Serrano and Gaxiola, 1994). Further, proline was reported to be involved in ROS detoxification and stabilization of cell membranes (Kishor *et al*., 2005). It can be concluded that the plants accumulate proline to resist the stress induced by tenuipalpid mite infestation and the amount of proline in infested leaves could be correlated with the severity of infestation, type of mite and the host plant.

Phenol plays an important role in plant defense mechanism and an increased concentration of phenol was observed in plants infested with fungi and also found to be increasing the physical and mechanical vigor of the host cell wall (Senthil *et al*., 2010). In the present study, results of phenol estimation in mite infested and control leaves of various host plants clearly revealed the elevation of phenol concentration in the mite infested leaves.

This was true for all the species of mites on all the host plants studied, supporting the previous reports on mite infested leaves of eucalyptus (Khattab, 2005). An enhancement in the production of phenolics was reported in castor, cassava and eucalyptus owing to pest attack and it was also noted that higher phenolic content would increase the resistance of hosts against the insects (Ananthakrishnan *et al*., 1992). Elevated levels of phenolics were recorded in leaves and roots of resistant pearl millet than that of the sensitive varieties (Gupta , 2001) .

Increase in phenolic contents of plant was reported to be one of the causes of photosynthetic inhibition (Puchalska, 2006). Such an increase in phenolic content was reported in mite infested plants such as tomato and bean (Kielkiewicz, 2005; Farouk and Osman, 2012). Thus the present study clearly revealed that plants infested with *T. micheli* and *T. chiclorum*, *B. phoenicis and R. indica* could synthesize increased amount of phenol to protect themselves from further damage through mite infestation.

Photosynthesis is the central energy acquiescent process in any ecosystem; any drop or inefficiency (Zelitch, 1975) in this process would usually be detrimental to plant growth and productivity. Chlorophyll fluorescence has been widely used for revealing the structural and functional aspects of photosynthetic apparatus in plants (Strasser *et al.,* 2000). In the present study, all photosynthetic parameters were found decreased owing to

infestation by *T. micheli* and *T. chiclorum, B. phoenicis* and *R. indica* . The decreased value of Fv/Fm observed in mite infested leaf samples would be an indication of the stress induced on affected plants, by abiotic or biotic factors (Shigeto and Makoto, 1998) and the fall in Fv/Fm value in infested plants might be a sign of the decrease in ability of PS II activity (Schnasker *et al*., 2006). Performance index (PI) is considered as an awfully perceptive parameter in most of the unfavourable conditions (Strasser *et al.,* 2000; Jiang *et al*., 2006; Christen *et al*., 2007; Oukarroum *et al.,* 2007) and plant vitality could be illustrated by performance index. This integrative parameter includes three independent parameters: (1) compactness of fully energetic reaction centers (RCs); (2) effectiveness of electron movement by trapped excitation into the electron transport chain away from the QA; and (3) the chance that an absorbed photon will be trapped by RCs. PI indicates the efficiency of both photosystems I and II and provide quantitative knowledge on the existing condition of plant performance during stress conditions (Strasser *et al*., 2004). The decreased PI value observed in leaves infested by *T. micheli* , *T. chiclorum, B. phoenicis* and *R. indica* reflects that the plants were under severe stress due to infestation. The Kautsky curve (area above the fluorescence curve between F0 and Fm) is proportional to the pool size of the electron acceptors QA on the reducing side of Photosystem II and this area was found reduced dramatically in the infested plants, as evident from the current study. Thus the results of the present study support the earlier findings

(Joliot and Joliot 2002). If electron transfer from the reaction centers to the quinone pool is blocked, this area will be dramatically reduced. The area above the fluorescence curve between F0 and Fm (Kautsky curve) is proportional to the pool size of the electron acceptors QA on the reducing side of Photosystem II. The reduced area recorded in the infested leaf samples might be reflecting the blocking of electron transfer between reaction centers to the pool (Joliot and Joliot 2002) as observed in plants infested by *T. micheli* and *T. chiclorum, B. phoenicis and R. indica*.

The outcome of developmental studies carried out on the 5 species of tenuipalpid mites revealed that the pattern of developmental processes was same in all species. The development of a tenuipalpid species comprises of four active stages viz, larva, protonymph, deutonymph and adult and an inactive (quiescent) stage between each of the active stage (Pontier *et al.,* 2000; Prabheena and Ramani, 2013).

Like other mite groups, tenuipalpids also show preference to the site selection for oviposition. *B. phoenicis* laid eggs in cracks, crevices and other confined vicinity on the plant surface (Reis *et al*., 2000 b.) and the sticky nature of eggs would help to ensure close adherence to the leaf surface (Haramoto, 1969). The minute eggs of *R. indica* were smooth, red and connected to the abaxial leaf plane by a slender stalk (Welbourne, 2006). *R. indica* was found to thrive on the lower surfaces of coconut leaves and the

eggs were deposited in colonies (Jeppson *et al*., 1975; Etienne and Fletchmann, 2006). *D. floridanus* preferred to lay eggs inside the tepals of areca nut along with other stages (Prabheena and Ramani, 2015). During oviposition, the females of *T. heveae* showed preference to the shallow holes on the surface of the leaflet or along the leaf veins (Pontier *et al.,* 2000). In the present study, the nature of oviposition in *T. micheli* and *T. chiclorum, B. phoenicis*, *D. floridanus* and *R. indica* was found to coincide with the earlier reports, so as to ensure protection to the immature stages.

Various factors like temperature, relative humidity, and type of host plant show great impact on the rate of development of Tenuipalpid mites (Morishita, 1954; Haramoto, 1969; Chandra and Channa Basavanna, 1974; Lal, 1978; Goyal *et al.*, 1985; Chiavegato and Mischan, 1988; Pontier *et al.,* 2000). The developmental rates of During the present study, the pre-oviposition period of *B. phoenicis* on *P. guajava* was recorded as 9, 8.6 and 7.4 days at 25 + 2^{o}C & 80 + 5% RH, 30 + 2^{o}C & 70 + 5% RH and 35 + 2^{o}C & 60 + 5% RH respectively and the result of this study revealed that the variation in the pre-oviposition period of *B. phoenicis* was dependent on temperature and relative humidity. The duration of pre-oviposition period of the species was comparatively less when the development was traced under increased temperature and decreased humidity conditions(Prabheena and Ramani , 2010) and it required only 4 days on another host plant, *O. gratissimus*. Thus the results of present study supports the earlier observations

made on the species (Haaramoto, 1969). The oviposition period of *B .phoenicis* could be recorded as 11.9, 10.6 and 9 days at 25 + 2°C & 80 + 5% RH, 30 + 2°C & 70 + 5% RH and 35 + 2°C & 60 + 5% RH respectively. This seems to be in agreement with the previous observations (Lal, 1979; Prabheena and Ramani, 2010). Similar variations could be observed on duration of post-oviposition period of the species also and the duration was minimum 6.9days at 35 + 2°C & 60 + 5% RH.

Considerable variations were recorded in the pre-oviposition, oviposition and post-oviposition periods of *T. chiclorum* and *T. micheli* also due to the changes in temperature and relative humidity. The duration of pre-oviposition period in *T. chiclorum* on the host plant, *M. zappota* was 7.3, 6.5 and 5.45 days at 25 + 2°C & 80 + 5% RH, 30 + 2°C & 70 + 5% RH and 35 + 2°C & 60 + 5% RH respectively and the *T. micheli* showed 6.6, 5.55 and 4.55 days at 25 + 2°C & 80 + 5% RH, 30 + 2°C & 70 + 5% RH and 35 + 2°C & 60 + 5%. These results are in support of earlier studies carried out on other species of *Tenuipalpus.* The optimum temperature of *T. punicae* was recorded as 33°C and followed by 30°C on the host plant, Pomegranate with a shortest pre-oviposition period (Ibrahim *et al.*, 2006). Thus temperature was proved as an important factor for the development of *T. punicae* (Zaher and Yousef, 1972). Similarly, the pre-oviposition period of *T. heveae*, was averaged to 4.4 days on PB260 rubber tree clone (Pontier *et al.,* 2000). The role of type of host plants on the development of *T. heveae* was demonstrated in three clones

of rubber trees (Feres *et al*., 2012). In the present study, the oviposition of *T. chiclorum* and *T. micheli* clearely exhibited variation in the oviposition periods based on variations in temperature and relative humidity. The durations of oviposition period of *T. chiclorum* were 11.2, 10.1 and 8.8 days respectively at 25 + 2ºC & 80 + 5% RH, 30 + 2ºC & 70 + 5% RH and 35 + 2ºC & 60 + 5% whereas in the case of *T. micheli* the mean durations of oviposition periods were 12.5, 11.7, 9.6 days at 25 + 2ºC & 80 + 5% RH, 30 + 2ºC & 70 + 5% RH and 35 + 2ºC & 60 + 5% respectively. *T. micheli* and *T. chiclorum* showed significant variations in the oviposition period from that of *T. heveae* infesting the host plant, PB260 rubber tree clone. On PB260 rubber tree clone, *T. heveae* had an average duration of 23.8 days (Pontier *et al*., 2000) for oviposition. Variations in the biochemical contents of different host plants might be a reason for the variation in the durations of developments of mites on different hosts. Hence it could be concluded that the oviposition period of mites are greatly influenced by the temperature, humidity and the type of host plant.

The mean durations of pre-oviposition of *D. floridanus* as observed during the present study were 2.45, 1.75, 1.45 days at 25 + 2ºC & 80 + 5% RH, 30 + 2ºC & 70 + 5% RH and 35 + 2ºC & 60 + 5%. This clearly supports the data obtained on pre-oviposition period of another species viz. *D.cocos* infesting coconut (Santhosh *et al*., 2009). *D. floridanus* on areca nut showed an oviposition period of 8.3+ 0.08 days at 25 + 2ºC & 80 + 5% RH, 7.1+ 0.03

days at 30 + 2°C & 70 + 5% RH and 6 + 0.07 days at 35 + 2°C & 60 + 5% RH whereas *D. cocos* on the host plant coconut was found to have an oviposition period of 3-6 days at 25 ± 1 and 88% RH. The post- oviposition period in *D. floridanus* also showed variations depending upon the variations in temperature and humidity conditions. These observations obviously revealed the consequence of temperature and relative humidity on the pre-oviposition and oviposition periods of *D. floridanus*. The eggs of *D. floridanus* were very delicate and always laid concealed habitats like the area underneath the perianth of arecanuts. Earlier studies suggested that the eggs of *D. floridanus* were soft bodied and prone to desiccation easily when exposed to bright light (Prabheena and Ramani, 2015).

Results of the present study also could depict the influence of temperature and relative humidity on the pre-oviposition, oviposition and post oviposition periods of the Red Palm Mite, *R. indica* and in general the population density of the mite. The mean duration of pre-oviposition period in *R. indica* was observed to be 5.9 + 0.07 days at 25 + 2°C & 80 + 5% RH, while it was 3.85 + 0.07 days at 30 + 2°C & 70 + 5% RH and 3.15 + 0.08 days at 35 + 2°C & 60 + 5% RH and similar variations could be recorded in oviposition period too. At 25 + 2°C & 80 + 5% RH, the average duration of oviposition period was 23 + 0.22 days while it was 21.7 + 0.18 days at 30 + 2°C & 70 + 5% RH and 19.90 + 0.17 days at 35 + 2°C & 60 + 5% RH. The relative humidity and annual rainfall were found to have a negative

correlation with the population density of *R. indica* whereas the atmospheric temperature exhibited a positive correlation with mite population. These results are in agreement with the results of earlier studies (Yadav Babu and Manjunatha, 2007; Mujeeb Rahman *et al*., 2012). The durations of pre-oviposition and oviposition periods of *R. indica* were found declined depending up on the increase in temperature under the laboratory conditions. This clearly supports the earlier observations made on the spider mite, *O. biharensis* infesting on the host, *M. esculenta* (Dhooria, 1985).

The number of eggs laid by a single female of *B. phoenicis* during its oviposition period showed variation depending upon temperature and relative humidity. The fecundity of *B .phoenicis* was recorded as 9-10, 10-12 and 10-14 at 25 + 2^{o}C & 80 + 5% RH, 30 + 2^{o}C & 70 + 5% RH and 35 + 2^{o}C & 60 + 5% respectively and the daily production of eggs by a single female was also found varied as 2 at 25 + 2^{o}C & 80 + 5% RH, 2 at 30 + 2^{o}C & 70 + 5% RH and 3 at 35 + 2^{o}C & 60 + 5% RH. The fecundity of *B. phoenicis* on *P. guajava* was found to be almost similar to that of the species infesting on *O. gratissimum* at 30^{o}C and 65% RH (Prabheena and Ramani, 2010). However, the number of eggs laid was comparatively very low than those of earlier reports (Haramoto, 1965 ; Childers *et al*., 2001). The present study revealed that *B. phoenicis* laid the maximum number of eggs on the 5th or 6th days of oviposition and the rate of fecundity got declined after 7th day. The same species on Tea laid the maximum number of eggs between 8 and 20days after

the onset of oviposition (Oomen, 1982). The outcome of the present study demonstrated the influence of temperature, relative humidity and type of host plant on the fecundity of *B. phoenicis.* The longevity of females *B. phoenicis* was found maximum 30 days at 25 + 2°C & 80 + 5% RH. This result was in agreement with the previous observation (Sadana and Kumari, 1987 a.) on the species which exhibited a longevity of 31 days on guava. Whereas on *O. indicum* and *C. siphonathus* , the respective longevity recorded for the species included 22 days and 21 days (Lal, 1979).

The daily production of eggs by the females of *T. chiclorum* and *T.micheli* also was found to vary depending upon the variations in temperature and relative humidity. The mean number of eggs laid by *T. chiclorum* was 12.10 ±0.11 at 25 + 2°C & 80 + 5% RH, 15.50±0.11 at 30 + 2°C & 70 + 5% RH and 15.10 ±0.11 at 35 + 2°C & 60 + 5% RH. The average fecundity of *T.micheli* was 11.60, 16.10 and 14.00 at 25 + 2°C & 80 + 5% RH, 30 + 2°C & 70 + 5% RH and 35 + 2°C & 60 + 5% RH respectively. Thus, both the species showed maximum fecundity at 30 + 2°C & 70 + 5% RH and the rate of egg production in both was comparatively greater than that of earlier studied species of the genus viz. *T. heveae* (Feres *et al*., 2002). This result also supports the earlier findings on other tenuipalpid mites like *Cenopalpus iranicus* infesting apple leaves, in which the rate of fecundity was found increased with increasing temperature from 20□C to 30□C and then showed a decrease at 32□C (Bazgir *et al*., 2014).

In the present study, the average number of eggs produced by the mated females of *D. floridanus,* infesting arecanut palms also was found to differ based on the differences in temperature and relative humidity. Thus, the mean fecundity of fecundity was observed as 11.57 at 25 + 2°C & 80 + 5% RH, 13.29 at 30 + 2°C & 70 + 5% RH and 11.50 at 35 + 2°C & 60 + 5% RH. The adult longevity of similar variation could be observed in *D. floridanus* in accordance with the temperature and relative humidity variations. The fecundity of *D. floridanus* was comparatively much higher than that of an earlier studied species of the genus viz. *D. cocos* on coconut and which was found to lay 6-12 eggs during its oviposition period of 3-6 days under laboratory conditions of 25 ± 1 ° C and RH of 88 % (Santhosh *et al*., 2009). The daily production of eggs was much lower, with a mean value of 2. In comparison with *D. cocos,* the body size of *D. floridanus* was also large and it produced moderately large eggs, having approximately one third of the size of the female body. Size and the energy of mite were obligatory to generate such large eggs, which suggest that the maximum egg production would not go beyond more than two per day (Poli, 1991).

During the present study, the mated females of *R. indica* were found to produce 21.74, 43and 38.14 eggs on an average at 25 + 2°C & 80 + 5% RH, 30 + 2°C & 70 + 5% RH and 35 + 2°C & 60 + 5% RH respectively. This is in agreement with the results of earlier studies which showed that the females of *R. indica* laid 28 to 50 eggs (Peña *et al*., 2006; Welbourn, 2006) and the daily

production of eggs by the species averaged to 2 and it continued for an average of 27 days (Peña *et al*. 2006). The longevity of the adults of the species was observed to be approximately one month and which supports the earlier finding on the species (Welbourn, 2006). Despite these, the female longevity and total number of eggs laid by *R. indica* were found considerably higher on coconut (Nageshachandra and ChannaBasavanna, 1984; Lima *et al.,* 2011). Such variations in the fecundity and longevity exhibited by the same species on different host plants would be a reflection of the variations in the nutritional resources enjoyed by the mite from their host plants.

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. Earlier studies also could establish variations in the duration of development from egg to adult stage of the species depending up on the host plant differences. 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 (Teodoro and Reis, 2006).

During the present study, similar variations in the durations of developmental stages could be observed in *T. chiclorum* and *T. micheli* also with respect to alterations in the temperature and relative humidity. *T. chiclorum* showed 35.6, 34.05 and 32.95 days duration for egg to adult

development at 25 + 2ºC & 80 + 5% RH, 30 + 2ºC & 70 + 5% RH and at 35 + 2ºC & 60 + 5% RH respectively. While *T. micheli* showed 37-43, 33-38 and 30-35 days duration for the development of egg to adult at 25 + 2ºC & 80 + 5% RH, 30 + 2ºC & 70 + 5% RH and 35 + 2ºC & 60 + 5% RH respectively. Thus the results of the present study supports the earlier observations made on another species viz. *C. irani* on apple leaves, which showed a decrease in developmental time of immature stages with an increase in temperature from 20□C to 32□C (Bazgir *et al*., 2014). This clearly could establish the positive impact of temperature on development and the completion of life cycle of tenuipalpid mites.

In the present study, *R. indica* was found to complete its development from egg to adult stages within 22-30 days, at 25 ± 2ºC & 80 ± 5% RH, 20-27 days at 30 ± 2ºC & 70 ±5% RH and 16- 22 days at 35 ± 2ºC & 60 ± 5% RH. Thus the rate of development was faster at 35± 2ºC & 60± 5% RH than that of the other temperature-humidity parameters studied . This is in support of earlier reports (Moutia ,1958) in which the shortest duration was observed at 35 ± 2ºC & 60 ± 5% RH and a negative correlation was established for species with rainfall and RH but and a positive correlation with temperature.

The developmental stages of *R. indica* were found to be influenced by temperature, relative humidity and host plant (Zaher and Yousef, 1972;

Gerson , 2008). The time required to complete the life cycle *R. indica* is 21-33 days (Zaher and Yousef, 1972; Jepson *et al*., 1975). Like all other tenuipalpid species, *D. floridanus* also exhibits certain degree of variation in the development of mite from egg to adult in different temperature and humidity conditions. The development of *D. floridanus* from egg to adults on *A. catechu* under dissimilar temperature-humidity conditions make possible to record a shorter duration of development at 35 ± 2ºC & 60 ± 5% RH and a longer duration at 25 ± 2ºC & 80 ± 5% RH compared to 30 ± 2ºC & 70 ± 5% RH. This variation in the period of the post embryonic development can be accounted for the variation in temperature and relative humidity.

The results of the present study enabled to acquire knowledge on the sex ratio in tenuipalpid mite population. Most species of tenuipalpid mites studied were found to possess comparatively higher number of females in their colonies than those of the male members. Interestingly, results of field cum laboratory studies revealed that *B. phoenicis* populations comprised entirely of female individuals. This result is confirmative with the earlier reports (Haramoto, 1969). Instances of feminization has been recorded earlier in tetranychoid genera like *Bryobia, Brevipalpus* etc. owing to endosymbiotic relationship of mites and bacteria such as *Wolbachia, Cardinium* etc. that obstruct the development of androgenic glands in males (Weeks *et al*., 2001; Weeks and Breeuwer, 2000; Groot *et al*., 2006). The longevity of these 5 tenuipalpid mites was found to be influenced by the temperature and relative

humidity. The longevity of females was relatively higher than that of males in all the species studied. Further, the results of the study also enabled to record that the longevity of mites was negatively affected by mating. Similar observations were made in other species also by several workers (Ray and Rai, 1981; Sangeetha and Ramani, 2007)

The 5 tenuipalpid mite species selected for the current study exhibited similarity in the process of hatching. Initiation of hatching was marked with the manifestation of a semicircular opening at the broader end of the egg, which got widened along either sides as a result of the wriggling movements of the emerging larvae .The emerging larva was found to protrude its first two pairs of legs through the slit and which was followed by the thrashing action of its propodosoma and movement of the first pair of legs. The process of hatching was found completed within 10-30 minutes. Similar observation was made in earlier studies on *D. cocos* (Santhosh *et al.,* 2009). The moulting of Tenuipalpid mites was demonstrated to be completed within 10-30 minutes. The moulting process was also almost similar in all the 5 species studied. Similar pattern of moulting was observed in many species of plant mites, especially the spidermites (Banu and ChannaBasavanna, 1972; Gupta, 1985; Sangeetha and Ramani, 2007)

The mating pattern of these 5 tenuipalpid species also showed close resemblance, but with slight variation in the duration of mating. The matting

pattern in *D. cocos* was reported to be similar to that of *R. indica,* though there was difference in duration (Santhosh *et al*., 2009). Thus the study could establish that the mating pattern of tenuipalpid mites are more or less similar, irrespective of species difference which often induce differences in duration, thereby giving due support to the earlier findings (Qureshi *et al.,* 1969; Banu and ChannaBasavanna, 1972; Penman and Cone, 1972).

Tenuipalpid mites were found to follow an unusual genetic system in its development. All the eggs deposited by mated females generated only female progeny while the unmated females developed into males. This is in agreement with the earlier study on *R. indica* (Chandra and ChannaBasavanna, 1974). Apart from the parthenogentic system, this group of mites also could produce progenies through sexual mode (Chandra and Channa Basavanna, 1974, Childers *et al.,* 2003 a., Prabheena and Ramani, 2014)

Results of morphological studies on developmental stages of the 5 species enabled to record a progressive increase in body size and number of setae on different regions of the body, from larvae to deutonymph. The newly hatched larvae all species were distinct to be easily distinguished based on their possession of three pairs of legs. Complete setal complements of the dorsal and ventral surfaces were found attained only during the adult stage, a common feature reported in the case all species of phytophagous mites studied (Childers *et al.,* 2003a.; Santhosh *et al*., 2009).

SUMMARY

Tenuipalpid mites, the commonly called false spider mites constitute a momentous group, which feed voraciously by sucking the sap of host plants and inducing diverse types of abnormalities like yellowing, necrosis, leprosies, leaf rolling, blister formation, stunted growth, gall formation etc. on crop plants. Apart from direct damage, many species are kenned to act as vectors of plant viral diseases, causing more potential loss to growers. Even-though tenuipalpid mites route rigorous damage to crop plants, these mites are still underestimated on a global level. Kerala's economy is very closely linked with agriculture and it forms the major source of livelihood of the people of the state. Fruit and plantation crops also play an inimitable part in the economy of Kerala, especially by improving the profits of the rural people and the present cognizance on the distribution, abundance and alimenting impact of tenuipalpid mites on the biochemical parameters and photosynthetic machinery of plants is scanty, especially in South India. This is detrimental in designing a better pest management strategy of these mites (IPM). Hence, the present investigation on the tenuipalpid mites associated with the fruit and plantation crops of Kerala can be considered as a rudimental framework for further research along this line.

The present study on the biological parameters of selected species of tenuipalpid mites infesting the fruit and plantation crops of Kerala was

arranged in three parts**,** viz. Part **A, B** and **C.** Part **A** deals with a detailed survey carried out on tenuipalpid mites associated with the fruit and plantation crops of Kerala, the distribution pattern of the species recovered from the host plants collected from various localities of Kerala with respect to geographical and seasonal variation, especially of the common and abundant species of local importance, host range of the selected common species etc. Part **B** comprises the morphological studies of five species of common tenuipalpid mites selected for detailed biological studies. Details of permanent slides preparation, taxonomic features and diagrammatic illustrations of the life stages of supported by camera lucida drawings and SEM photographs etc. are presented in this section. Part **C** deals with the biological studies carried out on five common species of tenuipalpid mites associated with the fruit and plantation crops of Kerala and this section is divided in two sections viz. Feeding biology and Breeding biology. Results of the qualitative and quantitative studies carried out on the damage induced by the selected species of these 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 **A** to the general faunal diversity as well as the common and abundant species of tenuipalpid mites, extensive surveys were carried out on the fruit plants and plantation crops cultivated/grown in 28 sites distributed

over 14 districts *viz.* Malappuram, Kozhikkode, Kannur, Kasaragod, Wayanad, Thrissur, Palakkad, Eranakulam, Idukki, Kottayam, Alappuzha, Pathanamthitta, Kollam and Thiruvananthapuram of Kerala. A total of 52 species of plants comprising 36 species of fruit plants under 28 genera and 19 families and 16 species of plantation crops under 16 genera and 15 families, was screened during the study period for collecting data on the host range and distribution pattern of associated species of tenuipalpid mites. Results of the survey revealed evidences of infestation by members of three orders, viz. Prostigmata, Mesostigmata and Oribatida, of which Prostigmata registered the maximum representation by acarine inquilines comprising 3 super families, such as Tetranychoidea, Tarsonemoidea and Eriophyoidea in all the 28 collection sites, thereby emphasizing the maximum diversity.

In the present study the following species were recovered from the fruit and plantation crops of Kerala *viz. Tenuipalpus chiclorum* De Leon, *Tenuipalpus micheli* Lawrence, *Dolichotetranychus floridanus* Banks, *Dolichotetranychus cocos* Flechtmann & Fernando, *Raoiella indica* Hirst, *Raoiella macfarlanei* Pritchard & Baker, *Cenopalpus pulcher* Canestini & Fanzago, *Brevipalpus phoenics* Geijskes, *Brevipalpus obovatus* Donnadieu and *Brevipalpus californicus* Banks. High incidence of these mites was observed on fruits trees like *Annona reticulata* Linn., *Manilkara zapota* Linn., *Passiflora edulis* Sims., *Psidium guajava* Linn., *Citrus sinensis* Linn., *Citrus maxima* Merr., *Syzygium cumini* Linn., *Malus domestica* Borkh, *Carica*

papaya Linn., *Punica granatum* Linn., *Artocarpus altilis* Fosberg. and plantation crops like *Areca catechu* Linn., *Cocos nucifera* Linn., *Coffea Arabica* Linn., *Camellia sinensis* Linn. and *Syzygium aromaticum* Linn. Of the diverse species of Prostigmatids observed, five species were recognized as the very common and abundant on our fruits and plantation crops of local importance and hence which were considered for detailed biological studies. The above 5 species were *Brevipalpus phoenics* Geijskes, *Dolichotetranychus floridanus* Banks, *Raoiella indica* Hirst, *Tenuipalpus chiclorum* De Leon and *Tenuipalpus micheli* Lawrence.

Studies on the seasonal distribution pattern of the various species of mites studied revealed their infestation in the peak, moderate and scanty levels in various periods of the year. *B. phoenics*, *R. indica*, *T. chiclorum* and *T. micheli* exhibited peak populations mainly during summer period, from February to May while, *D. floridanus* showed its peak population during May to October period. Of the 5 species, *B.phoenicis* was found as the most abundant species in terms of population density, followed by *R. indica, D. floridanus, T.chiclorum* and *T.micheli.* Data on differential distribution pattern of the above species of false spider mites revealed infestation by *T.chiclorum*, *B.phoenicis*, *T.micheli* and *R. indica* on the lower leaf surface, while *D. floridanus* showed preference to the inner surface of the tepals and the soft and delicate area around the meristematic region of tender areca nuts.

Part **B** of the thesis provides data on the morphological details of the 5 selected species of common tenuipalpid mites mentioned above. For studying the morphological features, the leaves and leaflets that confirmed mite infestation were collected and transferred to polythene bags and transported to the laboratory. The collected samples were examined under a Stereo Zoom microscope (MacroVis, MVNSZ-405). The mite specimens were segregated with the help of camel hair brush and put in 70% alcohol for preservation. The preserved specimens were later subjected taxonomic studies. Live mites collected from various host plants were 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 and SEM photographs. 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 quite often, with the help of experts.

Part **C** of the thesis includes the details of biological studies carried out on the selected species of tenuipalpid mites mentioned above**.** Laboratory

cultures of these species were raised in the laboratory on their respective host plants by adopting leaf flotation technique. Qualitative evaluation 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 during progressive feeding, through simultaneous field cum laboratory observations. Data on the nature of incidence, severity of infestation, population density of the species, distribution pattern of the species, damage symptoms induced, qualitative difference in the morphology of the infested and uninfested leaves etc. were recorded 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, phenol content, nitrogen, proline etc. of mite infested as well as uninfested (control) leaves of respective host plants. The chlorophyll contents of mite infested and uninfested (control) leaf samples were estimated by Arnon method. Kjeldahl method was followed for estimation of total nitrogen content of mite infested and uninfested leaf samples. Proline content of the mite infested and uninfested leaf samples were estimated following the method of Bates *et al.* (1973) and the total phenol content was estimated following Folin-Ciocalteu colourimetric method, based on oxidation-reduction reaction.

In order to determine the effect of mites on photosynthesis, the Photosynthetic efficiency of plants were measured using the Handy Photosynthetic Efficiency Analyser instrument (Handy PEA, Hansatech Ltd., Norfolk, U.K), by measuring various parameters like : Minimum fluorescence (F0 =the fluorescence level when the plastoquinone electron acceptor QA is fully oxidized), maximum fluorescence (Fm = the maximum fluorescence level measured, ideally when electron acceptor QA is fully reduced, variable fluorescence (Fv = the variable component of fluorescence, obtained from Fm subtracted by F0), Fv/Fm, Area etc.

Results of the feeding experiments carried out in laboratory on *R. indica* infesting *A.catecheu*; *B.phoenicis* on *P. guajava*; *T.chiclorum* on *M. sapota*; *D. floridanus* on *A.catecheu* and *T. micheli* on *S.cumini* leaves reflected active feeding habit of the different life stages by piercing the leaves and sucking the cell contents. Extensive feeding by the mites resulted in various symptoms ranging from acute chlorosis of the leaves to bronzing , leprosis of host plants.

All the species studied were found to induce significant loss in chlorophyll. The percent loss of chlorophyll 'a', 'b', and total chlorophyll respectively induced by *R. indica* were 62.21±0.63 %, 57.67±0.73 % and 59.88 ±0.38% , for *B. Phoenicis*: 36.75 ± 0.82%, 21.95 ± 0.62% and 29.12±0.45 %, for *T. chiclorum*: 42.67±1.16%, 46.45±1.03% and

43.674±0.713%, for *T. micheli*: 32.31±0.51%, 23.52±0.40% and 28.485±0.207% . In cases of severe infestation, this loss was found to reach 71%, 66% and 60% levels. On analysis, the percent increase of total phenol content showed an increase of about 91.18 ± 1.77% for *R. indica* infestation, 69.90±2.76 % for *B. phoenicis*, 46.27±3.87% for *T.chiclorum* and 115.46±11.36 % for *T.micheli.* The total proline content revealed an increase of about 0.791± 0.02 mg proline per gram tissue of plant material of areca due to *R. indica* infestation, 0.973±0.023 mg proline/100 gm plant material for *B. phoenicis*, 0.991±0.042 mg proline /100 gm plant material for *T.chiclorum* and 68.33±2.114 mg proline/100 gm plant material for *T.micheli.* In terms of percentage loss of Nitrogen, 51.92 ± 0.72 % could be for *R. indica,* 52.25 ± 0.73% for *B.phoenicis*, 49.43 ± 0.72% for *T.chiclorum* and 34.38 ± 0.95 % for *T. micheli*. All the results were analysed statistically and were found significant ($p<0.05$) against uninfested group.

The overall impact of mite feeding resulted in significant variations in the photosynthetic parameters like Minimum fluorescence F0, maximum fluorescence Fm, variable fluorescence Fv, Fv/Fm, P Index and Area. The total destruction of the photosynthetic machinery finally would lead to collapse of the plant. The results of the study showed that the leaves were potentially damaged by the sucking habits of the various developmental stages of the mites.

In the section on breeding biology, the duration of development of the above 5 selected species of tenuipalpid mites was traced under different temperature-relative humidity parameters. Cultures of individual species were kept in petridishes and maintained in the following temperature-humidity conditions viz., 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH . Regular observation was made to collect data on mating, oviposition, hatching, durations of pre-oviposition, oviposition and post–ovipositon periods, durations of larval, protonymphal and deutonymphal stages, quiescent stages, moulting, total duration of life cycle, longevity of adults, pattern of development etc. Results of studies on breeding biology revealed the occurrence of three immature stages prior to attaining adulthood. Each active immature stage was followed by a quiescent period, which then moulted to successive stages of development. Mating was found to occur immediately after moulting of female deutonymph and the process lasted for 2-3 minutes. The mated females developed into females whereas unmated females gave rise to male progeny alone. Thus parthenogenetic development could also be recorded in all the 5 species of tenuipalpid mites. A worth mentioning aspect of the study was the incidence of *D. floridanus* on *A.catecheu* which formed a new record of host plant, not reported so far.

The total duration of life cycle of *R. indica* on *A. catecheu* under different temperature-humidity conditions enabled to record shorter duration of development (16- 22 days) at 35 □ C ± 2°C & 60 ± 5% RH and longer

duration at 25 ± 2°C & 80 ± 5% RH (22-30days). At the same time, *B. phoenicis* produced more generations on *P. guajava* at 30 ± 2°C & 70 ± 5% within a short span of time (23-25 days). The developmental period of *T. micheli* on *S. cumini* was 30-35days at 35 ± 2°C & 60 ± 5% RH. The most favoured temperature-humidity combination of *T. chiclorum* on *M. sapota* was 30 ± 2°C & 70 ± 5% RH and they exhibited developmental period of 32-36days. The optimum condition of *D. floridanus* on *A. catecheu* was 30 ± 2°C & 70 ± 5% RH exhibited developmental period of 21-30days.

Corresponding to the temperature and humidity conditions, the above 5 species could complete 3-5 generations per year with shorter developmental period averaging 16 – 35 days. These conditions could be apperceived as the ideal one for the population build up of the mite in field conditions too. This would lead to explicate why these tenuipalpid mites could multiply to assume pest status, especially during the drier and sultrier months of the year in Kerala.

Based on the present investigation it can be concluded that Tenuipalpid mites have wide distribution in Kerala and their infestation would result in major economic damages to the plantation and fruits crops of Kerala.

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Table 7: Quantitative loss in Chlorophyll pigments induced by the feeding activity of *R. indica* on *A. catcheu*

Chlorophyll	S. No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Uninfested	Infested		
Chlorophyll a	1	1.31	0.52	0.79	60.30
	2	1.23	0.45	0.78	63.41
	3	1.22	0.47	0.75	61.48
	4	1.22	0.46	0.76	62.30
	5	1.12	0.41	0.71	63.39
	6	1.41	0.40	1.01	71.63
	7	1.10	0.43	0.67	60.91
	8	1.08	0.56	0.52	48.15
	9	1.30	0.51	0.79	60.77
	10	1.49	0.45	1.04	69.80
Mean ± SEM		1.25±0.01	0.47±0.01	0.78±0.02	62.21±0.63
Chlorophyll b	1	1.90	0.63	1.27	66.84
	2	1.69	0.68	1.01	59.62
	3	1.88	0.75	1.13	59.93
	4	1.67	0.73	0.94	56.56
	5	1.46	0.70	0.76	52.39
	6	1.69	0.73	0.96	56.88
	7	1.80	0.63	1.17	65.14
	8	1.80	0.64	1.16	64.58
	9	1.39	0.80	0.59	42.91
	10	1.85	0.89	0.96	51.83
Mean ± SEM		1.71±0.02	0.72±0.01	1.00±0.02	57.67±0.73
Total Chlorophyll	1	3.201	1.145	2.055	64.210
	2	2.912	1.127	1.785	61.299
	3	3.091	1.221	1.870	60.500
	4	2.883	1.187	1.697	58.840
	5	2.581	1.106	1.475	57.137
	6	3.092	1.121	1.971	63.740
	7	2.885	1.056	1.830	63.412
	8	2.865	1.196	1.669	58.261
	9	2.689	1.299	1.390	51.691
	10	3.335	1.343	1.993	59.747
Mean ± SEM		2.953±0.023	1.180±0.009	1.773±0.022	59.884±0.375

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Chlorophyll a	Equal Variance assumed	6.210	.023	17.352	18	.000	.78200	.04507	.68732	.87668
	Equal Variance not assumed			17.352	11.543	.000	.78200	.04507	.68337	.88063
Chlorophyll b	Equal Variance assumed	3.92	.061	16.458	18	.000	.99500	.06046	.86798	1.12202
	Equal Variance not assumed			16.458	12.893	.000	.99500	.06046	.86428	1.1257
Total Chlorophyll	Equal Variance assumed	6.707	.018	22.811	18	.000	1.773	.07774	1.6099	1.9366
	Equal Variance not assumed			22.811	11.646	.000	1.773	.0774	1.6033	1.9432

Table 8: Quantitative loss in Chlorophyll pigments induced by the feeding activity of *T. micheli* on *S. cumini*

Chlorophyll	S. No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Uninfested	Infested		
Chlorophyll a	1	1.10	0.77	0.33	30.25
	2	0.99	0.69	0.30	30.30
	3	1.15	0.75	0.40	34.78
	4	1.24	0.83	0.41	33.06
	5	1.26	0.81	0.45	35.71
	6	1.07	0.72	0.35	32.71
	7	1.03	0.62	0.41	39.81
	8	0.82	0.65	0.17	20.73
	9	1.21	0.78	0.43	35.54
	10	0.86	0.60	0.26	30.23
Mean ± SEM		1.07±0.02	0.72±0.01	0.35±0.01	32.31±0.51
Chlorophyll b	1	0.87	0.63	0.24	27.58
	2	1.03	0.73	0.30	29.13
	3	0.80	0.66	0.14	17.50
	4	0.95	0.77	0.18	18.94
	5	0.76	0.60	0.16	21.05
	6	0.88	0.69	0.19	21.59
	7	0.93	0.72	0.21	22.58
	8	1.04	0.74	0.30	28.85
	9	0.85	0.64	0.21	24.70
	10	1.33	1.02	0.31	23.30
Mean ± SEM		0.94±0.02	0.72±0.01	0.22±0.01	23.52±0.40
Total chlorophyll	1	1.973	1.396	0.577	29.225
	2	2.018	1.418	0.601	29.765
	3	1.950	1.401	0.549	28.147
	4	2.184	1.601	0.583	26.689
	5	2.016	1.413	0.603	29.888
	6	1.941	1.415	0.526	27.110
	7	1.951	1.341	0.610	31.256
	8	1.857	1.385	0.472	25.410
	9	2.059	1.418	0.641	31.141
	10	2.190	1.616	0.574	26.218
Mean ± SEM		2.014±0.011	1.440±0.009	0.574±0.005	28.485±0.207

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Chlorophyll a	Equal Variance assumed	3.216	.090	6.484	18	.000	.35100	.05414	.23726	.46740
	Equal Variance not assumed			6.484	13.643	.000	.35100	.05414	.23460	.46740
Chlorophyll b	Equal Variance assumed	.771	.391	3.516	18	.002	.22400	.06370	.09016	.35784
	Equal Variance not assumed			3.516	16.442	.003	.22400	.06370	.8925	.35874
Total Chlorophyll	Equal Variance assumed	.197	.663	12.927	18	.000	.57350	.4437	.48015	.66671
	Equal Variance not assumed			12.927	17.616	.000	.57350	.4437	.48015	.66685

Table 6: Quantitative loss in Chlorophyll pigments induced by the feeding activity of *B. phoenicis* on *P. guajava*

Chlorophyll	S. No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Uninfested	Infested		
Chlorophyll a	1	0.79	0.45	0.34	43.04
	2	0.79	0.57	0.22	27.85
	3	0.77	0.50	0.27	35.06
	4	0.63	0.44	0.19	30.16
	5	0.79	0.52	0.27	34.18
	6	0.79	0.58	0.21	26.58
	7	0.84	0.47	0.37	44.05
	8	0.89	0.46	0.43	48.31
	9	0.95	0.50	0.45	47.34
	10	0.84	0.58	0.26	30.95
Mean ± SEM		0.81±0.03	0.51±0.02	0.30±0.01	36.75 ± 0.82
Chlorophyll b	1	0.86	0.64	0.22	25.61
	2	0.91	0.76	0.15	16.48
	3	0.95	0.73	0.22	23.16
	4	0.96	0.66	0.30	31.25
	5	1.06	0.81	0.25	23.58
	6	0.78	0.56	0.22	28.21
	7	0.84	0.76	0.08	9.52
	8	0.83	0.65	0.19	21.69
	9	0.98	0.78	0.21	20.41
	10	0.94	0.77	0.17	18.09
Mean ± SEM		0.91±0.03	0.71±0.02	0.20±0.01	21.95 ± 0.62
Total chlorophyll	1	1.642	1.084	0.558	34.008
	2	1.696	1.327	0.369	21.742
	3	1.710	1.232	0.477	27.911
	4	1.589	1.100	0.489	30.772
	5	1.874	1.327	0.547	29.198
	6	1.568	1.135	0.433	27.620
	7	1.677	1.227	0.450	26.825
	8	1.720	1.112	0.608	35.326
	9	1.928	1.273	0.655	33.971
	10	1.777	1.353	0.424	23.859
Mean ± SEM		1.718±0.011	1.217±0.010	0.501±0.009	29.123±0.447

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the df Lower	Upper
Chlorophyll a	Equal Variance assumed	.428	.521	9.541	18	.000	.30100	. 03155	.23472	.36728
	Equal Variance not assumed			9.541	15.358	.000	.30100	. 03155	.23390	.36810
Chlorophyll b	Equal Variance assumed	.001	.974	5.440	18	.000	.19900	.03658	.12214	.27586
	Equal Variance not assumed			5.440	17.959	.000	.19900	.03658	.12213	.27586
Total Chlorophyll	Equal Variance assumed	.006	.939	10.268	18	.000	.50110	.04880	.39857	.60363
	Equal Variance not assumed			10.268	17.781	.000	.50110	.04880	.39848	.60372

Table 9: Quantitative loss in Chlorophyll pigments induced by the feeding activity of *T. chiclorum* on *M. zapota*

Chlorophyll	S. No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Uninfested	Infested		
Chlorophyll a	1	1.37	0.87	0.50	36.50
	2	1.32	0.65	0.67	50.76
	3	0.88	0.33	0.55	62.50
	4	1.19	0.63	0.56	47.06
	5	1.26	0.59	0.67	53.17
	6	1.15	0.64	0.51	44.35
	7	1.27	0.69	0.58	45.67
	8	1.23	0.88	0.35	28.46
	9	1.15	0.83	0.32	27.83
	10	1.12	0.78	0.34	30.36
Mean ± SEM		1.19±0.01	0.69±0.02	0.51±0.01	42.67±1.16
Chlorophyll b	1	1.62	0.74	0.88	54.32
	2	1.23	0.52	0.71	57.72
	3	1.46	0.82	0.64	43.84
	4	1.19	0.85	0.34	28.57
	5	1.55	0.90	0.65	41.94
	6	1.60	0.97	0.63	39.34
	7	1.67	0.80	0.87	52.10
	8	1.52	0.81	0.71	46.71
	9	1.49	0.93	0.56	37.58
	10	1.41	0.53	0.88	62.41
Mean ± SEM		1.47±0.02	0.79±0.01	0.69±0.02	46.45±1.03
Total chlorophyll	1	3.029	1.606	1.423	46.965
	2	2.547	1.164	1.383	54.303
	3	2.329	1.141	1.188	51.016
	4	2.371	1.475	0.896	37.787
	5	2.806	1.494	1.312	46.754
	6	2.766	1.607	1.159	41.887
	7	2.973	1.489	1.485	49.936
	8	2.779	1.683	1.096	39.434
	9	2.632	1.748	0.884	33.599
	10	2.517	1.635	0.882	35.054
Mean ± SEM		2.675±0.024	1.504±0.021	1.171±0.023	43.674±0.713

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Chlorophyll a	Equal Variance assumed	.329	.547	7.485	18	.000	.50500	.06747	.36325	.64675
	Equal Variance not assumed			7.485	17.382	.000	.50500	.06747	.36288	.64712
Chlorophyll b	Equal Variance assumed	.027	.871	9.823	18	.000	.68700	.06994	.54006	.83394
	Equal Variance not assumed			9.823	17.976	.000	.68700	.06994	.54005	.83395
Total Chlorophyll	Equal Variance assumed	.645	.432	11.813	18	.000	1.17070	.09911	.96248	1.3789
	Equal Variance not assumed			11.813	17.634	.000	1.17070	.09911	.96217	1.3792

Table 10 Quantitative loss in Nitrogen content induced by the feeding activity of *B. phoenicis* on *P. guajava*

S.No.	Milligram Nitrogen/gram tissue		Nitrogen loss in mg	% loss
	Uninfested	Infested		
1	19.80	11.70	8.10	40.91
2	20.90	11.20	9.70	46.41
3	21.30	8.40	12.90	60.56
4	18.70	9.10	9.60	51.34
5	21.40	11.98	9.42	44.02
6	19.20	8.90	10.30	53.65
7	20.50	9.80	10.70	52.20
8	22.20	11.00	11.20	50.45
9	23.10	8.70	14.40	62.34
10	20.60	8.10	12.50	60.68
MEAN ± SEM	**20.77 ± 0.13**	**9.89 ± 0.15**	**10.88 ± 0.19**	**52.25 ± 0.73**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Nitrogen	**Equal Variance assumed**	.669	.424	17.449	18	.000	10.88200	.62366	9.57173	12.192
	Equal Variance not assumed			17.449	17.861	.000	10.88200	.62366	9.5710	12.193

Table 11: Quantitative loss in Nitrogen content induced by the feeding activity of *R. indica* on *A. catechu*

S.No.	Milligram Nitrogen/gram tissue		Nitrogen loss in mg	% loss
	Uninfested	Infested		
1	22.90	12.20	10.70	46.72
2	22.00	13.90	8.10	36.82
3	24.30	9.50	14.80	60.91
4	22.30	11.77	10.53	47.22
5	25.70	10.90	14.80	57.59
6	24.70	9.50	15.20	61.54
7	26.60	11.70	14.90	56.02
8	22.10	11.31	10.79	48.82
9	19.40	8.90	10.50	54.12
10	23.14	11.69	11.45	49.48
MEAN ± SEM	**23.31± 0.20**	**11.14 ± 0.14**	**12.18 ± 0.24**	**51.92 ± 0.72**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Nitrogen	**Equal Variance assumed**	.936	.346	14.993	18	.000	12.17700	.81221	10.470	13.883
	Equal Variance not assumed			14.993	16.344	.000	12.17700	.81221	10.458	13.896

Table 12 Quantitative loss in Nitrogen content induced by the feeding activity of *T. micheli* on *S. cumini*

S.No.	Milligram Nitrogen/gram tissue		Nitrogen loss in mg	% loss
	Uninfested	Infested		
1	12.50	7.20	5.30	42.40
2	11.70	6.70	5.00	42.74
3	10.20	7.80	2.40	23.53
4	10.60	7.40	3.20	30.19
5	10.80	8.10	2.70	25.00
6	9.70	6.20	3.50	36.08
7	11.20	6.40	4.80	42.86
8	12.30	6.30	6.00	48.78
9	9.70	6.80	2.90	29.90
10	9.40	7.30	2.10	22.34
MEAN ± SEM	**10.81 ± 0.11**	**7.02 ± 0.06**	**3.79 ± 0.14**	**34.38 ± 0.95**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Nitrogen	**Equal Variance assumed**	2.956	.103	9.395	18	.000	3.79000	.40339	2.94251	4.63749
	Equal Variance not assumed			9.395	14.549	.000	3.79000	.40339	2.92787	4.65213

Table 13: Quantitative loss in Nitrogen content induced by the feeding activity of *T. chiclorum* on *M. zapota*

S.No.	Milligram Nitrogen/gram tissue		Nitrogen loss in mg	% loss
	Uninfested	Infested		
1	20.40	10.60	9.80	48.04
2	17.37	11.10	6.27	36.10
3	19.30	10.20	9.10	47.15
4	18.10	9.80	8.30	45.86
5	19.80	8.40	11.40	57.58
6	20.50	10.65	9.85	48.05
7	21.20	8.60	12.60	59.43
8	18.30	7.90	10.40	56.83
9	17.36	9.80	7.56	43.55
10	21.30	10.29	11.01	51.69
MEAN ± SEM	**19.36 ± 0.15**	**9.73 ± 0.11**	**9.63 ± 0.19**	**49.43 ± 0.72**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Nitrogen	**Equal Variance assumed**	2.198	.156	16.455	18	.000	9.62900	.58517	8.39961	10.8584
	Equal Variance not assumed			16.455	16.929	.000	9.62900	.58517	8.39030	10.8677

Table 19: Quantitative loss in phenolic content induced by the feeding activity of *R. indica* on *A. catcheu*

S. No.	Milligram Phenol/gram tissue		Raise in Phenol	% Raise in Phenol
	Uninfested	Infested		
1	1.446	2.768	1.322	91.42
2	1.353	2.772	1.419	104.88
3	1.195	2.348	1.153	103.00
4	1.465	2.605	1.141	77.82
5	1.473	2.336	0.863	58.59
6	1.295	2.754	1.459	112.66
7	1.349	2.625	1.276	94.59
8	1.281	2.601	1.320	103.04
9	1.488	2.490	1.002	67.34
10	1.614	3.192	1.578	97.77
Mean ± SEM	**1.40 ± 0.01**	**2.65 ± 0.02**	**1.25 ± 0.02**	**91.18 ± 1.77**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Phenol	**Equal Variance assumed**	1.944	.180	-14.303	18	.000	-1.25320	.08762	-1.4373	-1.0692
	Equal Variance not assumed			-14.303	13.198	.000	-1.25320	.08762	-1.4422	-1.06420

Table 20: Quantitative loss in phenolic content induced by the feeding activity of *T. micheli* on S. *cumini*

S. No.	Milligram Phenol/gram tissue		Raise in Phenol	% Raise in Phenol
	Uninfested	Infested		
1	0.42	1.12	0.70	166.7
2	0.54	0.96	0.42	77.78
3	0.57	1.13	0.56	98.25
4	0.53	1.07	0.54	101.89
5	0.40	0.89	0.49	122.50
6	0.41	0.91	0.50	121.95
7	0.48	1.19	0.71	147.92
8	0.54	1.04	0.50	92.59
9	0.45	1.03	0.58	128.89
10	0.57	1.17	0.55	96.14
Mean ± SEM	**0.49±0.02**	**1.05±0.03**	**0.56±0.02**	**115.46±11.36**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Phenol	**Equal Variance assumed**	1.848	.191	-14.200	18	.000	-.56000	.03944	-.64286	-.47714
	Equal Variance not assumed			-14.200	15.285	.000	-.56000	.03944	-.64392	-.47608

Table 18: Quantitative loss in phenolic content induced by the feeding activity of *B. phoenicis* on *P. guajava*

S. No.	Milligram Phenol/gram tissue		Raise in Phenol	% Raise in Phenol
	Uninfested	Infested		
1	0.4	0.68	0.28	70.00
2	0.39	0.69	0.3	76.92
3	0.45	0.77	0.32	71.11
4	0.57	0.92	0.35	61.40
5	0.54	0.9	0.36	66.67
6	0.51	0.86	0.35	68.63
7	0.47	0.74	0.27	57.45
8	0.42	0.72	0.3	71.43
9	0.47	0.89	0.42	89.36
10	0.56	0.93	0.37	66.07
Mean ± SEM	**0.48±0.02**	**0.81±0.03**	**0.33±0.01**	**69.90±2.76**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Phenol	**Equal Variance assumed**	6.688	.019	-8.819	18	.000	-.33200	.03765	-.41109	-.25291
	Equal Variance not assumed			-8.819	15.499	.000	-.33200	.03765	-.41202	-.25198

Table 21: Quantitative loss in phenolic content induced by the feeding activity of *T. chiclorum* on *M. zapota*

S. No.	Milligram Phenol/gram tissue		Raise in Phenol	% Raise in Phenol
	Uninfested	Infested		
1	0.46	0.62	0.16	34.78
2	0.37	0.60	0.23	62.16
3	0.53	0.74	0.21	39.62
4	0.42	0.64	0.22	52.38
5	0.57	0.86	0.29	50.88
6	0.48	0.63	0.15	31.25
7	0.39	0.58	0.19	48.72
8	0.47	0.76	0.29	61.70
9	0.45	0.69	0.24	53.33
10	0.61	0.78	0.17	27.87
Mean ± SEM	**0.48±0.02**	**0.69±0.29**	**0.22±0.02**	**46.27±3.87**

		Levene's Test for Equality of Variances		t-test for Equality means						
									95% Confidence Interval of the df	
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	Lower	Upper
Phenol	**Equal Variance assumed**	.796	.384	-5.700	18	.000	-.21500	.03772	-.29425	-.13575
	Equal Variance not assumed			-5.700	17.430	.000	-.21500	.03772	-.29443	-.13557

Table 14: Quantitative loss in proline content induced by the feeding activity of *B. phoenicis* on *P. guajava*

S. No.	Milligram Proline/gram tissue		Raise in Proline	% Raise in Proline
	Uninfested	Infested		
1	0.966	1.862	0.896	92.75
2	0.690	1.366	0.676	97.97
3	0.828	1.552	0.724	87.44
4	0.738	1.766	1.028	139.30
5	0.938	1.903	0.965	102.88
6	0.883	1.724	0.841	95.24
7	0.628	1.938	1.31	208.60
8	0.607	1.897	1.29	212.52
9	0.834	1.614	0.78	93.53
10	0.910	2.131	1.221	134.18
Mean ± SEM	**0.80 ±0.01**	**1.78 ±0.02**	**0.973±0.023**	**126.44±4.77**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Proline	Equal Variance assumed	1.941	.181	-.12.039	18	.000	-.97310	.08083	-1.14292	-.80328
	Equal Variance not assumed			-.12.039	14.527	.000	-.97310	.08083	-1.14587	-.8003

Table 15: Quantitative loss in proline content induced by the feeding activity of *R. indica* on *A. catcheu*

S. No.	Milligram Proline/gram tissue		Raise in Proline	% Raise in Proline
	Uninfested	Infested		
1	0.483	0.986	0.503	104.14
2	0.576	1.407	0.831	144.27
3	0.345	1.048	0.703	203.77
4	0.379	1.310	0.931	245.65
5	0.428	1.441	1.013	236.68
6	0.462	1.172	0.71	153.68
7	0.317	1.124	0.807	254.57
8	0.297	1.324	1.027	345.79
9	0.359	0.959	0.6	167.13
10	0.510	1.290	0.78	152.94
Mean ± SEM	**0.416±0.01**	**1.21±0.02**	**0.791±0.02**	**190.8±7.10**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Proline	**Equal Variance assumed**	7.037	.016	-12.77	18	.000	-.79050	.06187	-.92048	-.66052
	Equal Variance not assumed			-12.77	13.636	.000	-.79050	.06187	-.92352	-.65748

Table 16: Quantitative loss in proline content induced by the feeding activity of *T. micheli* on *S. cumini*

S. No.	Milligram Proline/gram tissue		Raise in Proline	% Raise in Proline
	Uninfested	Infested		
1	0.966	1.655	0.689	71.33
2	1.172	1.676	0.504	43.00
3	1.076	1.772	0.696	64.68
4	1.152	1.697	0.545	47.31
5	0.986	1.648	0.662	67.14
6	0.945	1.979	1.034	109.42
7	1.007	1.766	0.759	75.37
8	1.097	1.710	0.613	55.88
9	1.069	1.634	0.565	52.85
10	0.924	1.814	0.89	96.32
Mean ± SEM	**1.04 ± 0.01**	**1.74 ± 0.01**	**0.696±0.016**	**68.33±2.114**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Proline	**Equal Variance assumed**	.034	.856	-.16.241	18	.000	-.69570	.04284	-.78569	-.60571
	Equal Variance not assumed			-.16241	17.45	.000	-.69570	.04284	-.78591	-.60549

Table 17: Quantitative loss in proline content induced by the feeding activity of *T. chiclorum* on *M. zapota*

S. No.	Milligram Proline/gram tissue		Raise in Proline	% Raise in Proline
	Uninfested	Infested		
1	0.65	1.06	0.41	63.08
2	0.55	1.38	0.83	150.91
3	0.81	2.34	1.53	188.89
4	0.63	1.10	0.47	74.60
5	0.60	2.21	1.61	268.33
6	0.52	1.39	0.87	167.31
7	0.49	1.42	0.93	189.80
8	0.45	1.63	1.18	262.22
9	0.62	1.35	0.73	117.74
10	0.50	1.85	1.35	270.00
Mean ± SEM	**0.58 ± 0.01**	**1.57 ± 0.04**	**0.991±0.042**	**178.29±7.62**

		Levene's Test for Equality of Variances		t-test for Equality means						
		F	Sig	t	df	Sig. (2-tailed	Mean Difference	Std. Error Difference	95% Confidence Interval of the df	
									Lower	Upper
Proline	**Equal Variance assumed**	12.144	.003	-7.002	18	.000	-.99100	.14154	-1.28836	-.69364
	Equal Variance not assumed			-7.002	10.033	.000	-.99100	.14154	-1.30623	-.67577

Table 54: Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. chiclorum* on *Manilkara zapota* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25±2ºC AND 80±5% RH	1	7	11	8
	2	7	12	8
	3	7	11	7
	4	8	12	7
	5	8	10	6
	6	7	12	7
	7	7	11	7
	8	7	10	6
	9	8	12	8
	10	7	11	6
	Mean ±SEM	7.3±0.05	11.2±0.08	7.0±0.07
30±2ºC AND 70±5%RH	1	6	10	7
	2	6	9	5
	3	6	11	6
	4	7	9	5
	5	6	10	6
	6	7	10	6
	7	7	11	7
	8	6	10	5
	9	7	11	6
	10	7	10	8
	Mean ±SEM	6.5±0.05	10.1±0.07	6.1±0.09
35±2ºC & 80±RH	1	6	9	6
	2	5	9	6
	3	6	9	5
	4	6.5	10	6
	5	5	8	5
	6	5	9	5
	7	5	9	6
	8	5	8	4
	9	6	8	5
	10	5	9	6
	Mean ± SEM	5.45±0.06	8.8±0.06	5.4±0.07

Table 58: Duration (in days) of development of *T. chiclorum* on *Manilkara zapota* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of development
1.	7	8	2.5	7	2.5	6	4	37	F	S
2.	8	7	3	6	3	6	3	36	F	S
3.	9	7	2.5	6	2.5	7	3	37	F	S
4.	7	7	2.5	7	2	6.5	3	35	F	S
5.	8	6	3	6	3	7	2	35	M	P
6.	8	6	2.5	6	3	7	3.5	36	F	S
7.	8	6	3	6	2.5	7	3	35.5	F	S
8.	7	7	2	6	2.5	6	3	33.5	M	P
9.	8	7	2	8	2.5	6	3.5	37	F	S
10.	8	6	2	6	2	7	3	34	M	P
Range	7-9	6-8	2-3	6-8	2-3	6-7	2-4	33-37		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	7.80 ± 0.06	6.70 ± 0.07	2.50 ± 0.04	6.40 ± 0.07	2.55 ± 0.04	6.55 ± 0.05	3.10 ± 0.05	35.6±0.12 S= 36.21±0.11 P=34.16±0.02		

Table 59: Duration (in days) of development of *T. chiclorum* on *Manilkara zapota* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	M/ F	Nature of development
1.	7	8	2	7	3	5.5	3	35.5	F	S
2.	6	7	3	6	3	6	2	33	M	P
3.	6	6	2.5	7	3	7	2.5	34	F	S
4.	7	5	2.5	6	3	6	2.5	32	M	P
5.	7	6	2.5	7	2.5	7.5	3	35.5	F	S
6.	8	6	2	7	3	7	2	35	F	S
7.	8	6.5	3	7	2.5	6	3	36	F	S
8.	7	6	2	6	3	6	2	32	M	P
9.	7	7	2	6	3	6	3	34	F	S
10.	7	6	2	6	3	7	2.5	33.5	F	S
Range	6-8	5-8	2-3	6-7	2-3	5.5-7.5	2-3	32-36		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	7.0 ± 0.07	6.35 ± 0.08	2.35 ± 0.03	6.5 ± 0.05	2.90 ± 0.02	6.4 ± 0.06	2.35 ± 0.04	34.05±0.08 S=34.78±0.17 P=32.33±0.10		

Table 60: Duration (in days) of development of *T. chiclorum* on *Manilkara zapota* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	M/F	Nature of development
1.	6	6	2	7	3	5.5	3	32.5	F	S
2.	6	7	3	6	3	6.5	2.5	34	F	S
3.	6	6	2.5	7	3	7	2	33.5	F	S
4.	7	5	2.5	7	3	7	2.5	34	F	S
5.	7	6	2.5	6	2.5	5	2	31	M	P
6.	7	6	2	7	3	6	2	33	F	S
7.	7	6	2.5	7	2.5	6	2	33	F	S
8.	7	6	2	6	3	5	2	31	M	P
9.	6	7	2	7	3	6	3	34	F	S
10.	7	6	2	6	3	7	2.5	33.5	F	S
Range	6-7	5-7	2-3	6-7	2-3	5.5-7	2-3	31-34		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	6.6 ± 0.07	6.1 ± 0.08	2.3 ± 0.03	6.6 ± 0.05	2.9 ± 0.02	6.1 ± 0.06	2.35 ± 0.04	32.95±0.08 S=33.44±0.17 P=31.0±0.10		

Table 55: Fecundity of *T. chiclorum* on *Manilkara zapota* at 25 ± 2ºC & 80 ± 5% RH

	Number of eggs laid on different days of oviposition												Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**			
1	1	1	1	2	2	2	1	1	1	0	1	0	**13**	**M**	**26**
2	1	0	1	2	2	2	2	1	1	1	0	1	**14**	**M**	**27**
3	1	1	1	2	2	2	2	1	1	0	1	0	**14**	**M**	**25**
4	1	0	1	1	2	2	2	1	1	1	0	1	**13**	**M**	**27**
5	1	0	0	1	2	2	1	1	1	1	0	0	**10**	V	**24**
6	1	1	0	1	2	2	1	1	0	1	1	1	**12**	M	**26**
7	1	0	1	1	2	2	1	1	1	1	1	0	**12**	M	**25**
8	1	1	0	1	2	2	2	1	0	1	0	0	**11**	**V**	**23**
9	1	1	0	2	2	2	1	0	1	0	1	1	**12**	**M**	**28**
10	1	0	1	1	1	2	1	1	0	1	1	0	**10**	**V**	**24**
Range	1-1	0-1	0-1	1-2	1-2	2-2	1-2	0-1	0-1	0-1	0-1	0-1	**10 – 14**		**23 - 28**
Mean ± SEM	1.00 ± 0.00	0.50 ± 0.07	0.60 ± 0.09	1.40 ± 0.10	1.90 ± 0.06	2.00 ± 0.07	1.40 ± 0.05	0.90 ± 0.03	0.70 ±	0.70 ± 0.05	0.60 ± 0.04	0.40 ± 0.05	12.10±0.11 M=12.85± 0.09 V=10.33± 0.08		25.50±0.11 M=26.28±0.09 V=23.66±0.08

Table 56: Fecundity of *T. chiclorum* on *Manilkara zapota* at 30 ± 2ºC & 70 ± 5% RH

	Number of eggs laid on different days of oviposition											Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**			
1	1	1	2	2	2	2	2	2	1	1	0	**16**	**M**	**23**
2	1	1	2	2	2	1	1	1	1	0	0	**12**	**V**	**20**
3	1	1	2	2	2	2	2	2	1	1	1	**17**	**M**	**22**
4	1	1	2	2	2	2	2	1	1	0	0	**14**	**V**	**21**
5	1	1	2	2	2	2	2	2	1	1	0	**16**	M	**22**
6	1	1	2	2	2	2	1	2	2	1	0	**16**	M	**23**
7	1	1	2	2	2	2	1	2	2	1	1	**17**	M	**25**
8	1	1	1	2	2	2	1	1	1	1	0	**13**	**V**	**21**
9	1	1	2	2	2	2	2	1	1	1	1	**16**	**M**	**24**
10	1	2	2	2	2	2	2	2	2	1	0	**18**	**M**	**25**
Range	1-1	0-2	1-2	2-2	2-2	1-2	1-2	1-2	1-2	0-1	0-1	**12-18**		**20-25**
Mean ± SEM	1.00 ± 0.00	1.1 ± 0.03	1.90 ± 0.05	2.00 ± 0.03	2.00 ± 0.00	1.90 ± 0.05	1.60 ± 0.05	1.60 ± 0.03	1.30 ±	0.80 ± 0.03	0.30 ± 0.05	15.50±0.11 M=16.57± 0.09 V=13.0±0. 08		22.60±0.11 M=23.42±0.09 V=20.66±0.08

Table 57: Fecundity of *T. chiclorum* on *Manilkara zapota* at 35 ± 2ºC & 60 ± 5% RH

	Number of eggs laid on different days of oviposition										Total no. of eggs laid	M / V	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
1	1	1	2	2	2	2	2	2	1	1	**15**	**M**	**21**
2	1	2	2	2	2	2	2	2	1	1	**14**	**M**	**20**
3	1	2	2	2	2	2	2	2	1	1	**14**	**M**	**20**
4	1	2	2	2	2	2	2	2	1	0	**16**	**M**	**22.5**
5	1	2	2	2	2	2	2	2	1	0	**12**	V	**18**
6	1	1	2	2	2	2	2	2	1	1	**16**	M	**19**
7	1	2	2	2	2	2	2	2	1	0	**17**	M	**20**
8	1	1	2	2	2	2	2	1	1	0	**13**	**V**	**17**
9	1	2	2	2	2	2	2	1	1	0	**16**	**M**	**19**
10	1	1	2	2	2	2	2	1	1	1	**18**	**M**	**20**
Range	1-1	1-2	2	2-2	2-2	2-2	2-2	1-2	1-1	0-1	**14-18**		
Mean ± SEM	1.00 ± 0.00	1.60 ± 0.05	2.00 ± 0.03	2.00 ± 0.06	2.00 ± 0.00	2.00 ± 0.62	2.00 ± 0.06	1.70 ±	1.00 ± 0.00	0.50 ± 0.05	15.10±0.11 M=15.75±0.09 V=12.5±0.08		19.65±0.11 M=20.18±0.57 V=17.5±0.35

Table 47: Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. micheli* on *S. cumini* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25±2ºc & 80±5% RH	1	6	13	7
	2	7	13	7
	3	8	13	6.5
	4	7	13	6
	5	5.5	12	6
	6	7	12	8
	7	7.5	13	7.5
	8	6	12	5
	9	7	13	8
	10	5	11	6
	Mean±SEM	6.60 ± 0.09	12.50 ± 0.07	6.70 ± 0.09
30±2ºC & 70± 5% RH	1	5	12	6
	2	4.5	11	6.5
	3	5	11	4
	4	6	12	6
	5	6	12	6
	6	6	12	5
	7	6	12	6
	8	6	11	4
	9	6	12	6
	10	5	12	6
	Mean±SEM	5.55 ± 0.06	11.70 ± 0.05	5.5 ± 0.09
35±2ºC &60±5% RH	1	4	10	4
	2	5	9	5
	3	4	9	4
	4	6	9	5
	5	4	10	4
	6	5	10	4
	7	4	9	5
	8	4	9	4
	9	5.5	10	4
	10	4	11	5
	Mean ± SEM	4.55 ± 0.07	9.60 ± 0.07	4.40 ± 0.05

Table 51: Duration (in days) of development of *T. micheli* on *S. cumini* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**M/ F**	**Nature of development**
1.	11	9	3.5	6	3	6	2	40.5	F	S
2.	10.5	8	3.5	7	4	6	3	42	F	S
3.	9	9	4	8	3	6	3	42	F	S
4.	10	8	3.5	7	4	7	3	42.5	F	S
5.	9	8	3	7	3.5	5	2.5	38	M	P
6.	10	9	3	7	4	6	3	42	F	S
7.	9	9	3.5	7	3	7	3	41.5	F	S
8.	9	8	3	7	3	5	2.5	37.5	M	P
9.	9	8	3.5	8	3.5	7	3	42	F	S
10.	9	8	4	6	4	6	2.5	39.5	M	P
Range	9-11	8-9	3-4	6-8	3-4	5-7	2-3	37-43		M=MALE F=FEMALE S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	9.55 ± 0.07	8.40 ± 0.05	3.45 ± 0.03	7.00 ± 0.06	3.50 ± 0.04	6.10 ± 0.07	2.75 ± 0.03	40.75 ± 0.17 S= 41.79± 0.08 P=38.33± 0.28		

Table 52: Duration (in days) of development of *T. micheli* on *S. cumini* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of development
1.	8	7	3	6	2.5	6	3.5	36	F	S
2.	9	7	3	6	3	6	3	37	F	S
3.	8	6	3	6	3	5	2	33	M	P
4.	8	7	3	7	3	6	2	36	F	S
5.	9	7	2.5	5	2	6	3	34.5	F	S
6.	9	6	3	6	2	6	2.5	34.5	F	S
7.	8	6.5	3.5	6	2	5.5	2.5	34	F	S
8.	8	7	2.5	5	2.5	5	3	33	M	P
9.	9	7	3	6	3	7	3	38	F	S
10.	8	6	3	6	3	6	3	35	F	S
Range	8-9	6-7	2.5-3.5	5-7	2-3	5-6	2-3	33-38	35.10±0.16 S= 35.63±0.16 P= 33±0.00	M=MALE F=FEMALE S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	8.40 ± 0.05	6.65 ± 0.04	2.95 ± 0.03	5.90 ± 0.05	2.60 ± 0.04	5.85 ± 0.05	2.75 ± 0.05	35.10 ± 0.16		

Table 53: Duration (in days) of development of *T. micheli* on *S. cumini* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	M/F	Nature of development
1.	9	6	2.5	5.5	2	6	2	33	F	S
2.	8	7	2	6	2	6	1.5	32.5	F	S
3.	8	7	2	6	2	6	2	33	F	S
4.	8	6	2	5	2	5	2	30	M	P
5.	8	5.5	2.5	6	2	6	2	32	F	S
6.	8	7	2.5	6	2	6.5	2.5	34.5	F	S
7.	7	6.5	2	5.5	2	5	2	30	M	P
8.	8.5	6	2.5	6	2.5	6	2	33.5	F	S
9.	8	6	2.5	6	2.5	5	2	32	F	S
10.	8.5	7	2	6	2	6.5	2	34	F	S
Range	7-9	5.5-7	2-2.5	5-6	2-2.5	5-6.5	1.5-2.5	30-35		
Mean ± SEM	8.10 ± 0.05	6.40 ± 0.05	2.25 ± 0.03	5.80 ± 0.03	2.10 ± 0.02	5.80 ± 0.06	2.00 ± 0.02	32.45±0.14 S=33.06±0.08 P=30.±0.00		

Table 48: Fecundity of *T. micheli* on *S. cumini* at 25 ± 2ºC & 80 ± 5% RH

	Number of eggs laid on different days of oviposition													Total no. of eggs laid	M / V	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**			
1	1	0	1	1	2	2	2	1	0	1	0	0	1	**12**	**M**	**26**
2	1	1	1	1	2	2	1	0	1	1	1	0	1	**13**	**M**	**27**
3	1	1	2	1	2	2	1	0	1	0	0	1	1	**13**	**M**	**27.5**
4	1	1	1	1	2	1	1	1	0	0	1	0	1	**11**	**M**	**26**
5	1	0	0	1	2	2	1	1	1	0	0	1	0	**10**	V	**23.5**
6	1	1	1	2	2	2	1	0	1	1	0	1	0	**13**	M	**27**
7	1	1	1	0	2	2	1	0	1	1	1	1	1	**13**	M	**28**
8	1	0	1	1	2	1	1	1	0	1	0	1	0	**10**	**V**	**23**
9	1	1	0	2	2	2	1	0	1	0	1	0	1	**12**	**M**	**28**
10	1	1	0	1	2	1	1	1	0	0	1	0	0	**9**	**V**	**22**
Range	1-1	0-1	1-2	0-2	2-2	1-2	1-2	0-1	0-1	0-1	0-1	0-1	0-1	**9-13**		**22-28**
Mean ± SEM	1.00 ± 0.00	0.70 ± 0.05	0.80 ± 0.06	1.10 ± 0.05	2.00 ± 0.00	1.70 ± 0.05	1.10 ± 0.03	0.63 ± 0.05	0.60 ± 0.05	0.50 ± 0.05	0.50 ± 0.05	0.50 ± 0.05	0.60 ± 0.05	11.60 ±0.14 M=12.43±0.22 V=9.67±0.14		25.80 ±0.21 M=27.83±0.08 V=22.83±0.21

Table 49: Fecundity of *T. micheli* on *S. cumini* at 30 ± 2ºC & 70 ± 5% RH

	Number of eggs laid on different days of oviposition												Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	2	3	4	5	6	7	8	9	10	11	12			
1	1	1	1	1	2	2	2	2	1	1	1	1	16	M	23
2	1	1	1	1	2	2	2	1	2	2	0	1	16	M	22
3	1	1	1	1	2	2	1	1	1	0	1	1	13	V	20
4	1	1	1	2	2	2	1	2	1	2	1	1	17	M	24
5	1	1	1	1	2	2	1	2	2	1	1	1	16	M	24
6	1	1	1	2	2	2	2	2	2	1	1	1	18	M	23
7	1	1	1	2	1	2	2	2	2	1	1	1	17	M	24
8	1	1	1	1	2	2	1	2	1	1	0	1	14	V	21
9	1	1	1	2	2	2	2	1	1	2	1	1	17	M	24
10	1	1	2	1	2	2	2	1	2	1	1	1	17	M	23
Range	1-1	1-1	1-2	1-2	1-2	2-2	1-2	1-2	1-2	0-2	0-1	1-1	13-18		20-24
Mean ± SEM	1.00 ± 0.00	1.00 ± 0.00	1.10 ± 0.03	1.40 ± 0.05	1.90 ± 0.03	2.00 ± 0.00	1.60 ± 0.05	2.00 ± 0.05	1.50 ± 0.05	1.20 ± 0.06	0.80 ± 0.04	1.00 ± 0.00	16.10 ±0.14 M=16.75±0.07 V=13.50±0.25		22.80±0.13 M=23.38±0.07 V=20.50±0.05

Table 50: Fecundity of *T. micheli* on *S. cumini* at 35 ± 2ºC & 60 ± 5% RH

	Number of eggs laid on different days of oviposition											Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**			
1	1	1	2	2	2	2	2	1	1	1	0	**15**	**F**	**18**
2	1	1	2	2	2	2	2	1	1	0	0	**14**	**F**	**19**
3	1	1	2	2	2	1	1	1	1	0	0	**12**	**V**	**17**
4	1	2	2	2	2	2	2	1	1	0	0	**15**	**F**	**20**
5	1	1	2	2	2	2	1	1	1	1	0	**14**	**F**	**18**
6	1	2	2	2	2	2	1	0	1	1	0	**14**	**F**	**19**
7	1	1	2	2	2	2	2	2	1	0	0	**15**	**F**	**18**
8	1	0	1	2	2	2	1	1	1	0	0	**11**	**V**	**17**
9	1	2	2	2	2	2	1	1	1	1	0	**15**	**F**	**19.5**
10	1	1	1	2	2	1	2	2	1	1	1	**15**	**F**	**20**
Range	1-1	0-2	1-2	2-2	2-2	1-2	1-2	0-2	1-1	0-1	0-1	**11-15**		**17-20**
Mean ± SEM	1.00 ± 0.00	1.20 ± 0.06	1.80 ± 0.04	2.00 ± 0.00	2.00 ± 0.00	1.80 ± 0.04	1.50 ± 0.05	1.38 ± 0.05	1.00 ± 0.00	0.50 ± 0.05	0.10 ± 0.03	14.00±0.13 F=14.63±0.06 V=11.50±0.25		18.55±0.11 F=18.94±0.10 V=17±0.00

Table 40: Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *R. indica* on *A. catcheu* at different temperature-humidity conditions.

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2°C & 80 ± 5% RH	1	5	23	6
	2	5	24	7
	3	7	25	8
	4	5	21	6
	5	6	24	8
	6	6	19	8
	7	6	20	7
	8	7	25	8
	9	6	24	8
	10	6	25	9
	Mean ± SEM	5.9±0.07	23±0.02	7.5±0.09
30±2°c & 70±5% RH	1	4	23	6
	2	4	24	7
	3	5	23	7
	4	3	19	4
	5	4.	22	6
	6	3.5	20	4
	7	3	20	5
	8	3	20	5
	9	5	22	6
	10	4	24	6
	Mean ± SEM	3.85±0.07	21.7±0.18	5.60±0.11
35±2°c & 60±5% RH	1	2.5	20	1
	2	4	21	2
	3	3	21	2
	4	2.5	18	2
	5	2	18	1
	6	4	21	1
	7	3	18	1.5
	8	4	22	2
	9	4	22	1.5
	10	2.5	18	2
	Mean ± SEM	3.15±0.08	19.90±0.17	1.6±0.05

Table 44: Duration (in days) of development of *R. indica* on *A. catcheu* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto nymph**	**3rd Q**	**Total duration**	**M / F**	**Nature of development**
1.	8	7	2.5	4	2	4	1.5	29	F	S
2.	8	6	2	4	2	6	1.5	29.5	F	S
3.	9	6	1.5	4.5	2	4	2	29	F	S
4.	6	5	2	4	1	3	2	23	M	P
5.	9	6	2	4	2.5	4	2	29.5	F	S
6.	6	5	1.5	3.5	2	3	1.5	22.5	M	P
7.	7	4	2.5	3	2	3	2	23.5	M	P
8.	8	7	2.5	3.5	2	4	2	29	F	S
9.	9	6	2	4	2	4	2.5	29.5	F	S
10.	7	7	2.5	5	2	4	2.5	30	F	S
Range	6-9	4-7	1.5-2.5	3-5	1-2.5	3-6	1.5-2.5	22 -30		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	7.7± 0.12	5.9±0.10	2.1±0.04	3.95±0.06	1.95±0.04	3.9±0.09	1.95±0.04	27.45±0.31 S =29.35 ±.05 P = 23 ±0.17		

Table 45: Duration (in days) of development of *R. indica* on *A. catcheu* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**Male/ Female**	**Nature of development**
1.	6	5	2	5	1	4	2	25	F	S
2.	7	6	1	4	1.5	4.5	1.5	25.5	F	S
3.	6	6	2	4	2	4	1	25	F	S
4.	5	5	2	3	1.5	3	1.5	21	M	P
5.	7	6	1.5	3	1.5	4	1.5	24.5	F	S
6.	5	4	1	3	2	3	2	20	M	P
7.	5	4	1.5	4	1.5	3	1	20	M	P
8.	5	4	1.5	4	1.5	3	1.5	20.5	M	P
9.	6	6	1.5	4	2	5	2	26.5	F	S
10.	6	5	2	4	1.5	5	2	25.5	F	S
Range	5-7	4-6	1-2	3-5	1-2	3-5	1-2	20-26.5		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	5.8±0.08	5.1±0.09	1.6±0.04	3.8±0.06	1.6±0.03	3.85±0.08	1.6±0.04	23.35±0.26 S = 25.33± 0.11 P =20.38 ± 0.12		

Table 46: Duration (in days) of development of *R. indica* on *A. catcheu* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**M/ F**	**Nature of development**
1.	5	4	1	3.5	1	3	1	18.5	F	S
2.	5	5	1	3.5	1.5	4	1	21	F	S
3.	4	4	1	4	1.5	4	1	19.5	F	S
4.	4	4	1	3	1	3	1	17	M	P
5.	4	4	1	3	1	3	1	17	M	P
6.	6	4	2	3	1	4	1.5	21.5	F	S
7.	4	3	1	3	1	3	1	16	M	P
8.	5	5	1	3.5	2	3	2	21.5	F	S
9.	5	4	1	3	1.5	4	1	19.5	F	S
10.	5	3	1	3	1	3	1	17	M	P
Range	4-6	3-5	1-2	3-4	1-2	3-4	1-2	16-22		M=MALE F=FEMALE S=SEXUAL P=PARTHENOGENETIC
Mean ± SEM	4.7±0.07	4±0.07	1.1±0.03	3.25±0.04	1.25±0.04	3.4±0.05	1.15±0.03	18.85±0.21 S=20.25 ±0.21 P = 16.75±0.13		

Table 41: Fecundity of *R. indica* on *A. catcheu* at 25 ±2°C & 80 ± 5% RH

	Number of eggs laid on different days of oviposition																									Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
1	1	1	0	0	1	0	1	1	1	1	1	1	2	1	1	1	1	1	1	0	1	1	1	0	0	20	**M**	34
2	1	1	1	1	0	1	0	1	1	1	1	1	1	2	2	1	1	1	1	1	0	1	0	1	0	22	**M**	36
3	1	1	1	1	0	0	1	1	0	1	1	1	2	2	2	1	1	1	1	0	1	1	0	1	1	23	**M**	40
4	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	0	0	18	**V**	32
5	1	1	1	0	0	1	1	1	0	1	1	1	2	1	2	1	1	1	1	1	1	1	0	1	0	22	**M**	38
6	1	1	0	0	1	1	1	1	1	1	1	1	2	2	1	0	0	1	1	0	0	0	0	0	0	17	**V**	33
7	1	1	1	0	0	1	1	0	1	0	1	1	2	2	1	1	1	1	1	1	0	0	0	0	0	18	**V**	33
8	1	1	1	0	0	1	1	1	0	1	1	1	2	1	2	1	0	1	2	1	1	0	1	0	1	22	**M**	40
9	1	1	1	0	0	1	1	1	0	1	1	1	2	1	1	1	1	1	1	1	1	0	1	1	0	21	**M**	38
10	1	1	1	0	0	1	1	1	0	1	1	1	2	1	2	1	1	1	1	1	1	0	1	0	1	22	**M**	40
Range	1-1	1-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	1-1	1-1	1-2	1-2	1-2	0-1	0-1	1-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	**M= 20-22 V= -17-18**		**32-40 M= 34-40 V= 32-33**
Mean ± SEM	1±0.0	1±0.0	0.8±0.0	0.2±0.0	0.2±0.0	0.8±0.0	0.9±0.0	0.9±0.0	0.5±0.1	0.9±0.0	1±0.0	1±0.0	1.8±0.0	1.4±0.1	1.5±0.1	0.9±0.0	0.8±0.0	1±0.0	1±0.0	0.7±0.0	0.7±0.0	0.4±0.1	0.4±0.1	0.4±0.1	0.3±0.0	20.50±.21 M=21.74±0.09 V=17.67±0.06		36.40±0.32 M=38±0.23 V=32.67±0.19

Table 42: Fecundity of *R. indica* on *A. catcheu* at 30 ±2°C & 70 ± 5% RH

	Number of eggs laid on different days of oviposition																									Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	42	**M**	33
2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	46	**M**	35
3	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	0	43	**M**	35
4	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	0	0	0	0	34	**V**	26
5	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	0	40	**M**	32
6	1	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	0	0	0	0	0	33	**V**	27.5
7	1	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	0	0	0	0	0	33	**V**	28
8	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	0	0	0	0	0	34	**V**	28
9	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	0	0	41	**M**	33
10	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	46	**M**	34
Range	1-1	1-2	2-2	1-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	1-2	1-2	1-2	1-2	0-2	0-2	0-2	0-1	0-0	M=41-46 V=33-34		**M=33-35 V=26-28**
Mean ± SEM	1±0.0	1.2±0.0	2±0.0	1.8±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	1.7±0.0	1.6±0.1	1.6±0.1	1.5±0.1	1.1±0.1	0.9±0.1	0.6±0.1	0.2±0.0	0±0.0	39.20±0.05 M=43±0.25 V=33.5±0.06		31.15±0.34 M=33.67±0.12 V=27.38±0.08

Table 43: Fecundity of *R. indica* on *A. catcheu* at 35 ±2ºC & 60 ± 5% RH

	Number of eggs laid on different days of oviposition																						Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22			
1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	36	**M**	23.5
2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	38	**M**	27
3	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	0	39	**M**	26
4	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	0	0	0	32	**V**	22.5
5	1	0	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	0	0	0	0	30	**V**	21
6	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	0	40	**M**	26
7	1	1	1	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	0	0	0	0	29	**V**	22.5
8	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	40	**M**	28
9	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	40	**M**	27.5
10	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	0	0	0	0	34	**V**	22.5
Range	1-1	1-2	1-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	2-2	1-2	1-2	1-2	1-2	0-2	0-1	0-1	0-1	**M=36-40 V=29-34**		**M=23-28 V=21- 23**
Mean ± SEM	1±0.0	1±0.0	1.7±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	2±0.0	1.9±0.0	1.8±0.0	1.7±0.0	1.6±0.1	1±0.1	0.6±0.1	0.5±0.1	0.2±0.0	35.80±0.48 M=38.14±0.23 V=31.25±0.55		24.65±0.25 M=26.33±0.26 V=22.13±0.18

Table 26: Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *B. phoenicis* on *P. guajava* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25±2ºC & 80±5%RH	1	9	11	9
	2	9	11	9
	3	9	14	8
	4	9	13	8
	5	9	12	8
	6	9	12	10
	7	8	10	9
	8	10	11	9
	9	9	12	9
	10	9	13	10
	Mean ± SEM	9 ± 0.05	11.9 ± 0.12	8.9 ± 0.07
30±2ºC & 70±5% RH	1	9	11	8
	2	8	10	8
	3	9	10	8
	4	8	12	8
	5	8	10	8
	6	9	10	7
	7	9	10	8
	8	8	11	9
	9	9	10	8
	10	9	12	8
	Mean ± SEM	8.6 ± 0.05	10.6 ± 0.08	8 ± 0.05
35±2ºC &60 ±5% RH	1	8	10	7
	2	8	8	7
	3	8	10	8
	4	7	9	8
	5	8	8	5
	6	8	8	7
	7	6	9	6
	8	6	10	8
	9	7	9	7
	10	8	9	7
	Mean ± SEM	7.4 ± 0.08	9 ± 0.08	6.9 ± 0.11

Table 27: Fecundity of *B. phoenicis* on *P. guajava* at 25 ± 2ºC & 80 ± 5% RH

	Number of eggs laid on different days of oviposition														Total no. of eggs laid	F/V	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**			
1	1	0	0	1	1	2	1	0	1	1	0	0	0	1	**9**	**V**	**32**
2	1	1	0	1	1	1	1	0	1	1	1	0	0	0	**9**	**V**	**29**
3	1	1	1	1	0	1	1	1	1	1	0	0	0	1	**10**	**V**	**31**
4	1	0	0	1	1	2	1	1	1	0	0	1	1	0	**10**	**V**	**30**
5	1	1	0	1	1	2	1	1	0	0	1	1	0	0	**10**	**V**	**29**
6	1	1	0	1	1	1	1	1	1	1	0	1	0	0	**10**	**V**	**31**
7	1	1	1	1	2	1	1	1	0	1	0	0	0	0	**10**	**V**	**27**
8	1	1	0	1	2	2	1	1	0	0	1	0	0	0	**10**	**V**	**30**
9	1	1	0	0	1	2	1	1	1	0	0	1	0	0	**10**	**V**	**30**
10	1	0	1	0	1	1	1	1	1	1	0	1	1	0	**10**	**V**	**32**
Range	1	0-1	0-1	0-1	1-2	1-2	1	0-1	0-1	0	1	0	1	0	**9-10**		**27-32**
Mean ± SEM	1.00 ± 0.00	0.70 ± 0.05	0.30 ± 0.05	0.80 ± 0.04	1.10 ± 0.06	1.50 ± 0.05	1.00 ± 0.00	0.80 ± 0.04	0.70 ± 0.05	0.60 ± 0.05	0.30 ± 0.05	0.50 ± 0.05	0.20 ± 0.04	0.20 ± 0.04	**9.80 ± 0.04**		**30.10 ± 0.15**

Table 28: Fecundity of *B. phoenicis* on *P. guajava* at 30 ± 2ºC & 70 ± 5% RH

	Number of eggs laid on different days of oviposition												Total no. of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**			
1	1	1	0	1	2	1	1	1	1	1	1	0	**11**	**V**	**28**
2	1	1	1	2	2	1	1	1	1	1	0	0	**12**	**V**	**26**
3	1	1	1	1	2	2	1	1	1	1	0	0	**12**	**V**	**27**
4	1	0	1	1	2	2	1	0	1	1	1	1	**12**	**V**	**28**
5	1	1	1	1	1	1	1	1	1	1	0	0	**10**	V	**26**
6	1	1	1	1	2	2	1	1	1	1	0	0	**11**	V	**26**
7	1	1	1	1	2	2	1	1	1	1	0	0	**11**	V	**27**
8	1	1	1	1	2	2	1	1	1	1	1	0	**12**	**V**	**28**
9	1	1	1	1	2	2	1	1	1	1	0	0	**12**	**V**	**27**
10	1	1	1	1	1	1	1	1	1	1	0	1	**11**	**V**	**29**
Range	1	0-1	0-1	1-2	1-2	1-2	1	0-1	1	1	0-1	0-1	**10-12**		**26-28**
Mean ± SEM	1.00 ± 0.00	0.90 ± 0.03	0.90 ± 0.03	1.10 ± 0.03	1.80 ± 0.04	1.60 ± 0.05	1.00 ± 0.00	0.90 ± 0.03	1.00 ± 0.00	1.00 ± 0.00	0.30 ± 0.05	0.20 ± 0.04	**11.40 ± 0.07**		**27.20 ± 0.10**

Table 29: Fecundity of *B. phoenicis* on *P. guajava* at 35 ± 2ºC & 60 ± 5% RH

	Number of eggs laid on different days of oviposition										Total no. of eggs laid	F/V	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	6	**7**	**8**	**9**	**10**			
1	1	1	1	2	3	2	2	0	1	1	**14**	**V**	**25**
2	1	1	2	2	2	3	1	1	0	0	**13**	**V**	**23**
3	1	1	1	1	2	2	1	1	1	1	**12**	**V**	**26**
4	1	1	1	2	3	1	1	1	1	0	**12**	**V**	**24**
5	1	1	1	2	3	2	1	1	0	0	**12**	V	**23.5**
6	1	1	1	1	2	2	1	1	0	0	**10**	V	**23**
7	1	1	1	2	2	2	1	0	1	0	**11**	V	**25**
8	1	1	1	1	1	1	1	1	1	1	**10**	**V**	**24**
9	1	1	1	2	3	2	2	1	1	0	**14**	**V**	**23**
10	1	1	1	2	3	2	2	1	1	0	**14**	**V**	**24**
Range	1	1	1-2	1-2	1-3	1-3	1-2	0-1	0-1	0-1	**10-14**		**23-26**
Mean ± SEM	1.00 ± 0.00	1.00 ± 0.00	1.10 ± 0.03	1.70 ± 0.05	2.40 ± 0.07	1.90 ± 0.06	1.30 ± 0.05	0.80 ± 0.04	0.70 ± 0.05	0.30 ± 0.05	**12.20 ± 0.15**		**24.05 ± 0.10**

Table 30: Duration (in days) of development of *B. phoenicis* on *P.guajava* at 25 ± 2°C & 80 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**Male/ Female**	**Nature of development**
1.	4.5	5	2	5	.5	6	2	26	F	P
2.	5	5	1.5	5	2	5.5	2	26	F	P
3.	6	4.5	2	5	2	5.5	2	27	F	P
4.	4.5	5	2	5	2	5	2	25.5	F	P
5.	5	4	2	6	2	5	2	26	F	P
6.	5	5	2	5	2	4	2	26	F	P
7.	4	6	2.5	5	2	5	2	26.5	F	P
8.	4.5	5	2	5	1.5	6	2	26	F	P
9.	5	5	2	5.5	1.5	5	2	26	F	P
10.	6	4	2	6	2	5	1.5	26.5	F	P
Range	4-6	4-6	1.5-2.5	5-6	1.5-2	5-6	1.5-2.5	25.5-27		M=MALE F=FEMALE S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	4.95 ± 0.06	4.85 ± 0.06	2.00 ± 0.02	5.25 ± 0.04	1.75 ± 0.05	5.20 ± 0.06	1.95 ± 0.02	26.15 ± 0.04		

Table 31: Duration (in days) of development of *B. phoenicis* on *P. guajava* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**Male/ Female**	**Nature of development**
1.	4	4.5	1.5	6	1.5	4	2	23.5	F	P
2.	4.5	5	1	5	1.5	5.5	1.5	24	F	P
3.	4.5	4.5	1.5	5	2	5	1.5	24	F	P
4.	5	4	1	5	2	4	2	23	F	P
5.	4.5	5	1	6	2	5	2	25.5	F	P
6.	4.5	5	1.5	5	1.5	5.5	1.5	24	F	P
7.	5	5	1	5	2	5	2	25	F	P
8.	4.5	4	1.5	5	2	5	1	23	F	P
9.	5	4	2	5	1.5	5	1	23.5	F	P
10.	4.5	4	1.5	5	1.5	5	1	22.5	F	P
Range	4-6	4-5	1-2	5-6	1.5-2	5-6	1-2	23-25.5		M=MALE
Mean ± SEM	4.60 ± 0.03	4.50 ± 0.05	1.35 ± 0.03	5.20 ± 0.04	1.75 ± 0.03	4.90 ± 0.05	1.55 ± 0.04	23.80 ± 0.09		F=FEMALE S=SEXUAL

Table 32: Duration (in days) of development of *B. phoenicis* on *P. guajava* at 35 ± 2°C & 60 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**Male/ Female**	**Nature of development**
1.	4	4.5	2	5	1.5	3.5	2	22.5	F	P
2.	4	5	1.5	4	1.5	5	1.5	22.5	F	P
3.	3	4	2	5	1.5	4.5	1	21	F	P
4.	4	3.5	1.5	4.5	1.5	4	1.5	20.5	F	P
5.	4	4	1	5	2	4	1	21	F	P
6.	4	3.5	1.5	4.5	1	4.5	1	20	F	P
7.	4	4	1	4	1.5	4	2	20.5	F	P
8.	4	4	1.5	4	1	3	2	19.5	F	P
9.	3.5	4	1	4	1	3.5	1.5	18.5	F	P
10.	3.5	4	2	4	1	4	1.5	20	F	P
Range	3-4	3.5-5	1-2	4-5	1-2	3-5	1-2	18.5-22.5		M=MALE F=FEMALE S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	3.80 ± 0.03	4.05 ± 0.04	1.50 ± 0.04	4.40 ± 0.05	1.35 ± 0.03	4.00 ± 0.06	1.50 ± 0.04	20.60 ± 0.12		

Table 33: Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *D. floridanus* on *A. catcheu* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-Oviposition
25±2ºC and 80±5%RH	1	2	9	6
	2	2	9	7
	3	2	7	6
	4	3	7	6
	5	3	9	7
	6	2	9	5
	7	3	8	7
	8	3	9	7
	9	2	8	5
	10	2.5	8	6
	Mean ± SEM	2.45±0.05	8.3±0.08	6.2±0.08
30±2ºC and 70±5%RH	1	2	7	4
	2	2	7	6
	3	2	7	5
	4	2	7	4
	5	1.5	7	4
	6	1	7	6
	7	1	7	4
	8	2	7	4
	9	2	7	4
	10	2	8	4
	Mean ± SEM	1.75±0.03	7.1±0.03	4.5±0.08
35±2ºC and 60 ±5% RH	1	1	6	4
	2	1	6	3
	3	1	7	4
	4	2	6	3.5
	5	1.5	6	3
	6	2	6	4
	7	1	5	3
	8	2	7	4
	9	2	6	3
	10	1	5	3
	Mean ± SEM	1.45±0.05	6±0.07	3.45±0.05

Table 34: Fecundity of *D. floridanus* on *A. catcheu* at 25 ±2^{0}C & 80 ± 5% RH

	Number of eggs laid on different days of oviposition									Total no. of eggs laid	V/M	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
1	1	1	2	2	2	1	1	1	1	**12**	**M**	**17**
2	1	1	1	2	2	2	1	1	1	**12**	**M**	**18**
3	1	1	2	2	2	1	1	0	0	**10**	**V**	**15**
4	1	1	2	2	1	2	2	0	0	**11**	**M**	**16**
5	1	1	2	2	2	2	1	1	1	**13**	M	**19**
6	1	0	1	2	2	1	1	1	1	**10**	V	**16**
7	1	0	2	2	2	1	2	1	0	**11**	M	**18**
8	1	1	2	2	2	1	1	0	1	**11**	**M**	**19**
9	1	2	1	2	2	1	0	1	0	**10**	**V**	**17**
10	1	1	2	2	1	1	2	1	0	**11**	**M**	**16.5**
Range	1-1	0-2	1-2	2-2	1-2	1-2	0-2	0-1	0-1	**10-13**		**16-19**
Mean ± SEM	1 ± 0.00	0.9 ± 0.06	1.7 ± 0.05	2 ± 0.00	1.8 ± 0.04	1.3 ± 0.05	1.2 ± 0.06	0.7 ± 0.05	0.5 ± 0.05	11.10±0.10 M=11.57 ± 0.11 V=10±00		16.85±0.12 M=17.64±0.17 V=16±0.33

Table 35: Fecundity of *D. floridanus* on *A. catcheu* at 30±2^{0}C & 70 ± 5% RH

	Number of eggs laid on different days of oviposition								Total no. of eggs laid	V/M	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
1	1	2	2	2	2	2	1	0	**12**	**V**	**13**
2	1	2	2	2	2	2	2	0	**13**	**M**	**15**
3	1	2	2	2	2	2	2	0	**13**	**M**	**14**
4	1	2	2	2	2	2	2	0	**13**	**M**	**13**
5	1	2	2	2	2	2	2	0	**13**	M	**12.5**
6	1	2	2	2	2	2	2	0	**13**	M	**14**
7	1	2	2	2	2	2	2	0	**13**	V	**12**
8	1	2	2	2	2	2	2	0	**13**	**M**	**13**
9	1	2	2	2	2	2	1	0	**12**	**V**	**13**
10	1	2	2	2	2	2	2	2	**15**	**M**	**14**
Range	1-1	2-2	2-2	2-2	2-2	2-2	1-2	0-2	**12-15**		**12.5-15**
Mean ± SEM	1 ± 0.00	2 ± 0.00	2-2 ± 0.05	2 ± 0.00	2 ± 0.00	2 ± 0.00	1.8 ± 0.04	0.2 ± 0.06	13±0.08 M=13.29 ± 0.11 V=12.33±0.19		13.35±0.8 M=13.64±0.12 V=12.67±0.19

Table 36: Fecundity of *D. floridanus* on *A. catcheu* at 35 ±2^{0}C & 60 ± 5% RH

	Number of eggs laid on different days of oviposition							Total no. of eggs laid	V/M	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	**2**	**3**	**4**	**5**	**6**	**7**			
1	2	2	2	2	2	1	0	11	**M**	**11**
2	2	2	2	2	2	2	0	12	**M**	**10**
3	2	2	2	2	1	1	1	11	**M**	**12**
4	2	2	2	2	2	1	0	11	**M**	**11.5**
5	2	2	2	2	2	2	0	12	M	**10.5**
6	1	2	2	2	2	2	0	11	M	**12**
7	2	2	2	2	2	0	0	10	V	**9**
8	1	2	2	2	2	2	1	12	**M**	**13**
9	2	2	2	2	2	2	0	12	**M**	**11**
10	2	1	2	2	2	0	0	9	**V**	**9**
Range	1-2	1-2	2-2	2-2	1-2	0-2	0-1	9-12		**9-13**
Mean ± SEM	1.8 ± 0.04	1.9 ± 0.03	2 ± 0.00	2 ± 0.00	1.9 ± 0.3	1.3 ± 0.08	0.2 ± 0.04	11.1±0.10 M=11.50±0.07 V=9.5±0.35		10.90±0.13 M=11.37±0.12 V=9±0.00

Table 37: Duration (in days) of development of *D. floridanus* on *A. catcheu* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**M/ F**	**Nature of development**
1.	8	5	3	5	2.5	5	3.5	32	F	S
2.	9	5	2.5	4	2.5	5	3	31	F	S
3.	8	4	2	3	3	5	3	28	M	P
4.	8	3	3	3.5	2.5	6	7	33	F	S
5.	8	5	3	3	3	5	6.5	33.5	F	S
6.	9	5	3	5	2.5	5	3	32.5	F	S
7.	8.5	4	3	3.5	2	7	4	32	F	S
8.	9	5	3	3.5	2.5	7	4	34	F	S
9.	8	4	2	3	2.5	5.5	3	28	M	P
10.	10	4	3	3	2	5	3	30	F	S
Range	8-10	3-5	2-3	3 -5	2-3	5-7	3-7	28-33.5	M=MALE F=FEMALE	S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	8.55 ± 0.07	4.40 ± 0.07	2.75 ± 0.04	3.65 ± 0.08	2.5 ± 0.03	5.6 ± 0.08	4 ± 0.15	31.40±0.21 S:32.25±0.16 P:28±0.00		

Table 38: Duration (in days) of development of *D. floridanus* on *A. catcheu* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**Male/ Female**	**Nature of development**
1.	6	3	2	3	2	4	3	23	M	P
2.	7	6	2.5	2	2	6	2.5	28	F	S
3.	7	4	2	4	2.5	5	3	27.5	F	S
4.	8	4	2	4.5	2	5	4	29.5	F	S
5.	8	6	2.5	3	2	6	2.5	30	F	S
6.	8	5	3	2	2.5	6	3	29.5	F	S
7.	5.5	3	2	3	2	3.5	2	21	M	P
8.	7	4	2.5	3	2	5	3	26.5	F	S
9.	5	3.5	2.5	3	2.5	3	3	22.5	M	P
10.	6	4	2	3	2	4	3	24	F	S
Range	5-8	3-6	2-2.5	2-4.5	2-2.5	3-6	2-4	21-30		S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	6.75±0.11	4.25±0.11	2.30±0.03	3.05±0.08	2.15±0.02	4.75±0.11	2.90±0.05	26.15±0.33 S=27.86±0.30 P=22.67±0.51	M=MALE F=FEMALE	

Table 39: Duration (in days) of development of *D. floridanus* on *A. catcheu* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	**Egg**	**Larva**	**1st Q**	**Proto-nymph**	**2nd Q**	**Deuto-nymph**	**3rd Q**	**Total duration**	**M/ F**	**Nature of development**
1.	7	2	2	2.5	2	3	5	23.5	F	S
2.	6	2	1.5	2	1.5	4	5	22	F	S
3.	6	4	1.5	3.5	2	4	2	22	F	S
4.	5.5	2.5	2	2	2	4	5	23	F	S
5.	6	4	2	3	1.5	4	2	22.5	F	S
6.	6	4	2	4	2	4	2	24	F	S
7.	5	3	2	2	2	3	2	19	M	P
8.	6	2	2	2	2	4	4	22	F	S
9.	7	2	2	2	2	4	5	24	F	S
10.	5.5	2	2	2	1.5	4	2	19	M	P
Range	5-7	2-4	1.5-2	2-4	1.5-2	3-4	2-5	19-24	M=MALE F=FEMALE	S=SEXUAL P=PARTHOGENETIC
Mean ± SEM	6 ± 0.06	2.75 ± 0.09	1.90 ± 0.02	2.50 ± 0.07	1.85 ± 0.02	3.80 ± 0.04	3.40 ± 0.15	22.10±0.18 S=22.88±0.11 P=19±0.00		

Table 1: Host plants surveyed

Fruit crops

Sl. No.	Name of the plant		Family	Presence-Absence of Tenuipalpid mite
	Common Name	Scientific Name		
1.	Apple	*Malus domestica*	Rosaceae	+
2.	Passion fruit	*Passiflora edulis*	Passifloraceae	+++
3.	Guava	*Psidium guajava*	Myrtaceae	+++
4.	Orange	*Citrus sinensis*	Rutaceae	+++
5.	Lemon	*Citrus limon*	Rutaceae	+
6.	Pomelo	*Citrus maxima*	Rutaceae	+++
7.	Pear	*Pyrus pyrifolia*	Rosaceae	-
8.	Lychee	*Litchi chinensis*	Sapindaceae	-
9.	Sapodilla	*Manilkara zapota*	Sapotaceae	+++
10.	Jambolan plum	*Syzygium cumini*	Myrtaceae	+++
11.	Grape	*Vitis vinifera*	Vitaceae	++
12.	Rose Apple	*Syzygium samarangense*	Myrtaceae	+
13.	Cherry	*Prunus avium*	Rosaceae	-
14.	Custard apple	*Annona reticulate*	Annonaceae	+
15.	Otaheite gooseberry	*Phyllanthus acidus*	Phyllanthaceae	-
16.	Carambola	*Averrhoa carambola*	Oxalidaceae	-
17.	Common fig	*Ficus carica*	Moraceae	-
18.	Mango	*Mangifera indica*	Anacardiaceae	-
19.	Jackfruit	*Artocarpus heterophyllus*	Moraceae	-
20.	Rambutan	*Nephelium lappaceum*	Sapindaceae	-
21.	Mangosteen	*Garcinia mangostana*	Clusiaceae	-
22.	Strawberry	*Fragaria ananassa*	Rosaceae	-

23.	Butterfruit	*Persea Americana*	Lauraceae	-
24.	Bilimbi	*Averrhoa bilimbi*	Oxalidaceae	-
25.	Pappaya	*Carica papaya*	Caricaceae	+++
26.	Brindle berry	*Garcinia gummi-gutta*	Clusiaceae	-
27.	Pomegranate	*Punica granatum*	Lythraceae	+++
28.	Peach	Prunus persica	Rosaceae	-
29.	Breadfruit	*Artocarpus altilis*	Moraceae	+++
30.	Canistel	*Pouteria campechiana*	Sapotaceae	-
31.	Soursop	*Annona muricata*	Annonaceae	-
32.	Dhurian	*Durio kutejensis*	Malvaceae	-
33.	Pulasan	*Nephelium mutabile*	Sapindaceae	-
34.	Jujube	*Ziziphus jujube*	Rhamnaceae	-
35.	Amla	*Phyllanthus emblica*	Phyllanthaceae	-
36.	Lovi	*Flacourtia inermis*	Salicaceae	-

Plantation Crops

Sl. No.	Name of the plant		Family	Presence-Absence of Tenuipalpid mite
	Common Name	**Scientific Name**		
1	Arecanut	*Areca catechu*	Arecaceae	+++
2	Coconut	*Cocos nucifera*	Arecaceae	+++
3	Rubber	*Hevea brasiliensis*	Euphorbiaceae	+
4	Teak	*Tectona grandis*	Lamiaceae	++
5	Pepper	*Piper nigrum*	Piperaceae	-
6	Cashew nut	*Anacardium occidentale*	Anacardiaceae	-
7	Banana	*Musa acuminate*	Musaceae	++
8	Cocao	*Theobroma cacao*	Malvaceae	++
9	Nut meg	*Myristica fragrans*	Myristicaceae	-
10	Pineapple	*Ananas comosus*	Bromeliaceae	-
11	Coffee	*Coffea Arabica*	Rubiaceae	+++
12	Tea	*Camellia sinensis*	Theaceae	+++
13	Vanilla	*Vannila planifolia*	Orchidaceae	-
14	Queen sago	*Cycas circinalis*	Cycadaceae	-
15	Mahagoni	*Swietenia mahagoni*	Meliaceae	-
16	Clove	*Syzygium aromaticum*	Myrtaceae	+++

+++ = High incidence (5> mites/ cm^2), ++ = Low incidence (2- 5 mites/ cm^2), + = Scarce (1- 2 mites/ cm^2) & - = Absence of mites

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