BIOLOGICAL STUDIES OF SPIDER MITES (ACARI: TETRANYCHIDAE) INFESTING VEGETABLE CROPS

TThesis submitted in partial fulfilment
of the requirements for the award of Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

SANGEETHA G KAIMAL

DIVISION OF ACAROLOGY
DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
KERALA - INDIA

2009

CONTENTS

B. BREEDING BIOLOGY

1. **Postembryonic development of *Tetranychus neocaledonicus***

   1.1 Oviposition

   1.2 Hatching

   1.3 Duration of developmental stages

      1.3.1 Incubation period

      1.3.2 Larval period

      1.3.3 Protonymphal period

      1.3.4 Deutonymphal period

      1.3.5 Quiescent periods

      1.3.6 Moulting

      1.3.7 Adult Stages

   1.4 Mating

   1.5 Parthenogenetic versus sexual development

   1.6 Morphological description of life stages of *T. neocaledonicus*

2. **Postembryonic development of *Tetranychus ludeni***

   2.1 Oviposition

   2.2 Hatching

   2.3 Duration of developmental stages

      2.3.1 Incubation period

      2.3.2 Larval period

      2.3.3 Protonymphal period

      2.3.4 Deutonymphal period

      2.3.5 Quiescent periods

      2.3.6 Moulting

      2.3.7 Adult Stages

   2.4 Mating

DEPARTMENT OF ZOOLOGY

UNIVERSITY OF CALICUT

673 635, KERALA

Phone: Off: 0494-2401144*419

Dr. N. RAMANI Res:0494-2404195

Reader CALICUT

UNIVERSITY P.O.

Date: …….

CERTIFICATE

This is to certify that the thesis titled "**BIOLOGICAL STUDIES OF SPIDER MITES (ACARI: TETRANYCHIDAE) INFESTING VEGETABLE CROPS"** is an authentic record of the work carried out by **Ms. Sangeetha G. Kaimal** under my supervision and guidance in partial fulfilment of the requirements of the Degree of Doctor of Philosophy in Zoology in the Division of Acarology of this Department and that no part thereof has been presented before for any other degree or diploma.

N. RAMANI

ACKNOWLEDGEMENT

It is a pleasure to remember all those who have contributed for the successful completion of my doctoral study.

With great delight, I express my heartfelt gratitude and indebtedness to my supervising teacher Dr. N. Ramani, Reader, Department of Zoology, University of Calicut for her expert guidance, creative advice, timely suggestions, immense patience, constructive criticism and continual assistance which formed the basis for the successful completion of my work.

I am extremely grateful to Dr. M. Gokuldas, Professor and Head, Department of Zoology, University of Calicut for providing all facilities to carry out this investigation. Facilities extended by Dr. V.S. Krishnan Nair and Dr. K.P. Janardanan, Professors and Former Heads of the Department of Zoology, University of Calicut are also thankfully acknowledged.

I owe my sincere gratitude to Dr. T. C. Narendran, Emeritus Professor and Former Head, Department of Zoology, University of Calicut and Dr. Nandakumar Thampi, Former Head, Department of Botany, University of Calicut for their scholarly assistance, wilful support and liberal grant of precious advice.

I am particularly thankful to Dr. Shibu Vardanan, Reader, Department of Zoology, University of Calicut, Ms. Sarala, Department of Entomology, UAS, Bangalore, Dr. K.P. Dinesh, Zoological Assistant, ZSI, Kozhikode and Mr. Salam, Research Scholar, Department of Botany, University of Calicut for their assistance in SDS-PAGE work.

I acknowledge with gratitude, Dr M. Mohanasundaram, Professor and Head (Retd.), Department of Agricultural Entomology, TNAU, Coimbatore for his help in identification and confirmation of species of tetranychid mites. Thanks are also due to

Dr. A.K. Pradeep, Herbarium Curator, Department of Botany, University of Calicut for his assistance in identification of host plants involved in the study.

I record my sincere thanks to Dr. B. K. Chandrasekhar Sagar, Assistant. Professor and Ms. B.N. Hemavathy, Senior Technician, Department of Neuropathology, NIMHANS, Bangalore for their assistance in TEM studies. Thanks are also due to Dr. S. Vynatheya, Scientific Officer, MTD, CPRI, Bangalore for his scholarly help with the SEM studies.

I am greatly indebted to Sri. C. Radhakrishnan, Additional Director, ZSI, Kozhikode for providing necessary facilities to complete the drawing part of my thesis work. I am also thankful to the University of Calicut for the financial assistance extended in the form of fellowship.

I shall be failing in my duty, if I do not thank my research colleagues in the Division of Acarology of this Department, especially Ms. M.T. Shiji, Ms. E. Julie, Ms. U.M. Sheeja and Ms. Prabheena for their whole hearted support, co-operation and encouragement.

I express my thankfulness in depth to my husband, for his endurance, immense help and moral support, extended to me all through the course of this work. He has been the sole spirit behind my studies and his constant encouragement has worked wonders on many occasions of uncertainties. Again with immense gratitude I remember my parents and friends for their goodwill, encouragement and co-operation.

I register my thanks to Mr. Rajesh, Bina Photostat for the technical assistance rendered and all others who helped me in various ways during the course of my study. Above all, I am deeply indebted to the blessing of God.

Sangeetha G. Kaimal

DECLARATION

I do hereby declare that this thesis titled "**BIOLOGICAL STUDIES OF SPIDER MITES (ACARI: TETRANYCHIDAE) INFESTING VEGETABLE CROPS"** is an authentic record of the work carried out by me under the supervision and guidance of Dr. N. Ramani, Reader, Division of Acarology, Department of Zoology, University of Calicut and that no part of this has been submitted before for the award of any other Degree or Diploma.

Calicut University Campus,

Date: **Sangeetha G. Kaimal**

LIST OF PLATES INCLUDED

LIST OF TABLES INCLUDED

PLATE I

EXPLANATION OF FIGURES

Figs. 1 to 12: Natural infestation and nature of damage produced by *Tetranychus neocaledonicus* on the leaves of *Vigna unguiculata*.

1. Actively feeding adult female of *T. neocaledonicus*.

2. A heavily infested leaf of *V. unguiculata* showing life stages of *T. neocaledonicus*.
   E : Eggs, L : Larva, P : Protonymph, D : Deutonymph,
   QD : Quiescent deutonymph, F : Adult female, M : Adult male,
   MS : Moulting skin, CS : Chlorotic spots.

3. Another view of a leaf of *V. unguiculata* showing damage symptoms.
   E : Eggs, EC : Egg case, MS : Moulting skin.

4. Eggs and larva of *T. neocaledonicus.*
   E : Eggs, L : Larva.

5. Protonymph

6. Life stages of *T. neocaledonicus.*
   E : Eggs, QD : Quiescent deutonymph, F : Adult female,
   FP : Faecal pellets.

7. Life stages of *T. neocaledonicus.*
   F : Newly moulted adult females, MS : Moulting skin, QD : Quiescent deutonymph.

8. Competition between males for mating with a newly moulted adult female.
   F : Adult female, M : Adult male.

9. Mating pairs of *T. neocaledonicus.*
   F : Adult female, M : Adult male.

10. Ovipositing female of *T. neocaledonicus.*
    F : Adult female, E : Eggs, W : Web.

11. Hatching
    L : Larva, EC : Egg case.

12. Aedeagus of adult male.

PLATE XII

EXPLANATION OF FIGURES

Figs. 1 to 9: Natural infestation and nature of damage produced by *Tetranychus ludeni* on the leaves of *Mucuna deeringiana*.

1. A view of an infested leaf of *M. deeringiana.*.
   DS : Damage symptoms, MS : Moulting skin, BFP : Black faecal pellets, WFP : White faecal pellets.

2. Eggs of *T. ludeni*
   E : Eggs, EC : Egg case, MS : Moulting skin.

3. Larva

4. Protonymph

5. Quiescent deutonymph

6. Deutonymph

7. Adult female

8. Adult male

9. Mating pairs of *T. ludeni.*
   F : Adult female, M : Adult male

PLATE XIX
EXPLANATION OF FIGURES

Figs. 1 to 12: Natural infestation and nature of damage produced by *Tetranychus cinnabarinus* on the leaves of *Carica papaya*.

1. A view of an infested leaf of *C. papaya*..
   F : Adult female, E : Eggs.

2. Ovipositing female of *T. cinnabarinus.*
   F : Adult female, E : Eggs, W : Web.

3. Larva

4. Protonymph

5. A newly moulted deutonymph.
   MS : Moulting skin

6. A heavily infested leaf of *C. papaya* showing life stages of *T. cinnabarinus*.
   L : Larva, P : Protonymph, D : Deutonymph.

7. Quiescent deutonymph

8. Ovipositing parthenogenetic female of *T. cinnabarinus.*
   F : Adult female, E : Eggs, FP : Faecal pellets.

9. Another view of a leaf of *C. papaya* infested by *T. cinnabarinus*.
   LS : Life stages, MS : Moulting skin, Du : Dust particles.

10. Eggs

11. Newly moulted adult female
    F : Adult female, MS : Moulting skin.

12. Adult male

PLATE XXIX

EXPLANATION OF FIGURES

Figs. 1 to 6: Natural infestation and nature of damage produced by *Eutetranychus orientalis* on the leaves of *Moringa oleifera*.

1. Eggs

2. A view of a leaf of *M. oleifera* infested by *E. orientalis*.
   LS : Life stages, CS : Chlorotic spots.

3. Another view of an infested leaf of *M. oleifera.*
   F : Adult female, CS : Chlorotic spots, FP : Faecal pellets.

4. Deutonymph

5. Ovipositing female of *E. orientalis.*
   F : Adult female, E : Eggs.

6. A heavily infested leaf of *M. oleifera* showing life stages of *E. orientalis*.
   L : Larva, P : Protonymph, D : Deutonymph,
   MS : Moulting skin, EC : Egg case.

PLATE XXXVI

EXPLANATION OF FIGURES

Figs. 1 to 12: Natural infestation and nature of damage produced by *Oligonychus biharensis* on the leaves of *Manihot esculenta*.

1. A heavily infested leaf of *M. esculenta* showing life stages of *O. biharensis*.
   P : Protonymph, D : Deutonymph, CS : Chlorotic spots.

2. Another view of a leaf of *M. esculenta* showing damage symptoms.
   CS : Chlorotic spots, MS : Moulting skin, FP : Faecal pellets, EC : Egg cases.

3. A close view of heavily infested leaf of *M. esculenta*.
   EC : Egg cases, MS : Moulting skin, FP : Faecal pellets.

4. Eggs

5. Larva

6. Protonymph and egg of *O. biharensis*..
   P : Protonymph, E : Egg.

7. Quiescent deutonymph

8. Deutonymph and egg of *O. biharensis*..
   D : Deutonymph, E : Egg, FP : Faecal pellets.

9. Adult female.

10. Adult male.

11. Mating pairs of *O. biharensis*.
    F : Adult female, M : Adult male.

12. Aedeagus of adult male.

PLATE XLIII

EXPLANATION OF FIGURES

Figs. 1 to 6: Scanning electron micrographs of *O. biharensis*

1. Dorsal view of *O. biharensis*

2. Ventral view of *O. biharensis*

3. Leg
   EC : Empodium with claw

4. Leg
   EC : Empodium with claw

5. Dorsal view of mouth parts
   MP : Mouth Parts

6. Ventral view of mouth parts

PLATE XL

EXPLANATION OF FIGURES

Figs. 1 to 6: Transmission electron micrographs of leaves of *M. esculenta* infested by *O. biharensis*

1. Upper epidermis of a non-infested *M. esculenta* leaf exhibiting protoplast
   UE : Upper Epidermis

2. Upper epidermis of an infested *M. esculenta* leaf showing irregular and distorted epidermal cells.
   UE : Upper Epidermis

3. Cross section of a non-infested leaf showing upper epidermis and closely packed palisade parenchyma cells.
   UE : Upper Epidermis, PP : Palisade Parenchyma

4. Cross section of an infested leaf showing palisade parenchyma cells reduced in number and punctured with large intercellular spaces.
   PP : Palisade Parenchyma, PC : Punctured Cells, ES : Empty Space.

5. Clearly differensiated spongy parenchyma cells of a non-infested leaf.
   SP : Spongy Parenchyma

6. Collapsed spongy parenchyma cells of an infested leaf with long intercellular spaces and fewer chloroplasts.
   SP : Spongy Parenchyma, ES : Empty Space

PLATE XLI

EXPLANATION OF FIGURES

Figs. 1 to 6: Transmission electron micrographs of leaves of *M. esculenta* infested by *O. biharensis*

1. Spongy chloroplast of a non-infested *M. esculenta* leaf .
   CH : Chloroplast

2. Spongy chloroplast of an infested *M. esculenta* leaf showing fewer chloroplast.
   CH : Chloroplast

3. Chloroplast of a non-infested leaf surrounded by fine granular cytoplasm.
   CH : Chloroplast, CV : Central Vacuole

4. Unattacked cells of an infested leaf showing chloroplasts surrounded by coagulated cytoplasm.
   CH : Chloroplast, CP : Cytoplasm

5. Chloroplasts of a non-infested leaf surrounded by a definite outer membrane.
   CH : Chloroplast

6 Chloroplast of an infested leaf without an outer membrane, altered stromal thylakoids and coagulated protoplast.

PLATE IX

EXPLANATION OF FIGURES

Figs. 1 to 4: Morphological description of larva and protonymph of *T. neocaledonicus*

1. Larva - Dorsal view

2. Larva - Ventral view

3. Protonymph - Dorsal view

4. Protonymph - Ventral view

PLATE X
EXPLANATION OF FIGURES

Figs. 1 to 4: Morphological description of deutonymph and adult female of *T. neocaledonicus*

1. Deutonymph - Dorsal view

2. Deutonymph - Ventral view

3. Adult female - Dorsal view

4. Adult female - Ventral view

PLATE XI
EXPLANATION OF FIGURES

Figs. 1 to 2: Morphological description of adult male of *T. neocaledonicus*

1. Adult male - Dorsal view

2. Adult male - Ventral view

PLATE XVII
EXPLANATION OF FIGURES

Figs. 1 to 6: Morphological description of larva, protonymph and deutonymph of *T. ludeni*

1. Larva - Dorsal view
2. Larva - Ventral view
3. Protonymph - Dorsal view
4. Protonymph - Ventral view
5. Deutonymph - Dorsal view
6. Deutonymph - Ventral view

PLATE XVIII
EXPLANATION OF FIGURES

Figs. 1 to 2: Morphological description of adult female and male of *T. ludeni*

1. Adult female - Dorsal view
2. Adult female - Ventral view
3. Adult male - Dorsal view
4. Adult male - Ventral view

PLATE XXVII
EXPLANATION OF FIGURES

Figs. 1 to 6: Morphological description of larva, protonymph and deutonymph of *T. cinnabarinus*

1. Larva - Dorsal view
2. Larva - Ventral view
3. Protonymph - Dorsal view
4. Protonymph - Ventral view
5. Deutonymph - Dorsal view
6. Deutonymph - Ventral view

PLATE XXVIII
EXPLANATION OF FIGURES

Figs. 1 to 2: Morphological description of adult female and male of *T. cinnabarinus*

1. Adult female - Dorsal view

2. Adult female - Ventral view

3. Adult male - Dorsal view

4. Adult male - Ventral view

PLATE XXXIV
EXPLANATION OF FIGURES

Figs. 1 to 6: Morphological description of larva, protonymph and deutonymph of *E. orientalis.*

1. Larva - Dorsal view
2. Larva - Ventral view
3. Protonymph - Dorsal view
4. Protonymph - Ventral view
5. Deutonymph - Dorsal view
6. Deutonymph - Ventral view

PLATE XXXV

EXPLANATION OF FIGURES

Figs. 1 to 2: Morphological description of adult female and male of *E. orientalis*

1. Adult female - Dorsal view

2. Adult female - Ventral view

3. Adult male - Dorsal view

4. Adult male - Ventral view

PLATE XLIV

EXPLANATION OF FIGURES

Figs. 1 to 6: Morphological description of larva, protonymph and deutonymph of *O. biharensis.*

1. Larva - Dorsal view
2. Larva - Ventral view
3. Protonymph - Dorsal view
4. Protonymph - Ventral view
5. Deutonymph - Dorsal view
6. Deutonymph - Ventral view

PLATE XLV
EXPLANATION OF FIGURES

Figs. 1 to 2: Morphological description of adult female and male of *O. biharensis*

1. Adult female - Dorsal view

2. Adult female - Ventral view

3. Adult male - Dorsal view

4. Adult male - Ventral view

BIOLOGICAL STUDIES OF SPIDER MITES (ACARI: TETRANYCHIDAE) INFESTING VEGETABLE CROPS

Synopsis of the thesis submitted in partial fulfilment
of the requirements for the award of Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

SANGEETHA G KAIMAL

DIVISION OF ACAROLOGY
DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
KERALA - INDIA

2009

Chapter 1
Introduction

Acarology, the study of mites and ticks, has gained much importance in the scientific circle because of its significance in the fields of agriculture, horticulture, floriculture, animal husbandry, forestry, medical and veterinary fields, forensic science etc. Mites possess supreme adaptability to survive in extremely diverse ecological situations like the benthic zones of oceans, hostile conditions of caves, freezing sub-zero temperatures of Arctics and warm waters of thermal springs. Such exceptionally high adaptive capacity of the mites has elevated them to the rank of successful inhabitants of soil, air, water, animals and plants.

The ancestral Acari represented a conservative assemblage of omnivores that stemmed from a predatory class of Arthropods *viz*., Arachnida. The assemblage is now represented by a marvelously heterogenous group enjoying phytophagous, parasitic, phoretic, predatory, scavenging and commensalistic modes of life. As invasive species, mites are potentially harmful and destructive, more so because they are too small and difficult to detect and at the same time ubiquitous. Once they become established in a new area, certain inherent biological characteristics of the organisms take over to make them highly destructive pests to crops and livestock. Because of their microscopic size and cryptic behaviour, mites are generally overlooked by men in the field and the damage induced by them is usually assessed on the basis of their feeding response. The study of mites is gaining importance

universally on account of their role either in the beneficial or injurious ways.

Plant feeding mites cause various types of direct damage like loss of chlorophyll, appearance of striplings or bronzing of foliage, stunting of growth, formation of galls and erineal patches thereby causing an array of deformities and reduction of yield. Apart from direct damages, many are known to act as vectors of pathogenic plant viruses causing more potential loss to growers. In recent years, due to random use of chlorinated hydrocarbons for control of general pests, which in turn kill their natural enemies, and because of the adoption of improved cultivation practices, many species which were of less importance or of no value at all in the past have assumed the status of major pests. Drastic changes in environmental conditions also contributed their own role to the rapid build up of mite populations to exceed the economic threshold levels thereby assigning them under the label 'pests'. These, among other factors have further aggravated the situation of the problem of mites as pests.

Vegetables constitute one of the most important groups of plants among agricultural crops susceptible to mite infestation. A good number of mites are known to infest the vegetable plants throughout the world. The major phytophagous groups of mites recognized so far generally belong to the superfamilies Tetranychoidea (Spider mites, Flat mites), Tarsonemoidea (Broad mites, Cyclamen mites, Grass white mites, Rice white mites) and Eriophyoidea (Gall mites, Rust mites, Bud mites). The rice white mite injures the internal surface of leaf sheaths and causes

sterility of rice seeds by transmitting the rice sheath rot fungus and a mycoplasma-like organism. The rust mite causes extensive edge rolling and rusting of the flowers and leaves. Feeding damage by flat mites results in symptoms such as chlorosis, necrosis and striation of fruit surfaces, gall formation and malformation of fruit. The severity of the damage is increased when these mites are associated with viruses like citrus leprosis virus.

The superfamily Tetranychoidea comprises an exclusively phytophagous group characterized by long, needle like chelicerae which are fused basally, and is divided into 5 distinct families; Tetranychidae (Spider mites), Tenuipalpidae (False spider mites or Flat mites), Tuckerellidae, Allochaetophoridae and Linotetranidae (Cryptic false spider mites). Tetranychidae and Tenuipalpidae include majority of species which are of considerable economic importance. Tetranychidae erected by Donnadieu in 1975 is regarded as one of the most important family of the Acari represented by members that are important pests of agricultural crops and other plants of varied economic use owing to their faunistic diversity and the degree of injury caused to their host plants due to their phytophagous habit. At least 1233 species belonging to 2 sub families and 73 genera have been described so far.

Tetranychid mites are called spider mites because of their ability to spin silk to form the webbing for anchoring of eggs, protection or pheromonal transfer. The silk strands, produced from a pair of glands near the mouth, aid in dispersal by allowing the mites to spin down from infested to non-infested leaves. When

abundant, the silk also may shield the mites from pesticide sprays. The bizarre spider mites are characterized by eversible stylophore formed by fusion of cheliceral bases, 4-segmented palpi with strong claw, propodosoma with 3-4 pairs of setae and hysterosoma with 8-13 pairs of setae, duplex setae on tarsi of legs I and II, tenant hairs on tarsal claws, claw-like or pad-like empodium, round to oval shaped soft bodies, characteristic wrinkles and varied colours ranging from red, brown, yellow, to combinations of any of these, depending on the species and the life stage. Aedeagus of male is characteristic of the family and is the diagnostic feature for separation of species. Life history includes an egg stage, a six-legged larval stage, two eight-legged nymphal stages (protonymph and deutonymph) and three quiescent stages in between, before transforming into an eight-legged adult. Under optimum conditions, spider mites can complete their development from egg to adult in a short time, so there may be many overlapping generations in a single season. Therefore, populations can increase rapidly and cause extensive plant damage in a very short time.

The needle-like mouth parts of spider mites help in piercing the leaves of host plants and sucking out the fluids from individual plant cells. Leaves normally control water loss through a system of stomata or valves that can be opened and closed. When the stomata are closed the surface of a leaf is highly resistant to water loss. Spider mite feeding disrupts this system by creating holes that allow water to escape. This uncontrolled water loss eventually dehydrates the leaf. Ironically, the water stress caused by spider mite feeding makes the leaves a more preferred food

source for them because stressed leaves have elevated levels of sugars and soluble nitrogen. Hence infestation by the mite continues and this causes the leaves to have a stippled or flecked appearance, with pale dots where the cellular contents have been removed. Prolonged, heavy infestations cause yellowing or bronzing of the foliage and premature leaf drop similar to draught stress. Severely infested plants may become stunted or even killed. Most of the spider mites routinely damage economically important plant species.

The two spotted spider mite, *Tetranychus urticae* is the most common and destructive mite on deciduous ornamentals. It has an extremely wide host range and is considered as a 'warm season' mite, which thrives under hot, dry summer conditions. The European Red mite, *Panonychus ulmi* is yet another 'warm season' mite attacking flowering fruit trees and shrubs. The Spruce spider mite, *Oligonychus ununguis* known as the 'cool season' mite feeds on more than 40 species of conifers. Prolonged feeding causes yellowing, browning and premature needle drop, often originating from the canopy interior. Heavy attacks can cause branch die back or death of the plant. The most common and destructive spider mite on the broad-leaved evergreens is the Southern Red mite, *O. ilicis* that causes stippling, browning, occasional distortion and premature leaf drop.

Eutetranychus orientalis, a serious pest of a wide variety of agricultural, ornamental and medicinal plants, usually sucks the sap from leaves, tender shoots, bark and fruits turning them into yellowish brown causing drying and premature leaf

abscission. The mites often infests the upper surface of the leaves covered by heavy webs with dust particles adhered to it. The colonisation by these mites affects the normal physiological activities of the host plant thereby retarding the growth and vigour of the plant. Citrus varieties were found most susceptible to the mite and hence the name citrus brown mite.

As a major pest in India, the vegetable mite, *T. neocaledonicus* has a wide range of distribution throughout the tropical and subtropical areas and attacks over 110 different plants including flowers, fruits, vegetables, field crops, fodder crops and so on. Plant hosts of the vegetable mite of economic importance include *Amaranthus tricolor*, *Vigna unguiculata*, green beans, lettuce, mango, watermelon and the ornamentals, Chrysanthemum and Hibiscus. *T. neocaledonicus* sucks the sap from plant cells producing white spots that gradually coalesce as feeding continues. On some plants, the damaged portions of leaves turn red. Excessive feeding results in premature leaf abscission. Like any other spider mite, this species also produces webbing that forms a thick sheath that covers the entire plant. On host plants like orange and other citrus varieties, feeding by this species results in the development of yellow blotches.

T. cinnabarinus is yet another plant pest attacking vegetables, fruits, pulse crops, cotton, jute, tea etc. Feeding of the carmine mite on host plants results in yellowing, crinkling, crumpling, curling and twisting of leaves. In addition, they spin heavy webs on leaves which affect the photosynthetic rate of plants. Eventually,

the leaves dry up and fall off. Further, feeding by this mite severely affects the growth, flowering and fruit formation in crops. In tea, the leaves become pinkish and purplish. In jute and cotton, it causes malformation of the leaves. Severe infestation on apple resulted in yellowing and premature leaf abscission.

T. ludeni, like any other tetranychid mite, causes yellowing of leaves followed by formation of necrotic patches and drying up. It is one of the important mite pests of vegetable crops in India and has been reported to attack French bean, brinjal, potato, water melon and many others. As a highly polyphagous mite, *T. ludeni* occurs in the field almost throughout the year. Moreover, this is the only spider mite in India known to be a vector of the plant viral disease, *viz.* Dolichos Enation Mosaic Virus (DEMV) (Rajagopalan, 1974).

The spider mite species, *O. biharensis* is a sporadic pest of vegetable crops, rose, litchi, camphor and so on. Feeding by this mite causes numerous white spots and a characteristic dark bronzing on the leaf surface. Severe infestation and prolonged feeding results in crinkling, subsequent drying and defoliation of affected leaves. Attack by these mites normally affects the growth and vigour of host plants.

In many instances, lack of information on the correct identity of the mites, their biology and ecology has resulted in serious consequences to agriculture. In view of their importance in agriculture, the plant mites have drawn the attention of acarologists and agricultural entomologists to work in detail both on their fundamental and applied aspects. Most of the phytophagous mites have been

recognized as pests of various crop plants, causing internal damage to mesophyll cells resulting in chlorophyll loss and decline in photosynthetic activity in parallel with decline in stomatal conductance and transpiration leading to considerable loss in yield. This should be considered seriously, particularly in developing countries like India, which depends greatly on agricultural economy. In Kerala, the livelihood of more than 50% of the people is based on agriculture. In this regard, the present work is thought highly warranted, as it is an attempt to provide a general awareness on the developmental strategies of a few important acarine plant pests that would help in forecasting the outbreak of these dangerous pests. The present study thus includes a detailed investigation into the breeding aspects of 5 very common species of spider mite pests under different temperature-humidity parameters to supplement data on the optimum conditions for the population build up of these species. The various species selected for the study were the vegetable mite, *T. neocaledonicus* on *Amaranthus tricolor* & *Vigna unguiculata*; *T. ludeni* on *Mucuna deeringiana*; the carmine mite, *T. cinnabarinus* on *Carica papaya* & *Dolichos lablab*; the citrus brown mite, *E. orientalis* on *Moringa oleifera* and *O. biharensis* on *Manihot esculenta* and the temperature-humidity parameters were 25 $\pm$ 2^{o}C & 80 $\pm$ 5% RH, 30 $\pm$ 2^{o}C & 70 $\pm$ 5% RH and 35 $\pm$ 2^{o}C & 60 $\pm$ 5% RH. Further, damage potential of these species were also estimated through assessment of chlorophyll loss and subsequent data analysis by statistical methods and estimation of damage induced.

Chapter II
Review

Spider mites rank first as the predominant phytophagous group with ubiquitous pattern of distribution on plants of all economic categories. The potential of these mites to build up their population density to reach the status of major/minor pests and their overwhelming power to develop resistance against an array of acaricides have been reported globally. Giving due consideration to the increasing instances of mite infestation in Kerala, the present investigation was undertaken with an intention to gather knowledge on the biological aspects of the common spider mites, damaging our vegetable crops. Accordingly, the present review was organized, mainly concentrating on the developmental strategies of these mites along with their feeding impact on respective hosts.

The earliest record of phytophagous mites was made when Peal (1868) discovered the tea mites in Assam and named it as red-spider. Wood Mason (1884) went further in investigating this mite by describing it as *T. bioculatus* which was the first published reference on Indian plant mite of agricultural importance. Ewing (1914) made a significant contribution to the spider mite biology by recognizing the importance of webbing as a substratum for the attachment of eggs and quiescent individuals. Yokoyama and Ishii (1934) made a detailed study on the mites attacking mulberry leaves and the morphology and biology of *Panonychus mori*. The biology of the red spider mite, *T. telarius* was traced by Janjua (1942) in Baluchistan, who reported the duration of life cycle and host range of the mite. In India, Rahman and

Sapra (1946) conducted biological studies of the vegetable mite *T. cucurbitae* and reported the association of the species with more than 50 host plants. Cagle (1946) conducted studies on the life history, mode of infestation and type of damage induced by the European red mite, *P. ulmi*. Blair and Groves (1952) traced the life cycle and development of *Metatetranychus ulmi*, the common red spider mite of fruit trees. Biology and epidemiology of *T. altheae* on hop plant were investigated by Lienk (1953). Iglinsky and Rainwater (1954) studied the life cycle of *T. desertorum* and *T. bimaculatus* and also prescribed chemicals for checking their spread.

The life history of *E. uncatus* was studied by Ubertalli (1955). Biology of the spider mite *T. atlanticus* was studied by Cagle (1956). Boyle (1957) explored the dissemination tactics of *T. telarius* and established the occurrence of wind drift in this species. Muller (1957) provided information on the morphology, biology and control of the hawthorn spider mite, *T. viennensis*. Parent and Bealieu (1957) conducted studies on the life cycle of the European red mite and the injuries caused by them to their host plants. Biological studies of *T. macdanieli* were made by Nielsen (1958) in Utah, which also helped to reveal that *Amblyseius fallacis* as well as some other predators of the mites could effectively check their population outbreak in the field in Ontario. Based on the observations on the effect of relative humidity on egg-laying, hatching and survival of spider mites, Boudreaux (1958) suggested that an increase in relative humidity would ensure a check in the population build up of spider mites. Though hatching process was not affected, the survival of newly emerged ones in moist atmosphere was negligible. The

developmental biology and bionomics of the tea red spider *O. coffeae* were studied by Das (1959). Beglyarov (1959) suggested seasonal application of acaricides for the effective control of *T. crataegi*, and made studies on the bionomics of this species. While studying the biology of the red spider mite, *T. cinnabarinus*, Srivastava and Mathur (1962) observed that the mite took 14.3 days to complete its development on castor during the month of January. The longevity of adult female and male was observed to be 8-14 and 1-4 days, respectively.

Biological studies carried out by Boudreaux (1963) on phytophagous mites established occurrence of arrhenotokous parthenogenesis in *Tetranychus* and *Panonychus*. The pest status of *Eotetranychus kankitus* on citrus trees was established by Ehara (1964) in the island of Osaki-Shimojima in Japan. Studies on the embryonic development of two spotted spider mite *T. urticae* at room temperature was carried out by Dittrich (1965) and the results of the studies further revealed the occurrence of successive divisions of the egg at an interval of 30 minutes. The author showed that the first 2 divisions were of holoblastic and equal type, followed by superficial cleavage. Butler (Jr.) and Abid (1965) studied the duration of development of *O. platani* under different seasonal conditions.

While studying the genetics of spider mites, Helle and Bollard (1967) performed karyokinetic analysis of 13 species and established the occurrence of thelytokous parthenogenesis in *T. horridus*. Helle (1967) confirmed that fertilization occurred during very early stage of the egg development in the two spotted spider mite. The effect of temperature and humidity on the development of the tea spider

mite *O. coffeae* was studied by Das and Das (1967) who reported that the optimum condition required for hatching was within a temperature range of 20°-30°C and R.H. range of 49-94%. Qureshi *et al*. (1969) analysed the developmental process and dispersal mechanism of *T. evansi* on *Solanum douglasii* at 23.3°C ± 1°C & 40-50% RH and reported 24-30 annual generations for the species. The durations of incubation period, larval, protonymphal and deutonymphal periods of the species averaged 65.2, 42.8, 42.7 and 64.2 hours respectively. Laing (1969) studied the life cycle of the two spotted spider mite under diurnal temperature cycle of 15°-28.3°C and established life tables for immatures of both male and female separately.

Westigard and Berry (1970) provided information on the life history and control of the yellow spider mite on pear in southern Oregon. Putman (1970a) recorded the threshold temperature for complete postovarial development and deposition of viable eggs of the European red mite *P. ulmi* to range from 9.2°-11.7°C and 10.7°-11.7°C respectively. The same author (1970b) extended his studies on the biological aspects of *P. ulmi*, the results of which disclosed that their mating sequences and sex ratio differed with respect to seasons. While studying the biology of the citrus red mite, Beavers and Hampton (1971) observed their mating behaviour, development and longevity of individuals on citrus leaves. Cone *et al.* (1971a) investigated the mating behaviour of *T. telarius* and detected the presence of sex pheromones in the species. Further, the authors (1971b) traced the time of onset of male attraction as well as the influence of temperature and humidity on the process. Subsequently, Saba (1971) studied the post-embryonic development of *T.*

yusti and observed that the species completed its development within 9-10 days at a temperature of 25.5°C ± 1°C and a relative humidity of 75%. The author succeeded to furnish data on the life table of the species and delineated its economic importance.

Penman and Cone (1972) analysed the influence of web on male response to quiescent female deutonymph of the two spotted spider mite. They found that webbing facilitated attraction by males. Banu and ChannaBasavanna (1972) conducted studies on the host range and biology of *E. orientalis* and further collected information on the natural enemies of the species in the field. Based on their observation on the biology of *T. neocaledonicus*, Soliman *et al.* (1973) provided life table for this mite. Hazan *et al*. (1973) traced the life history of carmine spider mite *T. cinnabarinus* at 4 constant temperatures between 19°C and 35°C and 6 relative humidities from 0% to saturation. The authors recorded highest fecundity at 24°C and 38% RH and lowest mortality at 30°C and 38% or 63% RH. Gupta *et al*. (1974) studied the rate of development, longevity and fecundity of *O. indicus* on 3 host plants *viz*. sugar cane, sorghum and maize at 5 constant temperatures of 25°, 27°, 30°, 32.5° and 35°C. It was found that maize was the best food and 30°C was the most favoured temperature because of the minimum time taken to complete the life cycle and high fecundity of both fertilized and unfertilized females. Life history and population dynamics of *T. tumidus* was worked out by Saba (1974) in Florida, who provided information on the host range of the species. Penman and Cone (1974), while studying the mating behaviour of the males of the

two spotted spider mite, investigated the role of web, tactile stimuli and female sex pheromone in attracting males to the quiescent female deutonymphs. Hazan *et al.* (1974) introduced new methods for the quantitative evaluation of the production of web and evaluated the influence of various environmental factors on the webbing activity of the carmine spider mite, *T. cinnabarinus*. Effect of webbing on the process of egg hatching of the mite was also investigated by the same authors (1975) in Israel. According to them removal of eggs from the webbing into which they were deposited reduced hatchability at humidities 0-38% or 100%. Tanigoshi *et al.* (1975) conducted studies on the biological development of the McDaniel spider mite, *T. mcdanieli* at constant temperatures. Apart from finding the optimum temperature for successful development of the mite (35 $\pm$ 2°C), they also provided life tables and analysed developmental curves for each stage of the mite. The first ever comprehensive book on mites injurious to economic plants was brought out by Jeppson *et al.* (1975) which is a valuable reference on all aspects of plant mites.

Jesioter and Zbignui (1976) studied the influence of host plants on the reproductive potential of the two spotted spider mite, *T. urticae*. Life history of the carmine spider mite was traced by Hessein (1977), who showed that the incubation period of the mite ranged from 3-8 days. Further, the author provided morphological descriptions of the life stages of the mite. Shih *et al.* (1976) gathered information on the biology of *T. urticae* and found that the duration of development from egg to adult required 7.5 days at 27 $\pm$ 1°C and 95$\pm$ 5%RH. The same authors charted a life table for the species. Lal (1977) undertook studies on the biology of *E. orientalis* on 2 host plants, *viz. Rauwolfia serpentina* and *Bauhinia variegata* under 2 different

temperatures of 28.64°C & 23.61°C and reported longer duration of development at lower temperature on both plants. He added that the life cycle was affected by temperature but not by the host plants. Simultaneously, Tan and Ward (1977) collected information on the rate of egg deposition by the females of *O. pratensis* at different stages of their ovipositional period. They recorded that the females of *O. pratensis* initiated oviposition on the 6^{th} day of adult emergence.

The effect of 3 different citrus species on the biology of the citrus brown mite, *E. orientalis* was investigated by Rasmy (1978) who recorded highest fecundity rate for the mites reared on sour orange and lowest for the ones reared on mandarine leaves. However, no marked variation in the developmental periods or in the pre-oviposition period was noted. Maity and Chakrabarti (1978) studied the influence of temperature and relative humidity on the postembryonic development of *P. citri* on *Carica papaya* at 23.6 $\pm$ 1°C & 64.5% RH, 26.7 $\pm$ 1°C & 51.5% RH and 30.6 $\pm$ 1°C & 48.7% RH and found 30.6 $\pm$ 1°C & 48.7% RH as the most favourable combination for the development of the mite. Further, an increase in the duration of incubation period was noted with decrease in temperature. Biological studies of *E. uncatus* on *B. variegata* were initiated by Lal and Mukharji (1978) at 26.6 to 22.47°C. The life cycle was completed in 8.01 days and 20.32 days at an average of the temperatures selected for the study. The effect of temperature and various humidity levels on the hatching of eggs in the two spotted spider mites was assessed by Ferro and Chapman (1979) and they concluded that high humidity and temperature inhibited the process. Ho and Lo (1979) also made studies on the

influence of temperature on the life history and population parameters of the above mite. A comparative study conducted by Saito (1979a) on the duration of life cycles of 3 species of tetranychids viz., *T. urticae*, *O. ununguis* and *P. citri* showed that *T. urticae* had a higher fecundity level and shorter duration of development.

While investigating the biology of *T. ludeni* on French beans, Puttaswamy and ChannaBasavanna (1980a) studied the influence of temperature and relative humidity on the oviposition and development of the mite. They recorded optimum conditions for the favourable development and maximum survival of eggs of the species to be between 32 $\pm$ 1ºC & 35 $\pm$ 1ºC and 65 $\pm$ 3% & 75 $\pm$ 3% RH. High humidity (95 $\pm$ 3% RH) reduced the egg producing capacity of adults irrespective of temperature ranges. The same authors (1980b) observed that females and males required 12.48 $\pm$ 0.16 days and 11.96 $\pm$ 0.38 days respectively to complete their life cycles. Oviposition periods of mated and unmated females were 1.54 $\pm$ 0.30 days and 1.43 $\pm$ 0.11 days respectively and they laid on an average 165.88 $\pm$ 47.04 eggs and 132.00 $\pm$ 28.54 eggs during their ovipositional periods of 22.83 $\pm$ 4.56 days and 27.41 $\pm$ 4.75 days. Further studies made by them (1980c) revealed the occurrence of competition between population of *T. neocaledonicus* and *T. ludeni* and further confirmed the latter species as the more competent one in colonizing new leaves. The seasonal history of *E. orientalis* and *E. uncatus* were recorded by Lal and Mukharji (1980). They found that high temperature with low humidity and brighter sunny days favoured *E. orientalis*, while moderate temperature with moderate to high humidity favoured development of *E. uncatus*. Jesioter (1980) recorded the influence of different host plants on the reproductive potential of *T. urticae*.

Herbert (1981a) gathered information on the threshold temperature (10.6ºC) for development of *P. ulmi* and found that the duration of development from egg to adult required 31.2, 20.5 and 14 days for females and 21.9, 19.6 and 12.8 days for males at 15 º, 18 º and 21 ºC respectively. The same author (1981b) extended his work to *T. urticae* and charted a life table for the species. The durations of development at the respective temperatures were 141.3, 152.3 and 139.8 days for females and 134.2, 144.7 and 135.2 days for males. Studies carried out by Potter (1981) on the agonistic behaviour of the male spider mite proved the apparent involvement of chemosensory cues in the mediation of male behaviour. Kumar and Prasad (1981) collected data on the survival and development of *T. fijiensis* on citrus reticulate leaves of different ages. Ray and Rai (1981) worked out the biology of *T. neocaledonicus* on okra and revealed that pre-oviposition period lasted for 12 hours and eggs were laid singly on both surface of leaves. Larval and protonymphal periods lasted for 1 and 1.5-2 days, respectively. They further calculated that life cycle of the mite was completed in 4-5 days which often extended to 8 days. Ray and Rai (1981) further reported that in laboratory condition the total life cycle of *T. neocaledonicus* was completed in about 6-8 days in female and 4.5-6 days in males. Life span of adult female was 10-12 days and that of male was 8-10 days. Puttaswamy and ChannaBasavanna (1981a) recorded the seasonal incidence of *T. ludeni* on brinjal and reported that heavy rain washed off the active stages of the mite. Further, increase in population was associated with periods of less rainfall, lower RH and higher mean temperature. The influence of 6 host plants on the development, fecundity and longevity of *T. ludeni* was studied by Puttaswamy and

ChannaBasavanna (1981b) and they recorded shortest developmental time for the species on brinjal (9.24 days), maximum fecundity on okra (149.40 eggs) & French bean (148.90 eggs) and highest longevity on South American cucurbit (26.91 days) & French bean (21.08 days). Influence of 3 species of *Amaranthus* plants *viz., A. spinosus, A. tricolor* and *A. viridis* on the biology of *T. neocaledonicus* was studied by the same authors (1981c) at temperatures ranging from 23°-26°C and relative humidity of 74 – 81% and recorded significantly longer duration of development on *A. tricolor* (11.81 days), higher longevity (27.69 days) and fecundity (147.42 eggs) on *A. viridis.* The authors concluded that *A. spinosus* and *A. viridis* were the most suitable hosts preferred by the mite.

The above authors (1982b) made a comparative study on the life history of *T. neocaledonicus* on different hosts such as mulberry, castor, tapioca and *Amaranthus viridis*. It was observed that duration of development from egg to adult was longer on tapioca (12.11 days) than that of castor (10.48 days), *A. viridis* (10.20 days) and mulberry (10.14 days). Studies on ovipositional preference, host range and seasonal incidence of *E. orientalis* on 45 plants made by Dhooria (1982) enabled to record significantly high oviposition along the mid rib region and dorsal surface of leaf lamina and the least on the ventral surface in all hosts. The life histories of *T. urticae, T. pacificus* and *T. turkestani* were studied at 5 constant temperatures ranging from 15.5° to 29.4°C on cotton by Carey and Bradley (1982) and life tables were constructed accordingly from the survivorship and fecundity data collected at 23.8 and 29.4°C. Average developmental time ranged from 25.8 to 29 days at 15.5°C and from 6.1 to 6.7 days at 29.4°C for all the 3 species. An ecological study

of the influence of temperature, relative humidity and rainfall on the population of *T. neocaledonicus, E. orientalis, T. cinnabarinus* and a the thrip species, *Retithrips syriacus* on cassava carried out by Lal (1982) reflected a significant correlation of population increase with decrease in RH and non-significant correlation with increase in temperature. Plourde *et al.* (1983) studied the feeding effect of *P. ulmi* on chlorophyll content of apple leaves and found significant decrease in chlorophyll ($p<0.05$) with time in the presence of mites. The influence of host plants and temperature on the population build-up of *E. orientalis* was assessed by Salmon (1983). Dhooria and Butani (1983) observed peak population of *E. orientalis* on orange during May-June & September and there was negligible population during December to March. Further, they observed that the mite population positively correlated with high temperature and low relative humidity. While studying the effect of constant temperature, relative humidity and rainfall on development and survival of the spruce spider mite, *O. ununguis* on Fraser fir seedlings, *Abies fraseri* Boyne and Hain (1983) observed excellent response of the mite to temperatures averaging 26ºC and to relative humidity levels approaching 50 to 60%. Further, the authors added that simulated rainfall proved to be a factor limiting population density of the mite. The development, oviposition and mortality rates for Banks grass mite, *O. pratensis* on blue grama grass, *Bouteloua gracilis* were measured by Congdon and Logan (1983) and a complete set of life tables was charted for temperatures, 19º, 25º and 31ºC. Mallik and ChannaBasavanna (1983) recorded the respective durations of egg, larva, protonymph and deutonymph of *T. ludeni* on French bean as 106h, 32.5h, 34.5h and 49h. Based on the results of biological

studies of pecan leaf scorch mite, *E. hicoriae*, Jackson *et al.* (1983) suggested temperatures, 18.3° and 35°C as most unfavourable, inhibiting hatching and accelerating mortality of the immature stages.

The varietal preference of *T. neocaledonicus* on 4 varieties of brinjal in Rajasthan was investigated by Sharma and Kushwaha (1984) who observed high incidence of the mite on Black beauty variety, though no significant difference in oviposition or life stages could be recorded. Studies conducted by Dhooria (1985) on the development of *E. orientalis* on 4 host plants revealed that mean durations of larval and nymphal stages were higher on dorsal surface of young leaves followed by that on dorsal surface of old leaves in all the host plants. In terms of fecundity and longevity, castor proved to be the most suitable host followed by lime and French bean while mandarin proved to be the least suitable one for the mite. The effect of infestation by red spider mites on cotton was evaluated by Murega and Khaemba (1985). The authors reflected the potential severity of mite damage measured in terms of decline in vegetative growth, number and surface area of leaves (68.18%), seed development (36.67%) and yield (46.93%) of the plant. Stone (1986) reported the potential of *T. lintearius* for the regulation of the weed *Ulex* species. Simultaneously, Young *et al.* (1986) investigated the role of females of tetranychid mites in the regulation of sex ratio among the progenies. Pande and Sharma (1986) studied the biology of *T. neocaledonicus* on cucurbits at 5 different temperatures and found that the mite did not survive at a temperature beyond 37°C. While studying the biology of *T. urticae*, Atwa *et al*. (1987) illustrated the morphological features of the developmental stages of the species. Gotoh (1987)

studied the life history parameters of *P. ulmi* and recorded a net reproductive rate of 49.01 for the species. Effect of temperature and sperm supply on the reproductive potential of *T. evansi* was studied by Moraes and McMurtry (1987). According to Ali and Sarkar (1987), the development of *T. bioculatus* from egg to adult was completed in 15 days and longevity of adult male and female averaged 18.3 and 20.7 days respectively.

Chiavegato (1988) traced the biology of *P. citri* on the leaves and fruits of lemon and showed that the species preferred leaves than fruits for its development. In a review on the relationship between environmental variables and population dynamics of tetranychid mites, Holtzer *et al.* (1988) provided information on the direct and indirect effects of microenvironment on population dynamics. Simultaneously, Smitley and Kennedy (1988) analysed the mechanism of aerial dispersal of *T. urticae* and charted the influence of weather conditions on the process. The annual life cycle of the spider mite, *E. dissectus* on apple was traced by Gotoh (1988).

Manjunatha and Puttaswamy (1989) studied the biology of *T. neocaledonicus* in green house condition and found that the females and males of this species completed their life cycle in 10.44 ± 0.97 days and 10.19 ± 0.84 days respectively on French bean crop. Sirsikar and Nagabhushanam (1989) studied the biology of *O. tylus* and found that the mite required 9.90 ± 0.45 days to complete its development. Studies carried out by Krainacker and Carey (1989) on the reproductive limits of *T. urticae* revealed the occurrence of 3 phases of male

reproduction in this species. The authors further showed that the number of sperms transferred during each time of insemination was a limiting factor for higher male reproduction output. Shanks and Doss (1989) investigated the seasonal fluctuation in the population density of the two spotted spider mite on strawberry. The biology of *E. hicoriae* on guava was studied by Mallikarjunappa and Nageshchandra (1989). Dhooria and Sagar (1989) conducted a comparative study on the biology of *T. cinnabarinus* on 4 different varieties of Japanese mint and reported that the larval and nymphal development could be completed in 6 days. Further, they recorded the durations of pre-oviposition (1-3 days), ovi-position (2-17 days) and post-oviposition periods (0-6 days) of the species. Longevity of adult female ranged from 3-19 days while fecundity ranged from 0-77 eggs.

While studying the embryonic development of *T. cinnabarinus*, Rosero *et al.* (1990) observed that the development required 144 hours for completion. The influence of 5 temperatures ranging from 0.5° to 15 $\pm$ 0.5°C on the life history parameters of the yellow grape vine mite, *E. carpini* was studied by Bonato *et al.* (1990). With an increase in temperature, a subsequent decrease in total development time from 28.4 to 9.7 days and an increase in mean oviposition (3.2 eggs/day) were observed in the species. Goodwin (1990) investigated the seasonal abundance and control measures of spider mites infesting commercial strawberries in coastal New South Wales. Donahue and McPherson (1990) studied the ovipositional response of *T. urticae* against treatment of pyrethroids on soybean. Biology and control of *O. mangiferus* on *Terminalia* species were studied by Neelu Nangia *et al.* (1990).

Childers *et al.* (1991) completed studies on the biology and life table of *E. banksi* on grape fruit leaves at different temperatures. Beitia and Vivas (1991) studied the differences in the development of *P. citri* on the leaves of several citrus species. Das and Gupta (1991) made observation on the biology of the citrus mite, *E. orientalis* under field conditions in West Bengal. Manjunatha *et al.* (1991) studied the reproductive biology of *T. neocaledonicus* and observed that the biology of the mite differed from plant to plant in terms of longevity.

Ansari and Pawar (1992) carried out biological studies of *T. ludeni*, an inhabitant of water hyacinth. The development and induction of diapause in the Kanzawa spider mite, *T. kanzawai* were described by Fujibayashi and Sekita (1993). Induction of diapause in the carmine spider mite, *T. cinnabarinus* was studied by Wu and Jing (1993). Bali (1993) made preliminary investigations on the demography of the Pacific spider mite, *T. pacificus*. Wilson (1994) studied the effect of plant quality on the life history parameters of *T. urticae*. Pringle *et al.* (1994) conducted comparative studies on the developmental biology of carmine and green forms of *T. urticae*. Biology of *T. urticae* on some resistant plants was studied by Amer and Rasmy (1994). Simultaneously, a detailed investigation into the response of males of *T.* urticae to females was undertaken by Rasmy and Hussein (1994). According to the authors, mating adversely affected the release of sex pheromones and also induced a distinct inhibition in male response. Studies on the relationship of *Schizotetranychus cajani* population with temperature, relative humidity and rainfall were made by Karmakar *et al.* (1994) and they recorded maximum mite population at 26.95 ºC, 49.55% RH and 2.2mm rainfall.

Nandagopal and Gedia (1995) studied the biology of *T. cinnabarinus* on groundnut and the durations recorded for larva, protonymph and deutonymph of male and female respectively were 1.09, 1.11 & 3.17 days and 1.12, 1.08 & 5.04 days. Copulation competition of males of *T. urticae* and *T. kanzawai* with conspecific and heterospecific females and their isolation mechanism were investigated by Shih and Shiue (1995) and they revealed that these 2 ecologically homologous spider mites performed different inter- and intra-specific mating behaviour to have their advantage in competition. Collins and Margolies (1995) made significant observation on the effect of interspecific mating on sex ratios in the two spotted spider mite, *T. urticae* and the Banks grass mite, *O. pratensis.*

Moraes *et al.* (1995) studied the development of *Mononychellus tanajoa* on alternative plant hosts in North Eastern Brazil and found that the mite performed better on cassava. Though it developed to the adult stage, it failed to oviposit on common bean. Bonato *et al.* (1995a) investigated the effect of 5 constant temperatures, 16º, 22º, 26º, 31º and 36 ºC on biological and demographic parameters of *M. progresivus* and *O. gossypii* infesting cassava and found that both the species could be successfully reared at a temperature range of 22-36 ºC. While shortest development time was obtained at 31 ºC; 7.2 days for *M. progresivus* and 8.2 days for *O. gossypii*, maximum fecundity was recorded at 26 ºC with 42.1 and 36.3 eggs respectively for both the species. Further studies by Bonato *et al.* (1995b) on the influence of relative humidity on life history parameters of the same mites revealed that low (30% RH) and high (90% RH) air humidity had a negative effect on the life history traits of both species. While conducting studies on the survival, fecundity

and longevity of *M. progresivus* and *O. gossypii* infesting cassava, Bonato and Gutierrez (1996) observed that unmated females of both the species laid fewer eggs but lived longer than the mated ones. Aponte and McMurtry (1997) investigated the biology, life table and mating behaviour of *O. perseae* at 4 different temperatures (15º, 20º, 25º and 30ºC) and found that the net reproduction rate was highest at 25ºC. By exposing (0-16 hrs) life stages of *T. urticae* to low temperatures (0º, -5º and -10ºC) followed by rearing at 20ºC, Abukhashim and Luff (1997) revealed the negative effect of the treatment on juvenile survivorship, fecundity and longevity of the surviving adults.

Studies on the development, survivorship and reproduction of the tumid spider mite, *T. tumidus* on coconut palm were made at 6 constant temperatures (10º, 15º, 20º, 25º, 30º and 35ºC) by Liu and Tsai (1998), of which the optimum temperature for population growth was 30ºC. Salazar *et al.* (1998) conducted studies on the biology, phenology, life cycle, distribution and predators of *T. urticae* infesting raspberry crops and found that the population of this mite increased in the summer months, especially in February. Akira *et al.* (1998) studied the development and population increase of *T. urticae* on different varieties of Chrysanthemum. The duration of development, hatching rate and fecundity of *T. kanzawai* were investigated by Huaguo *et al.* (1998) at constant temperature-humidity conditions at 15ºC & 80% RH, 20ºC & 75% RH, 25ºC & 70% RH, 30ºC & 65% RH and 35ºC & 60% RH. The optimal temperature for their development was found to be within a range of 25-30ºC. Studies on the host preference of *T. urticae* made by Sarkar *et al.* (1998) on 5 host plants indicated the suitability of all the hosts for feeding and

breeding. While fastest development and longer longevity was recorded on French bean, higher fecundity on little gourd followed by cow pea, okra and French bean. However, brinjal was least preferred among the host plants.

Bonato (1999) conducted studies on the effect of 4 constant temperatures (21º, 26º, 31º and 36ºC) on survival and duration of developmental stages, fecundity, longevity of females, sex ratio and demographic parameters of *T. evansi*. The author recorded shortest developmental time (6.3 days) at 36ºC, maximum fecundity (123.3 eggs) at 31ºC and optimal temperature for population growth at 34ºC. The longevity and fecundity of inseminated and uninseminated females of *T. fijiensis*, *T. lambi*, *T. marianae* and *T. neocaledonicus* were investigated by Bonato and Gutierrez (1999). They found that the uninseminated females laid fewer eggs but lived longer than inseminated females. Allam *et al.* (1999) studied the influence of host plants on the development of *T. urticae* and the consequences of its infestation in citrus fields. The authors found that changes of hosts in *T. urticae* were associated with notorious loss of reproduction potentialities.

Gotoh *et al.* (1999) conducted studies on the reproductive compatibility of the two spotted spider mite infested with *Wolbachia* and found that the reproductive incompatibility was due to nuclear genes rather than the presence of *Wolbachia*. Studies on biology of the red spider mite *O. coffeae* at combinations of 2 constant temperature-humidities *viz*., 26ºC & 71.6% RH and 33.2ºC & 79.85% RH conducted by Saha *et al.* (1999) revealed that life cycle took shorter time (8.88 $\pm$ 0.60 days) with higher fecundity at 33.2ºC & 79.85% RH and it was longest (13.23 $\pm$ 0.61

days) with lowest fecundity at 26ºC & 71.60% RH. On the contrary, longevity of both male (10.53 ± 0.45 days) and female (21.35 ± 0.62 days) was shortest at 33.2ºC & 79.85% RH and longest (male: 12.43 ± 0.24 days & female 25.63 ± 0.63 days) at 26ºC & 71.60% RH. Nandagopal and Gedia (1999) made significant observation on the biology of the white spider mite *T. hypogaea*, a pest of groundnut and recorded 10.15 and 11.15 days respectively as the total durations for the life cycles of males and females. The effect of different levels of nitrogen, phosphorus and potassium on the biological activity of *T. urticae* maintained on cultivated cotton in a nutritive solution was studied by Trinidade and Chiavegato (1999). Saikia *et al.* (1999) studied the biology of *O. coffeae* and found that the mite could breed throughout the year and its life cycle was shorter, during April and May. Males were short lived (13.2 days) and attained maturity earlier than females.

The threshold temperature for post diapause development in over wintering eggs of *P. ulmi*, was determined by Broufas and Koveos (2000) after exposing the eggs to various temperatures *viz*., 5º, 10º, 15º, 20º and 25º C. The mean number of days needed for 50% hatch in each temperature was recorded as > 120, 44.5, 22.0, 14.5 and 8.1 days respectively. Bonato *et al.* (2000) studied the suitability of common bean, soybean and peanut as food substrates for the development of *T. ogmophallus* and suggested that the mite performed well on common bean, although it developed and reproduced on soybean and peanut. A comparison of the susceptibility of seven cultivars of avocado to the persea mite, *O. perseae* was made by Kerguelen and Hoddle (2000). According to the authors, the major factor

determining the susceptibility of avocado cultivars to *O. perseae* might be the nutritional quality of leaves.

Yanagida *et al.* (2001) observed the oviposition behaviour of *Yezonychus sapporensis* and correlated it as a predator avoidance tactic of the mite. The effect of aqueous extracts of neem, clove and chinaberry, on survival of eggs, larvae, nymphs and adult females of the cassava green mite, *M. tanajoa* was studied by Gon Calves *et al.* (2001) and the results of their study showed that neem extracts at concentrations higher than 2.5% could be promising for *M. tanajoa* control. Studies carried out by Bounfour and Tanigoshi (2001) on the effect of temperature on the development and demographic parameters of *T. urticae* and *E. carpini borealis* revealed that *T. urticae* required shorter developmental time when compared to *E. carpini borealis*. Gotoh and Nagata (2001) studied the developmental and reproductive traits of *O. coffeae* collected from tea on Okinawa Island. The threshold temperature for development was found to be 10ºC and a marked decline in the developmental time with increase in temperature was observed. While investigating the behaviour and life history of *S. tenuinidus and S. bambusae* infesting bamboo leaves in China, Zhang *et al*. (2001b) recorded the total absence of deutonymphal stage in the males of both the species. They recorded 14 and 21 days respectively as the total durations for the life cycle of S. *tenuinidus* at 28º-30ºC and 24º-26ºC. Further, they recorded significantly longer developmental time in females of *S. bambusae* at 24º-26ºC.

Thongtab *et al.* (2002) explored the bionomics of the citrus yellow mite, *E. cendani* on 5 different host plants at a temperature of 28 ± 1ºC and relative humidity of 58 ± 5%. The respective durations of egg, larva and nymphal stages ranged 4.9–5.8, 1.9-3, 1.9-2.6 and 1.8-2.7 days. Observations made by Fu *et al.* (2002) on the development, survivorship and reproduction of *T. piercei* reared on banana leaves at 16º, 20º, 24º, 28º, 32º and 36ºC enabled to record 25.8º- 32ºC as the most favourable temperature range for the species. Sakunwarin *et al.* (2003) traced the biology and life table of the cassava mite, *T. truncatus* and they suggested that the species could develop and reproduce within a wide range of temperatures. Of the various temperatures studied, the range 24º-31ºC appeared as the most favourable one for the development, survival and reproduction of the species. The temperature based life history and life table parameters of the Texas citrus mite, *E. banksi* on orange were studied by Badii *et al.* (2003). The durations of immature stages were observed to decline with rising temperature up to 32.5 ºC, and increased at 35ºC. The authors suggested a temperature range of 28º - 31 ºC to be optimal for the development of the mite. Gotoh *et al.* (2003) investigated the life history parameters of *P. ulmi, P. mori, P. bambusicola*, *P. citri, P. thelytokus* and *P. osmanthi* at 25ºC. The total developmental durations from egg to adult in the nine strains were found to be 11.4–12.3 days for females and 10.4–12.1 days for males. Further they recorded significantly longer developmental time in females of *P. ulmi* (N), *P. ulmi* (D), *P. osmanthi* (Rn) and *P. citri* strains. Studies on the developmental duration and reproduction rate of the hawthorn spider mite *Amphitetranychus viennensis* were carried out on 5 different apple cultivars at 25ºC and 65± 10% RH by Kasap (2003).

The respective durations of development of females and males varied from 7.4–18.8 days at 35 º and 20.8 ºC and 7.9–17.2 days at 30 º and 20.8 ºC.

A detailed investigation on the biology of *A. viennensis* on black cherry, *Prunus serotina* at 23 ± 1 ºC and 75 ± 5% RH was made by Golpayegani *et al.* (2004) and they reported that the mites took 16.18 and 11.93 days respectively for the development of females and males. The respective durations of pre-oviposition, oviposition and post-oviposition periods were 2.25, 4.91 and 1.12 days and the mites produced 3 generations per year in the laboratory. Gotoh *et al.* (2004) evaluated the potential severity of *T. puearicola* as a pest by determining its development, survivorship and life-history parameters on kidney bean. They found that at temperatures between 15º and 30ºC more than 89% eggs hatched and at 25ºC, females laid an average of 125 eggs during its mean oviposition period. Further, the intrinsic rate of natural increase (r_m) was 0.102 at 15ºC, 0.179 at 20ºC, 0.299 at 25ºC and 0.377 at 30ºC; the second highest r_m-value among tetranychid mites reported so far at 25ºC. Liu *et al.* (2004) made a detailed study on the temperature-dependent development and reproduction of the spider mite, *S. bambusae* on different age groups of bamboo. The survival and fecundity of *S. bambusae* on the detached leaves of the moso bamboo indicated that 3 year old bamboo was disadvantageous for the experimental population increase of *S. bambusae.*

Kasap (2004) traced the developmental duration and reproduction rate of the two spotted spider mite, *T. urticae* on 5 different apple cultivars at 25ºC and 65 ± 10% RH. The effect of different temperatures on the development and reproduction

of *T. abaceae* infesting *Musa* was studied by Geraldo *et al.* (2004). The host-plant mediated impact of simulated acid rain (pH 3, 3.5, 4, 5.6 and 6.8) on the behaviour, development and reproduction of carmine spider mite, *T. cinnabarinus*, were evaluated at 25ºC by Wang *et al*. (2004). They found that the mites feeding on acid rain-treated leaves (pH 3-5.6) had significantly greater reproductive potential and longevity than those feeding on deionized water-treated leaves. While conducting biological studies of the same mite on *Solanum melongena* in different seasons, Biswas *et al.* (2004) observed negative impact of temperature on hatching, duration of development and reproduction though no significant influence of relative humidity was noted. Studies on population build up of European red mite, *P. ulmi* made by Sangita and Bhardwaj (2004) indicated that increase in mite population could be achieved by a subsequent increase in temperature and relative humidity to 20.85-22.85°C and 72.8-90.4%RH respectively, which proved favourable for the mite.

Laboratory population based life table parameters of *A. viennensis* were studied at 15º, 20º, 25º, 30º and 35°C by Ji *et al.* (2005a). The highest mean number of eggs (157.40 eggs/female), with the highest daily oviposition rate (6.49 eggs/female/day), was observed at 35°C while the lowest daily oviposition rate (1.80 eggs/female/day) was observed at 15°C with a total of 99.30 eggs/female. The longevity (32.3 $\pm$ 1.1 days) was the lowest at 35°C and highest (105.6 $\pm$ 73.4 days) at 15°C. The greatest daily oviposition was 17 eggs/female/day at 35°C. The same authors (2005b) conducted similar studies on *O. biharensis* at same constant temperatures and recorded lowest longevity (19 $\pm$ 3.11 days) and highest fecundity

(71.6 eggs/female) at 35°C. While at 15°C, longevity was highest (98.9 ± 20.77 days) and fecundity was lowest. The authors concluded that higher temperature (35°C) favoured population growth in *O. biharensis.* Simultaneously, Chen *et al.* (2005) explored the bionomics of *O. biharensis* on 4 different cultivars of litchi and found that Baitangying litchi was the most suitable host plant and Feizixiao litchi, the most unsuitable host plant for *O. biharensis*. Male preference for virgin and mated females of *T. kanzawai* was tested by Oku *et al.* (2005) under dual choice conditions on kidney bean leaves and suggested the probability of the use of odours by males to discriminate the mating status of females. They added that the males preferred virgin females who were more gregarious and remained on the leaves for longer time than the mated ones so as to increase the mating opportunities.

Ghoshal *et al.* (2006) reported the duration of different developmental stages of *T. neocaledonicus* on a mangrove plant, *Rhizophora mucronata* at 30ºC as 3.33 ± 0.23 days, 3.25 ± 0.22 days, 3.8 ± 0.17 days and 3.6 ± 0.15 days respectively for egg, larva, protonymph and deutonymph. The total duration, fecundity, longevity and sex ratio (male: female) were 13.5 ± 0.15 days, 39.8 ± 0.85 eggs, 13.2 ± 0.23 days and 1: 1.65, respectively. Noronha (2006) made significant observation on the biology of *T. marianae*, a pest of passion fruit at 25 ± 1 ºC and 80 ± 10 % RH and recorded 10.73 ± 0.18 days as the total duration of development from the egg to the adult stage. Further, the mean female longevity and the daily mean oviposition were 24.53 days and 3.69 eggs/female respectively. The effects of two leafy vegetable crops, *A. cruentus* and night shade, *Solanum macrocarpon* on the development and demographic parameters of *T. ludeni* at 27 ºC and 70 ± 10 % RH were examined by

Adango *et al.* (2006). They observed that *T. ludeni* performed better on *S. macrocarpon* than on *A. cruentus* in terms of net reproductive rates and adult survival rates. Czajkowska and Puchalska (2006) showed lack of acceptance of European larch and sweet chestnut as host plants for spruce spider mite, *O. ununguis*. They recorded a maximum of 7 days of female life on both the hosts and termination of life at the nymphal stages on larch.

Haque *et al.* (2007) conducted studies on the duration of development of red spider mite, *O. coffeae* infesting rose and recorded shortest and highest durations as 5.3 $\pm$ 0.16 days at 30.28 ºC & 70% RH and 12.91 $\pm$ 0.21 days at 19.8 ºC & 75.41% RH respectively. The authors added that temperature exerted significant effect on all the developmental stages except deutonymph while the relative humidity had no significant effect except deutonymph. Biological studies of the vegetable mite *T. neocaledonicus* conducted by Sangeetha and Ramani (2007a) enabled to add a new host *Moringa oleifera* to the existing host range of the mite. The total duration of development of sexual males, sexual females and parthenogenetic males were 9.5 $\pm$ 0 days, 10.9 $\pm$ 0.15 days and 8.875 $\pm$ 0.04 days respectively. The same authors (2007b) recorded significant loss ($p<0.01$) in chlorophyll content of *M. oleifera* leaves due to infestation by *T. neocaledonicus* regardless of the developmental stages of the mite. Fecundity of *T. neocaledonicus* on *M. oleifera* was evaluated by Sangeetha *et al.* (2007). They found that the mite deposited 26.7 $\pm$ 0.63 eggs within an average oviposition period of 6 days at 25ºC and 80% RH.

Further, the authors (2008a) made studies on the embryonic development of *T. neocaledonicus* infesting *M. oleifera* through *in situ* examination of eggs in successive days of incubation and provided data on the sequence of events involved. The effect of temperature and relative humidity on the oviposition of *T. neocaledonicus* was also studied by the above authors (2008b) under 3 constant temperature-humidity combinations of 34 ± 1ºC & 50 ± 5%RH, 30 ± 1ºC & 40 ± 5%RH and 25 ± 1ºC & 80 ± 5%RH. Shortest pre-oviposition period (1.5 ± 0.12 days) was noted at 34 ± 1ºC & 50 ± 5%RH and highest at 25 ± 1ºC & 80 ± 5%RH (1.9 ± 0.07 days). Humidity though had little influence on the pre-oviposition and post-oviposition periods, higher humidity proved to have negative impact on the egg laying capacity as shown by adult females. A decrease in the duration of oviposition period was recorded at low temperatures and higher humidity. Vasquez *et al.* (2008) studied the biology of the avocado brown mite *O. punicae* on six grapevine cultivars *viz.*, Tucupita, Gillanueva, Red Globe, Sirah, Sauvignon and Chenin Blanc at 27 ± 2ºC & 80 ± 5%RH. They recorded relatively high fecundity on Tucupita leaves (2.8 eggs/female/day) during 11.4 oviposition days and low fecundity on Sirah and Gillanueva leaves, with 0.9 and 1.8 eggs/female/day during 7.9 and 6.7 days, respectively.

The reproductive behaviour of *T. neocaledonicus* was closely observed in the laboratory on *M. oleifera* leaves by Sangeetha and Ramani (2009) at 34 ± 1ºC & 50 ± 5%RH and the authors concluded that the process followed the basic pattern as studied with other known tetranychid mites.

Review

The objective of the present study was to obtain a better understanding of the biology of 5 important spider mite species on different vegetable crops and at different temperature-humidity conditions with a perspective to develop the best IPM programme in future.

a. Host plants surveyed

The present survey was carried out with an intention to study the tetranychid mite fauna associated with 40 species of economically important plants, especially vegetable crops belonging to 36 genera and 22 families cultivated in agricultural fields, home yards and kitchen gardens in different localities covering 6 districts of Kerala *viz.*, Malappuram, Kozhikode, Kannur, Wayanad, Palakkad and Thrissur. A brief and concise account of the plants surveyed (Table I) would be more befitting in depicting the nature of the plants surveyed and their importance. These plants were selected for the study owing to their uniform presence throughout the state coupled with their nutritional importance to man and also the extensive degree of visible damage caused by the attack of mites on them.

As depicted above, the current investigation was undertaken to unravel the biological parameters of a few common and dominant species of spider mites infesting vegetable crops of Kerala. On par with the objectives of the proposed work, the study also was extended to record an account of the influence of 3

different temperature and relative humidity conditions on the life history parameters of the mites and the nature and extent of damage caused to the host plants. Hence selection of the plant was done duly considering its local availability, supreme economic status to mankind as well as the intensity of mite infestation on them.

1. *Moringa oleifera* Lam

M. oleifera, a representative of the family Moringaceae is known by different names, viz., ben-oil tree, horse-radish tree and muringa, a culinary triumph in Kerala menu. Moringa tree grows in several sub-desert and tropical areas around the world. It has amazing health properties as it is packed with vitamins (A, B and C), minerals (calcium, iron and potassium) and proteins essential for growth (Freiberger *et al.*, 1998). Even the humble little leaves of this tree serve as a powerhouse of nutrients. It is used as an antibiotic and for thousands of years it has been used to treat dehydration, as a preventive against malnutrition. Further, it aids in fighting against a number of ailments and diseases. Excellent oil is derived from its seeds, which is used as cooking oil and for lubrication of delicate mechanisms. In spite of the ubiquitous nature of the tree, very little quantum of research has been carried out so far to save the tree from invasion of pests that affect its life and productivity. This prompted to undertake the present study on the biological aspects of one of the major mite pest infesting the tree viz., *E. orientalis* and also to assess the damage potential of the above species.

2. *Manihot esculenta* L.

Cassava (*M. esculenta*) which belongs to the family Euphorbiaceae is a robust productive starchy root crop that is grown clonally almost entirely within the tropics, grown chiefly as a food. But it is also an important animal feed, and it has several significant industrial uses. Cassava is a perennial crop, originated in Brazil with Central America and introduced to Sri Lanka in the Dutch regime. Since then, cassava stands out in the country as the most important source of energy for the calorie deficient low-income population strata. But from the recent past it has now become a major horticultural export commodity, earning foreign exchange. Cassava roots combine high energy and high levels of some vitamins, minerals and dietary fibre. The edible green leaves of cassava are a good source of protein, vitamins and minerals and are often used to augment the rural diet. Like *M. oleifera*, this particular plant proved to be a potential host for the successful establishment of *O. biharensis* throughout the year.

3. *Amaranthus tricolor* L.

Amaranthus, collectively known as amaranth, is a cosmopolitan genus of rapidly-growing annual herbs noted for its brilliantly coloured foliage, variegated in shades of red, green, or yellow. Although several species are often considered as weeds, amaranths are valued world wide as leafy vegetables and ornamentals. The red spinach, *A. tricolor* belonging to family Amaranthaceae is an annual, broad-leaved, erect herb, growing up to 1.25m high and is cultivated in Asia for its edible leaves and seed. The simple (often purplish) leaves of spinach are used either raw or in its steamed form in the preparation of salads, soups and stews. The leaves are rich

in proteins (3.5%), carbohydrates (6.6%), minerals (calcium, iron, magnesium, phosphorus, potassium, zinc, copper and manganese) and vitamins (vitamin A, vitamin B_1, B_6, vitamin C, riboflavin and foliate). The leaves owing to their medicinal value are also used against external inflammation, diuretics (treatment for bladder distress) and to control haemorrhage following abortion. The whole plant is known for its astringent property and a decoction of old plants when taken internally improves vision and strengthens the liver. Leaves of *A. tricolor* showed signs of heavy infestation of the vegetable mite, *T. neocaledonicus* and therefore the plant was duly considered for regular collection for biological studies.

4. *Vigna unguiculata* (L.) Walp.

V. unguiculata or the cowpea, a member of the family Fabaceae, is one of the most important food legume crop in the semi-arid tropics covering Asia, Africa, southern Europe and America. It is a herbaceous, climbing annual growing to a height of 15-80 cm**.** Being a drought tolerant and warm weather crop, cowpea is well-adapted to a wide range of soils and pH thereby making it compatible as an intercrop with maize, sorghum, sugarcane, cotton and so on. It also has the ability to fix atmospheric nitrogen through its root nodules thereby adding to soil fertility. *V. unguiculata* is one of the most important tropical multi-purpose legumes**,** cultivated for its seeds (shelled green or dried), pods, leaves that are consumed as green vegetables, grain, forage, hay, silage and green manure. The edible pods are 10-23 cm long with 10-15 seeds/pod. The seeds, pods and tender shoot apices typically contain proteins, fats, carbohydrates, fibers, minerals (calcium, phosphorous, iron,

sodium and potassium) and vitamins (A, B-thiamine, riboflavin, niacin and C) and are therefore a potential source of human nutrition. Cowpea seeds are believed to be medicinal to many tribes and are prescribed for treatment of sick children. Considering the nutritive value of the plant, ease of establishment and the infestation by dense populations of *T. neocaledonicus* on it throughout the year, studies on the biology of the vegetable mite were initiated on cowpea.

5. *Carica papaya* L.

Papaya (*C. papaya*), of the family Caricaceae, is a large tree-like plant with a single stem growing from 5 to 10 meters tall, with spirally arranged leaves confined to the top of the trunk. The lower trunk is conspicuously scarred where leaves and fruit were borne. The leaves are large, 50-70 cm diameter, deeply palmately lobed with 7 lobes. Originally from southern Mexico, Central America and northern South America, the papaya is now cultivated in most countries with a tropical climate including India. The ripe papaya fruit is usually eaten raw without the skin or seeds. The unripe green fruit is often cooked as curries, salads and stews and the young leaves are steamed and eaten like spinach. The black seeds are also edible and are sometimes used as a substitute for black pepper. The nutritive values of papaya include carbohydrates, fats, proteins, vitamins (A, B_1, B_2, B_3, B_6 and C) and minerals (calcium, iron, magnesium, phosphorus, potassium and sodium). Green papaya fruit and the tree's latex are rich in an enzyme called papain, a protease which is useful in tenderising meat and other proteins. Its ability to break down tough meat fibers was utilized for thousands of years as a component in powdered

meat tenderizers and is also marketed in tablet form to treat digestive disorders. Papain ointment commonly made from fermented papaya flesh, is also popular as a topical application in the treatment of cuts, rashes, stings, sores and burns.. Apart from its nutritive value, papaya has a quantum of medical applications which include the analgesic properties of leaves and roots and anti-inflammatory, antihelmintic and anti-fungal properties of seeds. Further, the mature fruits are used widely in treating ringworm, green fruits in treating high blood pressure, leaves as heart tonic and leaves and seeds in treating stomach ache. Medical research has also confirmed the contraceptive and abortifacient capability of papaya and also found that papaya seeds have contraceptive effects possibly in humans by suppressing the effects of the hormone progesterone. Being a fruit and also a vegetable at the same time and having more than a dozen multipurpose attributes to its account, papaya was considered as the host plant for conducting biological studies of the carmine spider mite, *T. cinnabarinus* which was found occurring on it almost the entire year.

6. *Mucuna deeringiana* (Bort.) Merr.

M. deeringiana or the common velvet bean of the family Leguminosae is a strong-growing annual plant native to the tropics. The slender stems may grow to 30 feet in some kinds. They are mainly grown with a support crop, on which they climb and are partially supported. The leaves are trifoliate, with large ovate leaflets. Pods are pubescent, up to 6 inches long, with 3 to 6 seeds per pod. Velvet beans are well adapted to sandy soils and require a long growing season to produce much pasturage. They are grown mainly as livestock fodder and for soil improvement. The

plants are highly palatable to the livestock. Velvet bean has also shown to exhibit nematicidal property and is planted as either a rotational crop or an inter-planted crop in diverse geographical areas. Planting of velvet bean is significant in lowering fungal populations at the end of the season and bacterial populations in the following season, compared to cowpea (Kloepper, *et al*., 1999). Velvet bean also influences bacterial diversity, generally increasing frequency of bacilli, *Arthrobacter* spp. and *Burkholderia cepacia*, while reducing fluorescent pseudomonads. Hence, it marks its importance in the field of agriculture and livestock management. Moreover, all parts of the plant are nutritious and the long hairy pods are used for preparation of curries. Heavy infestation of the spider mite, *T. ludeni* was found to occur on the leaves of velvet bean on a large scale. Hence this plant was considered for studying the life history parameters of *T. ludeni*.

7. *Dolichos lablab* L.

The lablab bean, *D. lablab*, a member of the family Fabaceae, originated in Asia and is now grown for food throughout the world. It is a very popular pulse crop grown as an important source of food in the tropics. The plant is easy to grow in poor, acidic to alkaline soils and takes 90-150 days to reach maturity. It is a twining vine with broad leaflets, flowers and flat pods containing beans. Young immature pods are cooked and eaten like green beans. Leaves and flowers are eaten raw in salads or cooked like spinach. The large starchy root tubers and immature /dried seeds are boiled or baked for food. The mature seeds are also used as bean sprouts. The plant is sometimes grown as a cover crop, livestock fodder and green manure.

Lablab bean is also known for its capacity to fix atmospheric nitrogen and enhance soil fertility. Since the experimental plant showed significant infestation by *T. cinnabarinus*, biological studies of the mite on this plant were carried out.

b. Sampling localities

The sampling localities included in the present investigation represented vegetable fields, kitchen gardens, home yards, agricultural fields and so on from 25 representative sites distributed over 6 districts of Kerala. The sites which recorded the occurrence of considerable mite fauna were visited frequently for the collection of mites. A short account on the collection sites considered for sampling has been presented in Table II.

Live specimens of the different species of spider mites in all stages of development were collected during the study period by examining infested leaves and leaflets of the host plants grown in various localities. Preliminary survey and collection of mites though had been initiated from various localities distributed over the above districts, the major collection sites were selected in and around the Calicut University Campus itself for frequent availability of the host plants, as and when required.

Frequent sampling of mite-infested leaves/twigs was made from the following localities:

1. Site I

This site includes the Calicut University Campus, which being a shrub jungle embraces hills, valleys, open dry lands and small patches of cultivated areas. The soil of this site is mainly laterite type with patches of gravel and loam. The Campus covers an area of about 5000 square metres, situated 23 kms south of Kozhikode district. It lies within the latitude 11°, 35'-45' and longitude 75°, 40'-50'. Altitude of the place is 40-60 m. The Campus is exceedingly rich in floral diversity and the plants, *M. oleifera* and *C. papaya* were found growing extensively in every nook and corner of the Campus. In addition, plants like *M. esculenta, V. unguiculata, Solanum melongena, Abelmoschus esculentus, D. lablab, A. tricolor, Citrus lemon, Mangifera indica, Pisum sativum, A. viridis, Lycopersicon esculentum, Areca catechu, Cassia occidentalis, Rosa indica* etc were grown in the botanical garden and different quarters of the campus.

2. Site II

This area called Thalappara is situated about 8 kms away from the Calicut University Campus towards the South. The site was originally an open paddy field consisting of about 110 hectares of land. When the area suffered acute shortage of water for irrigation, the area was subdivided into small plots for vegetable crop cultivation. The dominant species cultivated on a large scale over an area of 90 hectares was *M. esculenta*. The remaining area was used for cultivation of a variety of vegetables viz., *V. unguiculata, A. esculentus, A. tricolor, A. viridis, Momordica charantia, P. sativum, Trichosanthes anguina, Lagenaria siceraria, Luffa acutangula, S. nigrum, Musa sp., Cucumis sativus, Cucurbita pepo, C. maxima* and

so on. Intercultivation of plantation crops like *A. catetchu* and *Cocos nucifera* was of usual practise among cassava cultivated areas.

3. Site III

The 'Chettiarmadu' area, situated 1 km away from the Calicut University Campus towards North, covered an area of about 5 acres which was originally a paddy field. Lack of steady irrigation facilities prompted the cultivators to convert the land practically for other vegetable crops like *A. tricolor, V. unguiculata, D. lablab, M. esculenta, A. esculentus, Trichosanthes anguina, Murraya koenigii, Daucus carota, S. lycopersicum, Brassica oleracea, Glycine max* etc. Periphery of this plot was characterised by the presence of trees like *C. nucifera, A. catetchu*, *M. indica etc*. A narrow channel of water flowing across the plot provided irrigation facility to some extent.

4. Site IV

This site situated hardly 1 km away from the Calicut University campus was at 'Villunniyaal'. The site was a stretch of land of about 2-3 acres constituting homely area, where *S. melongena, A. esculentus, A. tricolor, M. charantia, V. unguiculata, M. deeringiana, D. lablab, Phaseolus vulgaris, B. oleraceae, Coccinia cordifolia, C. lemon, D. carota, L. esculentum* etc. were cultivated in small plots of 1-2 acres. Water from a small canal running along the periphery of the area was used for irrigation purposes. Flora including *M. indica, C. nucifera* and *Musa sp.* were found grown in this site.

5. Site V

This site is situated at Kozhikode district about 6 kms away from the Calicut University Campus towards North at 'Azhinjilam'. The site consists of a vegetable garden of about 1 acre and a plot of about 0.5 acre on top of a small hill. Plants belonging to almost all vegetable crops were grown in the garden. They included *V. unguiculata, A. esculenta, A. tricolor, A. viridis, M. deeringiana, S. melongena, D. carota, C. pepo, C. sativus* and so on. The plot was mainly used for *M. esculenta* cultivation. *Artrocarpus indicus* and *C. papaya* provided partial shade to the cultivation.

c. Sampling of infested plant parts

Aerial parts of the plants, particularly the leaves and leaflets showing symptoms of mite infestation were collected with the help of a scissors and transferred to polythene bags, loosely tied with rubber band, labelled and transported to the laboratory for examination. Within the laboratory, the collected leaf samples were examined individually under a Stemi DV_4 stereozoom microscope and the live mites were directly picked up with the help of a moistened camel hair brush. The mites thus picked up were either transferred to 70% alcohol for further processing or to fresh leaves for biological studies.

d. Rearing of mites

Biological studies inevitably demand culturing of individual species, as otherwise continued observation on biological activities like feeding, breeding and

development would become practically impossible. Field studies would be more severe especially when the organism to be handled is microscopic in nature. Therefore, during the tenure of the present work several culture techniques were developed for the successful rearing of the different species of interest. Both indoor and outdoor culturing was carried out as discussed below.

1. Outdoor culturing of mites

Live cultures of spider mites were maintained on their respective host plants in the field to analyse the damage potential of individual species of mites. This method was adopted in order to observe closely the mode of infestation and progressive damage symptoms induced on the host plant and also to make quantitative estimation of damage potential of the concerned species. To achieve this objective, experimental and control plots (3m x 3m) were set up and were kept wide apart from each other (100m) to ensure protection from pest attack. Artificial infestation of experimental plants was made when they reached 1-2 months old, depending on the host

1.1 Cultivation of host plants

Seeds of *D. lablab*, *V. unguiculata* (Cowpea), *C. papaya* and *A. tricolor* (Red spinach) were sown separately in enriched soils of the experimental and control plots prepared for the study. In the case of *M. esculenta* and *M. oleifera*, stem cuttings of the plant from uninfested fields were collected and planted in experimental and control plots. The plots were irrigated regularly and the seedlings/stem cuttings were grown with utmost care.

2. Laboratory culturing of mites

Laboratory culturing was carried out for making observations on the biology of the species of mites, recording the impact of temperature and relative humidity parameters and also for acquiring information on their varied life activities. Live cultures of different stages of the mites were maintained in the laboratory on fresh leaves of respective host plant, collected from the plots at an interval of 2 days or at the time of need. Each culture set consisted of 2-4 leaves, kept in petridishes lined with moist cotton pads and were treated as experimental sets. Stock cultures of the mites were also maintained in the laboratory in the same manner so as to ensure constant supply of life stages.

e. Biological Studies of Spider mites

A. Feeding biology

1. Qualitative assessment of feeding injury

Qualitative assessment of damage induced by *T. neocaledonicus, T. ludeni, T. cinnabarinus, E. orientalis* and *O. biharensis* to the leaves of the respective host plants was made after release of these mites on to individual set of experimental plants and raising pure cultures of each species. For this purpose, field collected infested and healthy leaf samples were brought to the laboratory in separate polythene bags. Healthy leaves were thoroughly checked for the presence of mites or any other organisms. Known number of adult specimens of the selected species were picked up from infested samples using moist camel hairbrush and transferred onto the healthy leaves. Such artificially infested leaves were carried to the

experimental plot and stapled on to the leaves. Soon after release of pest mites, the experimental and control plots were covered with fine nets in order to avoid further pest invasion. Regular observation was made on the feeding activities of all the life stages of the mites, damage symptoms and the progress of infestation etc. Confirmation of feeding damage was made through repeated field cum laboratory studies.

Transmission Electron Microscopic studies

In order to reflect upon the mechanical injury and to have a closer observation into the minute details of damage induced to the host leaves by the feeding of pest mites, transmission electron microscopic (TEM) studies of the experimental and control leaves of *M. esculenta* infested by *O. biharensis* were carried out

Protocol for processing of tissue for TEM

Fixed the experimental and control samples in 3% gluteraldehyde fixative in phosphate buffer (pH-7.2) for 24 hours. Washed the samples with phosphate buffer for 4-5 times and kept in 1% Osmium tetroxide for 1.5 hours. After washing the specimens in buffer, they were placed in 70%, 80% & 90% alcohol, 2% uranyl acetate in 95% alcohol and absolute alcohol for one hour each. Clearing of the specimens was done twice in propylene oxide for 10 -15 minutes. Following clearing, infiltration of the specimens was done using 1:1 mixture of araldite and propylene oxide placed in an OKEN roataor overnight. Infiltration using fresh araldite-DDSA-DBP-DMP mixture was done thrice with a gap of 3-4 hours and the

specimens were embedded and kept at 60ºC for 48 hours. The blocks were sectioned at 800Aº thickness using Leika Ultra cut U_6 microtome and the ultra thin sections were collected on metal grids. The grids were double stained in uranyl acetate for 1-2 hours followed by lead citrate for 5-7 minutes. Washing was done immediately by holding the grid under the jet of double distilled water, dried and preserved in a grid box.

The specimens thus prepared were observed under Biotwin Technai Spirit Transmission electron microscope (80 KV) and the areas of interest were photographed and presented.

2. Quantitative assessment of damage potential

a. Estimation of Chlorophyll loss

Damage potential of *T. neocaledonicus*, *T. ludeni*, *T. cinnabarinus*, *E. orientalis* and *O. biharensis* to their respective host plants was estimated quantitatively by estimating leaf chlorophyll contents of experimental and control leaves. Fully expanded upper 2 or 3 leaves showing varying degrees of chlorotic symptoms induced by individual mite species were collected from 4 plants per plot for extraction. The exuviae, eggs, life stages and faecal matter of the mites were removed from the infested leaves through careful examination under a Stemi DV_4 Stereozoom microscope.

Procedure

Weighed 2 grams of finely cut and well-mixed representative samples and ground to a fine pulp in a clean mortar with the addition of 20 ml of 80% acetone. Centrifuged at 4000 rpm for 5 minutes and decanted the supernatant through a filter paper into a 100ml volumetric flask. Repeated the procedure until the residue became colourless and made up the volume to 100 ml with 80% acetone. Pipetted 5ml of the solution into a 50ml volumetric flask and made up the volume with 80% acetone. The absorbance of each solution was then measured at 645 nm and 663 nm against the solvent (80% acetone) blank using a Shimadzu UV-VIS spectrophotometer (Model UV – 1601).

The concentrations of chlorophyll (a and b separately) present in the experimental and control samples were estimated following the equation (Ekanayake and Adeleke, 1996).

Milligram chlorophyll a / gram tissue:

20.2 (A_{645}) (50/1000) (100/5) (1/2)

Milligram chlorophyll b / gram tissue:

8.02 (A_{663}) (50/1000) (100/5) (1/2)

where A = Absorbance at specific wave lengths

b. Estimation of Total Phenol content in leaf sample

The response of plants to mite attack in terms of concentration of total phenols content of each extract was determined using methods previously described by Singleton *et al.* (1999).

Procedure

One gram of fresh leaf sample was ground in a pre-cooled mortar into fine paste with 10 ml of 80% ethanol. The homogenate obtained was centrifuged at 10,000 rpm for 20 min, the supernatant was saved, and to the residue 5 ml of 80% ethanol was added for re-extraction. Pooled supernatant was evaporated to dryness in a hot water bath. Dried residue was dissolved in 5 ml of distilled water. To 1 ml of the above solution, 2 ml of distilled water was added to make up the volume to 3 ml and 0.5 ml of Folin-Ciocalteau reagent was added and kept for 3 min for incubation. Following incubation, 2 ml of 20% Sodium bi-carbonate solution

(freshly prepared) was added, mixed thoroughly and kept in boiling water bath for 1 min. The reaction mixture was cooled to room temperature and the absorbance value was read at 650 nm using a Shimadzu UV-VIS spectrophotometer (Model UV – 1601) against a reagent blank. Final concentration of phenol present in each test sample was calculated by plotting a standard graph prepared using different concentrations of standard Tannic acid (100 mg Tannic acid was dissolved in 100 ml distilled water and diluted 10 times for working standard). Values are expressed in terms of mg phenols/100g material.

c. Estimation of Protein Profile

Protein profiles of the experimental and control leaves of *M. esculenta* infested by *O. biharensis* were prepared by SDS Poly Acrylamide Gel Electrophoresis (Gaal *et al.*, 1980).

c_1. Preparation of buffers and reagents for Electrophoresis

1. Stock Acrylamide solution (30%) - Dissolved 30g of acrylamide & 0.8g bisacrylamide in distilled water and made up to 100ml.
2. Resolving gel buffer - Dissolved 227g (1.875M) of Tris HCl in 75 ml distilled water and made up to 100ml. Adjusted the pH to 8.8.
3. 10% Sodium Dodecyl Sulphate - Dissolved 10g SDS in 100ml distilled water.
4. 10% Ammonium Per Sulphate - Dissolved 200mg APS in 2ml distilled water (freshly prepared)

5. TEMED - 20µl and 8µl of TEMED were taken for resolving gel buffer and stacking gel buffer respectively.

6. Extraction Buffer - The extraction buffer was prepared by dissolving Tris (0.1M), Ascorbic acid (0.1%), Cystein HCl (0.1%), PVP (1gm), DIECA (200mg) in100ml distilled water and the pH was adjusted to 7.5.

7. Sample Buffer - Dissolved 1.2g Tris in 10ml 10% SDS. Added 50ml glycerol and 0.05mg bromophenol blue and diluted to 100ml with distilled water.

8. Stacking gel Buffer - Dissolved 7.26g Tris HCl (0.6M) in 75ml distilled water and made up to 100ml. Adjusted the pH to 6.8

9. Tank Buffer - Dissolved 3.02g Tris base and 14.4g glycine in distilled water. Added 10ml 10% SDS, made up to 1litre and adjusted the pH to 7.2.

10. Staining solution - Dissolved 200mg of coomassie brilliant blue in 50ml methanol and 7ml acetic acid in 43ml of distilled water and filtered.

11. Destaining solution – Dissolved 7ml acetic acid and 30ml methanol in 63ml of distilled water

Procedure

c_2. Extraction of Protein

The leaf samples were collected from the field, washed under running tap water and removed the mid vein of the leaves and all life stages of the mite including exuviae and faecal matter. 1gm of leaf tissues of each sample in duplicate were weighed separately and ground into a fine paste in ice cold condition using 5ml of extraction buffer and fine sand powder. In order to control the phenolic oxidation,

β - mercaptoethanol (200µl) was used during the preparation. The fine paste obtained after grinding was transferred to centrifuge tube (6-8ml) and spun at 10,000 rpm at 4°C using a refrigerated centrifuge (Plast Crafts Model – Rota 4R – V/F M) for 30 minutes. The supernatant was collected using micropipette in a separate micro-centrifuge tube and stored at -28°C for further electrophoretic work.

c_3. Gel casting

The glass plates, comb and spacers were washed in absolute alcohol and wiped with tissue paper. Then the plates were cleaned with acetone and positioned the comb in between the glass plates, one on each side. The glass plates with the comb were placed in casting tray and tightened the clips.

1. Resolving Gel - The composition of 15% resolving gel includes double distilled water (7ml), 30% acrylamide stock (15ml), 0.6M Tris HCl at pH 8.8 (7.5ml), 10% SDS (300 µl), 0.1% APS (300µl) and TEMED (20µl).

The resolving gel was poured into the space between the glass plates placed in the casting tray. Distilled water was added on top of the resolving gel to form a layer so as to prevent its contact with air and kept aside for 30 minutes. Later, distilled water was removed by decanting and the edge of the glass plate was wiped with tissue paper

2. Stacking gel – Dissolved 30% acrylamide (1.3ml), 1.5M HCl at pH 6.8 (1 ml), 10% SDS (80µl), 10% APS (80µl) and TEMED (8µl) in double distilled water (5.5ml) for preparing 8ml stacking gel.

The stacking gel was poured between the glass plates on top of the resolving gel layer. Then the comb was placed gradually from one end slanting to avoid bubble formation and the set up was kept undisturbed. The comb was removed after half an hour and the wells were cleaned with the reservoir buffer.

3. Sample preparation for Gel Loading – Mixed 40 µl of the test sample with 10 µl of 10 % Sucrose, 10 µl of Bromophenol Blue and 1 ml of Gel loading buffer.

50 µl of sample was taken to load the wells. Protein marker diluted with extraction buffer was also run along with the sample. Then the apparatus (Genei Mini Model Electrophoresis Unit) was assembled for running. The lower and upper tank was filled with 300 ml reservoir buffer and the electrodes were connected to a power pack. Then power was switched on and voltage set at 80 V. After about an hour, the voltage was raised to 100 V when the bands reached the bottom of the stacking gel. Power was switched off when the bands reached the bottom of the resolving gel. The gel unit was taken out and drained off the buffer, unscrewed the apparatus and removed the spacers. The gel was taken out and placed in the staining solution overnight. The following day, the gel was transferred to destaining solution. Once the gel was sufficiently destained, photographs of the gel were taken using a digital camera (Sony W5). Molecular weights of the bands were determined using Quantity One software.

B. Breeding biology

1. Postembryonic development

Developmental studies were initiated by maintaining adequate supply of live cultures of the mite in the laboratory. Constant availability of live specimens was found absolutely essential for making regular observation on the various aspects of the developmental biology. This was particularly true in the case of the spider mites as they exhibited a seasonal distribution pattern on host plants.

Cultures of individual stages of the mite were initiated on fresh leaves of respective hosts, excised from plants 3-5 days after expansion and placed abaxial or adaxial side up in 120mm petridishes lined with 110x110x5mm cotton pads. The cotton pads were made wet daily with water to maintain the leaves' vitality. When the leaves showed signs of decay, all the mites were transferred to fresh ones. For studying sexual development, 5-10 colonies of newly moulted females were introduced along with 2-4 new males and pre-oviposition periods were recorded. The males were removed soon after the females laid their first set of eggs. Studies on parthenogenesis were initiated starting from 5-10 quiescent female deutonymphs that moulted to females and laid their first batch of eggs without mating. These eggs were considered for subsequent studies of life cycle of the individual mites. The number of eggs laid by the mated and virgin females were recorded on a daily basis. Each female was then transferred onto fresh clean leaf disc. The old leaf discs, which contained the eggs, were placed on freshly prepared leaf disc arenas. Eggs were kept on the same cultivar until adult emergence occurred; in this way the sex

ratio was calculated for mites from each cultivar. Spider mites on each leaf disc were observed daily from egg to adult stage. The developmental duration of each stage was evaluated separately for males and females.

Oviposition and post-oviposition periods of females were calculated from the time the first egg was deposited to the time the last egg was deposited, and from the time the last egg was deposited to the time of death of the female, respectively. These observations were continued until the death of the last individual of the generation.

During the period of the present study, a combination of 3 different temperature – humidity parameters and different host plants were selected for assessing their impact on life cycle of 5 species of spider mites *viz*., *E. orientalis*, *T. ludeni*, *T. cinnabarinus*, *T. neocaledonicus* and *O. biharensis*. The selected temperature – humidity parameters were 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH. For each temperature – humidity set up, 5 sets of cultures were maintained and repeated several times in an environmental growth chamber or in an incubator containing saturated salt solution for confirmation of the obtained data. The host plants duly selected for the study were *A. tricolor* (Spinach) and *V. unguiculata* (Cowpea) for *T. neocaledonicus*, *M. deeringiana* (Velvet bean) for *T. ludeni*, *C. papaya* (Papaya) and *D. lablab* for *T. cinnabarinus*, *M. oleifera* for *E. orientalis* and *M. esculenta* (Cassava) for *O. biharensis.*

Regular observation was made on each culture set at 6h intervals under 32 x magnifications, in order to gather information on mating, oviposition and eggs,

incubation and hatching, larval and nymphal stages, quiescence and moulting and total duration of F_1 generation. Data collected on the above lines of study were recorded, tabulated and presented. Values were expressed as Mean ± SEM (Standard Error of Mean), 'n' indicates the number of trials. Relevant photographs were also taken with the help of a Canon digital camera attached to an Axioskop 2 plus Zeiss Trinocular Research microscope and presented.

2. Preparation of saturated salt solutions to maintain constant RH

To determine the effect of relative humidity on the biology of the mite, saturated salt solutions were prepared by dissolving salt to saturation in boiling water. The solution was partially cooled and more salt was added. After the solution was cooled completely, more salt was added and the mixture was allowed to stand from 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).

3. Morphological studies of developmental stages

In order to study the morphological characters of the larval, nymphal and adult stages, specimens of the various life stages were preserved in 70% alcohol and were dehydrated by passing through 80%, 90% and absolute alcohol and cleared in a mixture of lactic acid and absolute alcohol (1:1 ratio). The cleared specimens were slide mounted in a drop of polyvinyl medium or Hoyer's medium and kept overnight in an oven set at 45-50^{o}C until the desired clarity of specimen was obtained. Morphological details of the various developmental stages viz., the larva,

protonymph, deutonymph and adults (male and female) were drawn using a Camera Lucida attached to a Meopta Research microscope. Measurements of the various life stages were made using stage and ocular micrometers. Photographs of the life stages were taken with a Canon digital camera attached to an Axioskop 2 plus Zeiss Trinocular Research microscope.

3.1 Scanning Electron Microscopic Studies

An attempt to study the minute morphological details of the mite, *O. biharensis* was made using LEICA S440i Scanning electron microscope following fixation in 3% gluteraldehyde, dehydration in alcohol series, subsequent drying and gold coating of the specimen using a sputter coater. The photographs of the mite, mouth parts, anterior leg segments and ventral region have been presented.

4. Preparation of mounting medium

a. Polyvinyl medium

1. Elvanol 74-24 (Du pont polyvinyl alcohol) was dissolved in 4 volumes of water at 90^{o}C.
2. The solution was filtered.
3. Concentrated the clear filtrate on a water bath until the solution became syrupy.
4. 20 parts of lactic acid were added to 56 parts of the PVA solution and used for slide mounting.

b. Hoyer’s medium

Plant mites were best mounted in Hoyer's medium.

Gum Arabic	–	100 gms
Distilled water	–	50 ml
Chloral hydrate	–	200 gms
Glycerine	–	30 ml

1. Crushed the gum arabic crystals and soaked in distilled water over night.

2. Dissolved the crystals by stirring with a glass rod.

3. Added chloral hydrate and glycerine and mixed well.

4. Filtered the mixture through 2 folds of fine glass wool and used for mounting.

TABLE I Host plants surveyed

Sl. No.	Name of the plant		Family	Economic importance	Presence-Absence of Spider mite
	Common name	Scientific name			
1.	Horse-radish tree	*Moringa oleifera* L.	Moringaceae	Food & Medicinal value	+++
2.	Cassava	*Manihot esculenta* L.	Euphorbiaceae	Food & Industrial value	+++
3.	Red Spinach	*Amaranthus tricolour* L.	Amaranthaceae	Food & Medicinal value	+++
4.	Cow pea	*Vigna unguiculata* (L.) Walp	Fabaceae	Food & Medicinal value	+++
5.	Papaya	*Carica papaya* L.	Caricaceae	Food & Medicinal value	+++
6.	Velvet bean	*Mucuna deeringiana* (Bort.) Merr.	Leguminosae	Food & Fodder value	+++
7.	Lablab bean (Avarakkai)	*Dolichos lablab* L.	Fabaceae	Food & Fodder value	+++
8.	Cabbage	*Brassica oleracea* L.	Brassicaceae	Food & Fodder value	+
9.	Chilly	*Capsicum annuum* L.	Solanaceae	Food & Medicinal value	++
10.	Coriander	*Coriandrum sativum* L.	Apiaceae	Food & Fodder value	+

Sl. No.	Name of the plant		Family	Economic importance	Presence-Absence of Spider mite
	Common name	Scientific name			
11.	Ivy gourd	*Coccinia cordifolia* Cogn.	Cucurbitaceae	Food & Medicinal value	+++
12.	Mango	*Mangifera indica* L.	Anacardiaceae	Food, Medicinal & Industrial value	+++
13.	Pepper	*Piper nigrum* L.	Piperaceae	Food & Medicinal value	++
14.	Scarlet gourd Kovakkai	*Coccinia indica* Wight & Am.	Cucurbitaceae	Food & Medicinal value	+
15.	Green Spinach	*Amaranthu viridis* L.	Amaranthaceae	Food & Fodder value	+++
16.	Brinjal	*Solanum melongena* L.	Solanaceae	Food & Medicinal value	+++
17.	Lady's finger	*Abelmoschus esculentus* L.	Malvaceae	Food, Medicinal & Industrial value	+++
18.	Snake gourd	*Trichosanthes anguina* L.	Cucurbitaceae	Food & Medicinal value	+++
19.	Curry leaves	*Murraya koenigii* (L.) Spreng.	Rutaceae	Food, Medicinal & Industrial value	-
20.	Carrot	*Daucus carota* L.	Apiaceae	Food & Medicinal value	+++

Sl. No.	Name of the plant		Family	Economic importance	Presence-Absence of Spider mite
	Common name	Scientific name			
21.	Pumpkin	*Cucurbita pepo* L.	Cucurbitaceae	Food & Taeniacidal value	+++
22.	Cucumber	*Cucumis sativus* L.	Cucurbitaceae	Food & Medicinal value	+++
23.	French bean	*Phaseolus vulgaris* L.	Fabaceae	Food, Fodder & Medicinal value	+++
24.	Bitter gourd	*Momordica charantia* L.	Cucurbitaceae	Food, Medicinal & Industrial value	+++
25.	Tomato	*Lycopersicon esculentum* Mill.	Solanaceae	Food, Fodder & Industrial value	+
26.	Bottle gourd	*Lagenaria siceraria* (Mol.) Standl.	Cucurbitaceae	Food & Medicinal value	++
27.	Ridged gourd	*Luffa acutangula* (L.) Roxb.	Cucurbitaceae	Food & Medicinal value	+++
28.	Yam	*Amorphophallus companulatus* Blume ex Decne	Araceae	Food & Medicinal value	+++
29.	Coffee weed (Takara)	*Cassia occidentalis* L.	Fabaceae	Food & Medicinal value	+++
30.	Taro (Chembu)	*Colocasia esculenta* (L.) Schott.	Araceae	Food & Industrial value	++

Sl. No.	Name of the plant		Family	Economic importance	Presence-Absence of Spider mite
	Common name	Scientific name			
31.	Lemon	*Citrus limon* (L.) Burm.f.	Rutaceae	Food & Industrial value	++
32.	Green gram	*Vigna radiata* (L.) R. Wilczek	Fabaceae	Food & Medicinal value	+++
33.	Potato	*Solanum tuberosum* L.	Solanaceae	Food value	+
34.	Banana	*Musa sp.*	Musaceae	Food & Industrial value	+
35.	Jack fruit	*Artocarpus heterophyllus* L.	Moraceae	Food & Industrial value	+
36.	Sweet pea	*Pisum sativum* L.	Fabaceae	Food value	++
37.	Soya bean	*Glycine max* (L.) Merr.	Fabaceae	Food, Fodder & Industrial value	+
38.	Sweet potato	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	Food & Industrial value	+
39.	Pudhina (Mint) leaves	*Mentha* L.	Lamiaceae	Food, Medicinal & Industrial value	+
40.	Beet root	*Beta vulgaris* L.	Chenopodiaceae	Food, Medicinal & Industrial value	++

+++ = High incidence, ++ = Low incidence, + = Scarce & - = Absence of mites

Chapter IV
Observation

Results of the field survey on the mite fauna associated with some important vegetable crops cultivated in different localities covering 6 districts of Kerala yielded several species of varying taxonomic positions. Apart from mites, several group of insects also claimed their presence on the vegetable plants surveyed. Analysis of the systematic position of the mites recovered from the plants revealed the occurrence of the members of 3 acarine orders Prostigmata, Mesostigmata and Oribatida. Prostigmata constituted 90% of the acarine inquilines on the plants surveyed figured by 3 superfamilies, Tetranychoidea (Spider mites, Flat mites), Tarsonemoidea (Broad mites, cyclamen mites, grass white mites, rice white mites etc) and Eriophyoidea (Gall mites, Rust mites, Bud mites and so on). Members of this group were detected in all of the collection sites, thereby claiming maximum diversity. They were closely followed by members of Mesostigmata represented by predatory mites belonging to the family Phytoseiidae. Oribatida on the other hand comprised less than 1% of the total acarine fauna since they were recovered only to a smaller extent. However, on par with the objectives of the present work, the tetranychid fauna alone was considered for further biological studies.

Of the various species of plant mites recovered, 5 species of spider mites belonging to 3 genera *viz.*, *Tetranychus*, *Eutetranychus* and *Oligonychus* were considered for detailed biological studies. The above 5 species were *T. neocaledonicus* Andre, *T. ludeni* Zacher, *T. cinnabarinus* (Boisduval), *E. orientalis*

(Klein) and *O. biharensis* (Hirst). These species often colonised the mature leaves of the plant and built large colonies. All stages of these mites including adults, nymphal and larval stages were found engaged in active feeding. They often penetrated their stylets into the epidermal layer of the host leaf and sucked the leaf sap. This caused the leaves to have a stippled or flecked appearance, with pale spots where the cellular contents were removed. Prolonged, heavy infestations caused yellowing or bronzing of the foliage and premature leaf drop. Observation on the seasonal distribution of the selected species of mites during the study period revealed their presence throughout the year at peak, moderate or scanty levels (Table III). *T. neocaledonicus*, *T. cinnabarinus, E. orientalis* and *O. biharensis* occurred at peak levels mainly during summer from February to April or May while *T. ludeni* showed its presence at peak levels from May to July.

Study of relative abundance of the selected species of spider mite was yet another objective of the current study. Interspecific and intraspecific variations in the relative abundance of the 5 species are presented in Table IV. Of the 5 species, *T. ludeni* was found to be the most abundant species in terms of population density and *E. orientalis* marked the least. The former species occurred in high incidence at 12 out of 22 sites surveyed followed by *T. cinnabarinus*, *T. neocaledonicus* and *O. biharensis* which were encountered at high incidences at 9, 6 and 3 sites out of 19, 17 and 14 sites surveyed respectively. *E. orientalis* happened to occur only at low to scarce levels. Among the tetranychids studied, *T. ludeni* appeared to be the major species which constituted 54% of the total tetranychid species selected. *T. ludeni* was closely followed by *T. cinnabarinus* contributing 47%, *T. neocaledonicus*

ranking 3rd with 35% and *O. biharensis* constituting 21% in terms of relative abundance. The presence of *E. orientalis* was detected in 10 collection sites, but only to a smaller extent.

Differential distribution pattern of the spider mites on various parts of the host plant was another feature noted during the present investigation. All the 5 species of tetranychid mites inhabiting the plants evidenced more or less similar distribution trend. They showed a general tendency of colonizing the mature leaves of the host plant. On the leaf blade, *E. orientalis* and *T. ludeni* preferred upper surface, being covered under heavy web with dust particles adhered to it while *T. neocaledonicus* and *T. cinnabarinus* in all stages remained confined to the undersurface of leaves covered with thin webs and dust particles. *O. biharensis* on the other hand showed equal distribution on both sides of the leaf blade. Further, the former 4 species were found readily moving to the other surface of the leaf on completion of their feeding at the preferred leaf surface. During heavy infestation, all the 5 species were found colonising the leaf petioles also.

A. FEEDING BIOLOGY

1. Nature of infestation by *T. neocaledonicus*

The distribution of *T. neocaledonicus* on *V. unguiculata* and *A. tricolor* provided ample evidence for mite infestation on mature leaves. Results of field observation showed a general tendency of the mite to colonise the mature leaves of the host plant, (Plate I, Figs. 1 to 3) leaving the stem and other parts. On the leaf blade, *T. neocaledonicus* preferred the lower surface, where they were found

congregating mainly along the adjacent regions of the midrib and veins of the leaves. Developing stages, during overcrowding, showed a tendency to colonise secluded areas available on the leaves where intense webbing was present.

1.1 Feeding activity of *T. neocaledonicus*

Results of microscopic observation on the feeding habits of *T. neocaledonicus* enabled to understand the feeding mechanism of the individuals as well as initiation and progression of the damage to the host plants. Feeding was initiated by the adult mites (males and females), which colonised the lower surface of the leaf lamina. While feeding, the individuals penetrated the epidermal layer of the leaf with their stylets and sucked out the cell contents (Plate I, Figs. 1 to 2). The feeding activity at a particular point lasted for a short period of 1 to 2 minutes. The stylets were then retracted and the individuals were found moving at random for selecting new feeding sites. At times when the population density was high, the individuals were found feeding in groups. On occasion when the population density attained the peak level, the individuals readily moved to the upper surface of the leaf and initiated feeding activity. As a result of sucking action, the chloroplasts were found destroyed and the mesophyll cells and cells of pallisade layer were also destroyed. The stylet punctures were found formed serially, usually in a circular manner, which finally led to the formation of small primary chlorotic spots (Plate I, Fig. 2). Progressive feeding often led to the formation of irregular spots, due to integration of primary spots, which on prolonged exposure became white or yellowish or greyish in colour (Plate I, Fig. 3).

Apart from the life stages, (Plate I, Figs. 1 to 7) the leaf surface was also found characterized by the presence of intense webbing by the mites (Plate I, Fig. 10). Feeding was followed by the deposition of faecal pellets (Plate I, Fig. 6) haphazardously as small black and violet granules respectively on *V. unguiculata* and *A. tricolor*, attached to the web. Concomitant with feeding, the females also initiated reproductive activity, which was marked by the deposition of eggs. These eggs (Plate I, Figs. 2, 3, 4, 6 & 10) were found protected by a waxy coating produced by the females, which helped in keeping the egg cases in places of deposition, even after the emergence of the larva. The larvae (Plate I, Figs. 2 to 4) and subsequent nymphal stages (Plate I, Figs. 2, 5 & 6) often initiated their quiescence (Plate I, Figs. 2, 6 & 7) due to which, the moulting skins remained adhered to the leaf surface (Plate I, Figs. 2 to 3). These innumerable egg cases, exuviae, faecal pellets and the webbing further facilitated accumulation of dust particles on the leaf surface. Eventually, all these particles together formed a more or less thick coating over the leaf surface.

1.2. Damage symptoms induced by *T. neocaledonicus*

The symptoms of injury produced by *T. neocaledonicus* on the leaves of *V. unguiculata* and *A. tricolor* were microscopic in the initial stage and marked by the appearance of white spots at the points of suction of sap from the plant cells. Simultaneously, extensive feeding by the members of the colony resulted in the formation of innumerable number of such spots, which got coalesced leading to acute chlorosis of the leaves. Microscopic examination of such leaves during

advanced stages of infestation (Plate I, Figs. 2 to 3) revealed the presence of large number of adults, faecal pellets, egg cases and exuviae. The symptoms were quite clear at this stage when the mites started migrating to fresh leaves from such depigmented leaves, which eventually collapsed by wilting and premature abscission. As a result of this, both vegetative growth and flowering of the plant got minimised.

1.3. Quantitative estimation of chlorophyll content

For rating the damage caused to the host plant by the infestation of the vegetable mite, loss of chlorophyll content of the leaves was estimated. Quantitative data regarding the amount of chlorophyll 'a' and 'b' present in the experimental and control leaves have been presented in Table V. As represented in the table, marked reduction was observed in the chlorophyll content of infested leaves, as the quantities of both chlorophyll 'a' and 'b' were subjected to a substantial loss due to heavy feeding by the mite. As depicted in the table, the loss in chlorophyll a and b were 3.40 $\pm$ 0.23 and 3.37 $\pm$ 0.25 mg/gm tissue respectively. The percentage loss appeared to be 47.58 $\pm$ 2.1 % and 48.30 $\pm$ 2.2 % respectively for chlorophyll 'a' and 'b'. Statistical analysis of the data showed that the results were significant ($p < 0.01$).

1.4. Quantitative estimation of phenol content

A preliminary attempt for estimating the phenol content of experimental and control leaf samples of *V. unguiculata* revealed an increase in total phenols following *T. neocaledonicus* infestation. An increase of about 2 - 2.5 mg phenol/100 gm plant material was recorded.

2. Nature of infestation by *T. ludeni*

Observation on the infestation of *T. ludeni* on *M. deeringiana* showed a progressive increase in the population on the upper surface of the leaves. Also a gradual tendency of migration towards the lower leaf lamina was noted with the advancement in population growth at high rates.

2.1 Feeding activity of *T. ludeni*

Feeding activity of *T. ludeni* commenced soon after successful colonisation on fresh leaves of *M. deeringiana*. Mode of feeding of this species was similar to that explained earlier for *T. neocaledonicus*. But the symptoms of the attack by this species were perceivable even at early stage of infestation. Microscopic observation of infested leaves revealed the presence of actively feeding individuals often in isolated groups. The larval and nymphal forms (Plate XII, Figs. 3, 4 & 6) were also found piercing their stylets even into the leaf petioles for sucking the tissue fluids. At this stage, the leaves often harboured eggs, juveniles, adults, large masses of faecal matter and moulting skins.

T. ludeni produced two types of faecal matter (Plate XII, Fig. 1) which were found scattered among the silken webbing or occasionally deposited in groups on the leaf surface. The faecal matter was transparent and globular with a central core area formed of small white or black granules compactly glued together. Masses of creamy white pellets were produced abundantly prior to that of black pellets. However, the number of granules in a white pellet was less than 10, where as it was greater than 75 in the case of black pellets. The faecal matter retained its intact

nature for a few seconds following which they collapsed or shrunk soon after deposition. The white pellets soon became inconspicuous with the perishing of the outer covering and were seen as irregular structures on the webbing. But the black pellets remained conspicuous even after the collapse of the outer covering.

The colony structure as reflected in the current study was highly complex and attained through the formation of silken webbing by the individuals. The larval and nymphal stages equaled the adults in the production of silky secretions. The secretion was discharged from the palpal apex which on hardening attained the status of silken threads. *T. ludeni* often constructed compact network of white threads over the leaf surface by random movements and secretions. Webbing was often seen to extend from leaf to leaf and to the entire plant during heavy infestation. The individuals could be seen moving in between leaves through these interconnected webbing. The colony structure was therefore more complicated than other tetranychid representatives studied.

2.2. Damage symptoms induced by *T. ludeni*

Analysis of damage symptoms of the species on *M. deeringiana* revealed the development of small irregular etiolated spots on the leaf surface. Persistent feeding resulted in the overlapping of these spots leading to the formation of chlorotic patches. Heavily infested leaves were completely deprived of their natural green colour and exhibited bleached appearance (Plate XII, Fig. 1). Eventually the leaves perished by drying.

2.3. Quantitative estimation of chlorophyll content

As an attempt for rating the damage caused to *M. deeringiana* by the infestation of this species, loss of chlorophyll content of the leaves was estimated (Table VI). Quantitative reduction in chlorophyll 'a' and 'b' was observed to be 2.76 ± 0.16 and 2.80 + 0.26 mg/gm tissue respectively. Per cent loss in chlorophyll 'a' and 'b' was 34.57 ± 2.2 % and 43.32 + 3.3 % respectively. Results were subjected to statistical analysis and were found significant at 1% level.

3. Nature of infestation by *T. cinnabarinus*

Contrary to the nature of infestation by *T. ludeni*, *T. cinnabarinus* showed a tendency to colonise on the lower lamina of the host leaves of *C. papaya* and *D. lablab* though they migrated to the opposite surface of lamina also on the onset of population outbreak. They mostly congregated near the mid rib and major veins of the leaf (Plate XIX, Figs. 1, 2, 6, 8, 9 & 11).

3.1 Feeding activity of *T. cinnabarinus*

The mechanism of feeding followed similar sucking pattern like that of *T. neocaledonicus* and *T. ludeni*. The characteristic symptoms of damage appeared after the establishment of the individuals on the host leaves. Simultaneous with feeding, development of individuals also proceeded which in turn resulted in the production of eggs, exuviae and large number of life stages (Plate XIX, Figs. 1, 2, 6, 8 & 9). Active feeding resulted in the production of black coloured faecal pellets which were found scattered on the leaf surface and entangled in the webbing (Plate

XIX, Fig. 8). Construction of web was yet another feature noted concomitant with reproduction (Plate XIX, Figs. 1, 2 & 8). Continuous production of exuviae and faecal matter along with web often led to the accumulation of dust and formation of a thick covering over the colony (Plate XIX, Fig. 9).

3.2. Damage symptoms induced by *T. cinnabarinus*

Initial infestation of this species was marked by the appearance of minute pale white dots on the lower leaf surface which gradually overlapped with each other as feeding continued (Plate XIX, Figs. 1 & 10). Subsequently the leaves changed to yellowish, followed by crumpling, curling or twisting during heavy infestation. The individuals moved to upper leaf surface when the feeding sites on the lower surface were saturated. Prolonged attack retarded the growth, flowering and pod formation of the plant.

3.3. Quantitative estimation of chlorophyll content

In order to quantify the extent of damage induced by the feeding activity of the mite, chlorophyll content of the infested leaves was compared with that of control leaves and presented in Table VII. As depicted in the table, loss in quantities of chlorophyll 'a' and 'b' were 3.29 + 0.19 and 3.12 + 0.13 mg / gm tissue of experimental leaves. Further, estimation of the percent loss in chlorophyll 'a' and 'b' yielded 41.07 $\pm$ 2.1 % and 50.81 $\pm$ 1.6 % respectively. The data proved to be significant ($p < 0.01$) when analysed statistically.

4. Nature of infestation by *E. orientalis*

Field and laboratory studies enabled to unveil the nature of infestation of *E. orientalis* on *M. oleifera*. The mite showed a general preference for infesting the upper surface of the leaf lamina, constructing heavy webs prior to egg deposition and colony building. At times when the population density reached the peak, the mites colonised the lower surface also in order to procure adequate food supply.

4.1 Feeding activity of *E. orientalis*

. During feeding, the individuals were found firmly adhering to the leaf surface with their anterior pair of legs and inserting their stylets into the leaf epidermis (Plate XXIX, Fig. 3). The sucking action of the mouth parts could be well perceived by alternate movements of the stylophore and rostral tip. Following this, an inflow of greenish fluid into the digestive tract of the mites was observed. At the end of feeding, the individuals were found moving to newer feeding sites.

Feeding activity often coincided with the deposition of black faecal pellets (Plate XXIX, Fig. 3), web construction as well as breeding activity on the leaf surface. Eggs were firmly adhered to the leaf surface by a sticky substance secreted by the ovipositing female. A large number of egg cases, moulting skin of the individuals, life stages, faecal pellets, intense webbing, dust particles and damage symptoms (Plate XXIX, Fig. 6) marked the signs of a successfully established colony of *E. orientalis*.

4.2. Damage symptoms induced by *E. orientalis*

Initiation of infestation by this species on *M. oleifera* was marked by the appearance of very small yellowish spots (Plate XXIX, Fig. 2, 3, 5 & 6) at the point of penetration by the mouth parts. All active stages of the mite were found sucking the sap from leaves and tender shoots of the plant, causing the affected leaves to turn yellowish and finally brown. During heavy infestation, simultaneous and repeated feeding resulted in the formation of irregular greyish brown patches on the leaf surface. The symptoms could be easily perceived by the bronzed appearance of the leaves. Following such depigmentation, the mites actively migrated to fresh leaves and initiated colonisation. The damaged leaves eventually collapsed by drying and crumpling. These retarded the growth and vigour of the plant, causing drastic decrease in pod formation.

4.3. Quantitative estimation of chlorophyll content

A better picture on the impact of feeding by *E. orientalis* could be perceived through a comparative estimation of chlorophyll content of experimental and control leaves of *M. oleifera*. Heavy infestation by the mite often resulted in a drastic reduction in the amount of chlorophyll 'a' which was recorded to be 3.09 $\pm$ 0.09 mg / gm tissue and the per cent loss of which was 36.26 $\pm$ 0.99 %. The loss in chlorophyll content as well as the per cent loss in chlorophyll 'b' was in the tune of 2.54 $\pm$ 0.16 mg / gm tissue and 35.40 $\pm$ 2.0 % respectively (Table VIII). The values were found significant at 1% level upon statistical analysis, following t test.

5. Nature of infestation by *O. biharensis*

Equal preference to both surfaces of the leaf lamina of *M. esculenta* was observed in the case of *O. biharensis*. The mite colonised on either leaf surfaces particularly at the petioles which provided concealment and protection to the colony.

5.1 Feeding activity of *O. biharensis*

O. biharensis represented another group of leaf sucking forms encountered on *M. esculenta* during the survey. It colonised the mature leaves and built large colonies. However, young or newly sprouted leaves of the host plant were left unfed by the mite. The adults, larval and nymphal stages equally engaged in active feeding by piercing their stylets set on protrusible stylophore that could be seen moving back and forth during feeding and sucking the tissue fluids out from the leaves (Plate XXXVI, Figs. 1 to 2). The mechanism of feeding closely followed that of other tetranychid representatives discussed earlier.

The mites were found constructing thinner webs on the leaf surface connecting the petioles and major veins of the leaf. Females initiated oviposition soon after web construction and laid golden brown eggs at random on the leaf surface (Plate XXXVI, Fig. 4). As feeding progressed, deposition of faecal matter was also observed (Plate XXXVI, Fig. 2). The faecal matter which was deposited as black globules got spread on the leaf surface soon after ejection from the body. Such black patches could be seen scattered all over the leaf surface amidst eggs, egg cases, moulting skin, life stages, dust particles and damage symptoms (Plate XXXVI, Figs. 2 to 3).

5.2. Damage symptoms induced by *O. biharensis*

Initial symptoms of damage were manifested in the form of numerous white spots at the points of feeding on the leaf surface (Plate XXXVI, Figs. 1 to 2). Continuous sucking by all stages of this mite from leaves and petioles caused fusion of these spots and formation of large chlorotic patches. Following this, a change in colour from white to yellowish brown patches could be observed. Severe infestation and prolonged feeding encompassed the formation of dark brown patches, crinkling and subsequent drying and defoliation of affected leaves. Attack by these mites affected the growth and vigour of cassava plants.

5.2.1 Mechanical injury induced by *O. biharensis*

Electron microscopic studies on the damage induced by *O. biharensis* clearly reflected upon the mechanical injury caused to the host plant, *M. esculenta*. The mesophyll tissues were the most targeted structures (Plate XL, Figs. 4 & 6) disrupted as a result of mite attack though epidermal layer showed small degree of damage (Plate XL, Fig. 2). The mesophyll layer had fewer chloroplasts (Plate XL, Figs. 4 & 6 and Plate XLI, Figs. 2 & 6) in comparison with that of the control leaf (Plate XL, Fig. 3 & 5 and Plate XLI, Figs. 1, 3 & 5) while the spongy tissues showed a significant increase in free space (Plate XL, Figs. 4 & 6). However, no damage to the vascular bundles was observed in the current study.

5.2.2 Protein profile of *M. esculenta* following infestation by *O. biharensis*

Preliminary studies on the protein profile of *M. esculenta* leaves revealed 5

prominent bands each, both in the experimental as well as the control samples (Plate XLII). However, the positions of these bands were identical in both the leaf samples. Of the 5 bands, the third band from the top (62 kDa) was quantitatively the major one as indicated by the band width and staining intensity. The other bands recorded substantially very low concentration in comparison to the major band. Further, the control leaf samples invariably had a higher protein concentration than the experimental samples as the former had more intensity of staining than the latter. Following infestation and damage by *O. biharensis*, a decrease in the protein concentration in the experimental leaves was observed though no significant change in the protein profile could be recorded in the present investigation.

5.3. Quantitative estimation of chlorophyll content

The chlorophyll content of experimental and control leaves of *M. esculenta* plant was estimated in order to quantify the loss of chlorophyll 'a' and 'b' as a result of infestation by *O. biharensis*. The values have been tabulated and presented in Table IX. The respective values recorded for loss in chlorophyll 'a' and 'b' were 2.67 $\pm$ 0.17 and 3.70 $\pm$ 0.08 mg / gm tissue. Percent loss in chlorophyll a and b content were recorded to be 29.40 $\pm$ 1.6 % and 46.03 $\pm$ 1.0 % respectively. The results when statistically analysed proved to be significant at 5% level.

5.4 Quantitative estimation of phenol content

Infestation by *O. biharensis* on *M. esculenta* could account for a highly significant increase in total phenol content ranging from 10 – 12 mg phenol/100

gm plant material.

TABLE V

Quantitative difference in chlorophyll content (mg/gm tissue) of *V. unguiculata* leaves due to infestation by *T. neocaledonicus*

Chlorophyll	Sl No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Experimental	Control		
Chlorophyll a	1.	3.7683	6.9748	3.2065	45.97
	2.	3.9791	7.4785	3.4994	46.80
	3.	3.7126	7.0380	3.3254	47.25
	4.	4.8229	7.5433	2.7204	36.06
	5.	3.8537	7.8573	4.0036	50.95
	6.	3.1926	5.3700	2.1774	40.55
	7.	3.7667	8.2798	4.5131	54.51
	8.	2.6794	5.3815	2.7021	50.21
	9.	4.7720	8.5178	3.7458	43.98
	10.	2.8250	6.9880	4.1630	59.57
Mean ± SEM		**3.74 ± 0.22**	**7.14 ± 0.33**	**3.40 ± 0.23**	**47.64 ± 2.1**
Chlorophyll b	1.	3.4091	6.0149	2.6058	43.42
	2.	3.8363	6.3626	2.5263	39.77
	3.	2.7474	6.0583	3.3109	54.62
	4.	2.2487	6.2457	3.9970	54.48
	5.	3.7035	6.5317	2.8282	43.38
	6.	3.8000	6.4631	2.6631	41.18
	7.	3.5500	8.3932	4.8432	57.69
	8.	4.2500	8.7289	4.4789	51.31
	9.	4.4200	7.5832	3.1632	41.68
	10.	2.6600	5.9686	3.3086	55.44
Mean ± SEM		**3.46 ± 0.22**	**6.83 ± 0.32**	**3.37 ± 0.25**	**48.30 ± 2.2**

TABLE VI
Quantitative difference in chlorophyll content (mg/gm tissue) of *M. deeringiana* leaves due to infestation by *T. ludeni*

Chlorophyll	Sl No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Experimental	Control		
Chlorophyll a	1.	6.1280	8.3219	2.1939	26.36
	2.	5.5960	8.1420	2.5460	31.27
	3.	6.9331	9.1210	2.1879	23.98
	4.	5.7680	7.8712	2.1032	26.72
	5.	4.7650	8.0582	3.2932	40.87
	6.	4.4427	7.3551	2.9124	39.60
	7.	4.3520	7.6570	3.3050	43.16
	8.	4.5819	7.2853	2.7034	37.10
	9.	4.8141	8.2316	3.4175	41.52
	10.	5.4656	8.4300	2.9644	35.16
Mean ± SEM		**5.28 ± 0.26**	**8.05 ± 0.17**	**2.76 ± 0.16**	**34.57 ± 2.2**
Chlorophyll b	1.	3.5742	6.8234	3.2492	47.62
	2.	3.1210	6.4322	3.3112	51.48
	3.	3.4472	5.9890	2.5418	42.44
	4.	3.0544	6.9521	3.8977	56.07
	5.	4.8025	6.0980	1.2955	21.24
	6.	4.8645	7.5832	2.7187	35.85
	7.	3.0577	6.9814	3.9237	56.20
	8.	3.3212	5.6350	2.3138	41.06
	9.	4.0170	6.7302	2.7132	40.31
	10.	2.9890	5.0583	2.0693	40.91
Mean ± SEM		**3.62 ± 0.22**	**6.43 ± 0.23**	**2.80 ± 0.26**	**43.32 ± 3.3**

TABLE VII

Quantitative difference in chlorophyll content (mg/gm tissue) of *D. lablab* leaves due to infestation by *T. cinnabarinus*

Chlorophyll	Sl No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Experimental	Control		
Chlorophyll a	1.	4.2448	8.0600	3.8152	47.33
	2.	3.8880	7.2422	3.3542	46.31
	3.	4.8230	7.3541	2.5311	34.42
	4.	4.9927	8.3642	3.3715	40.31
	5.	4.6600	8.5720	3.9120	45.64
	6.	4.6826	7.8630	3.1804	40.45
	7.	5.6823	7.8300	2.1477	27.43
	8.	5.0300	8.2621	3.2321	39.12
	9.	4.1222	8.1820	4.0598	49.62
	10.	5.0082	8.3520	3.3438	40.04
Mean ± SEM		**4.71 ± 0.16**	**8.01 ± 0.14**	**3.29 ± 0.19**	**41.07 ± 2.1**
Chlorophyll b	1.	2.3445	5.8664	3.5219	60.04
	2.	3.2250	5.7411	2.5161	43.83
	3.	3.2518	6.6535	3.4017	51.13
	4.	2.9122	6.3667	3.4545	54.26
	5.	3.4210	6.2424	2.8214	45.20
	6.	3.2901	6.5844	3.2943	50.03
	7.	3.5126	6.5000	2.9874	45.96
	8.	2.4216	5.3190	2.8974	54.47
	9.	3.0356	6.7781	3.7425	55.21
	10.	2.7782	5.3366	2.5584	47.94
Mean ± SEM		**3.02 ± 0.13**	**6.14 ± 0.17**	**3.12 ± 0.13**	**50.81 ± 1.6**

TABLE VIII

Quantitative difference in chlorophyll content (mg/gm tissue) of *M. oleifera* leaves due to infestation by *E. orientalis*

Chlorophyll	Sl No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Experimental	Control		
Chlorophyll a	1.	5.3621	8.3420	2.9799	35.72
	2.	5.5284	8.9662	3.4378	38.34
	3.	5.5221	8.5369	3.0148	35.31
	4.	5.5379	8.6781	3.1402	36.18
	5.	5.7157	8.9000	3.1843	35.78
	6.	5.5270	8.8554	3.3284	37.59
	7.	5.4020	8.5642	3.1622	36.92
	8.	5.0110	7.8782	2.8672	36.39
	9.	4.8500	8.2795	3.4295	41.42
	10.	5.8291	8.2056	2.3765	28.96
Mean ± SEM		**5.43 ± 0.09**	**8.52 ± 0.11**	**3.09 ± 0.09**	**36.26 ± 0.99**
Chlorophyll b	1.	5.2266	7.1872	1.9606	27.28
	2.	5.0880	7.3032	2.2152	30.33
	3.	4.6756	6.9951	2.3195	33.16
	4.	4.9344	6.9255	1.9911	29.75
	5.	4.0030	6.9926	2.9896	42.75
	6.	4.1263	6.7925	2.6662	39.25
	7.	5.1810	7.3780	2.1970	29.78
	8.	4.2666	7.4661	3.1995	42.85
	9.	4.8790	7.3936	2.5146	34.01
	10.	4.0931	7.4264	3.3333	44.88
Mean ± SEM		**4.65 ± 0.15**	**7.19 ± 0.08**	**2.54 ± 0.16**	**35.40 ± 2.0**

TABLE IX

Quantitative difference in chlorophyll content (mg/gm tissue) of *M. esculenta* leaves due to infestation by *O. biharensis*

Chlorophyll	Sl No.	Milligram Chlorophyll/gram tissue		Loss in chlorophyll	% chlorophyll loss
		Experimental	Control		
Chlorophyll a	1.	6.7530	9.5264	2.7734	29.11
	2.	7.0366	10.530	3.4934	33.18
	3.	6.0239	8.9277	2.9038	32.53
	4.	6.6363	9.1144	2.4781	27.19
	5.	7.1432	9.9631	2.8199	28.30
	6.	6.6479	8.4263	1.7784	21.11
	7.	6.2444	8.2810	2.0366	24.59
	8.	5.2428	8.0600	2.8172	34.95
	9.	6.5654	8.7689	2.2035	25.13
	10.	5.5230	8.8915	3.3685	37.88
Mean ± SEM		**6.38 ± 0.20**	**9.05 ± 0.24**	**2.67 ± 0.17**	**29.40 ± 1.6**
Chlorophyll b	1.	4.5736	8.5831	4.0095	46.71
	2.	4.2180	8.0690	3.8510	47.73
	3.	4.0120	7.5782	3.5662	47.06
	4.	4.1125	7.8645	3.7520	47.71
	5.	5.1045	8.6630	3.5585	41.08
	6.	4.2511	8.2550	4.0039	48.50
	7.	3.7700	7.2324	3.4624	47.87
	8.	4.1936	8.0352	3.8416	47.81
	9.	5.0182	8.2112	3.1930	38.89
	10.	4.2265	7.9640	3.7375	46.93

Mean ± SEM		**4.35 ± 0.13**	**8.04 ± 0.13**	**3.70 ± 0.08**	**46.03 ± 1.0**

1. Postembryonic development of the vegetable mite, *T. neocaledonicus* Andre

1.1 Oviposition

Adult females were found depositing eggs more frequently on the lower surface of the leaves of the host plants, *A. tricolor* and *V. unguiculata*. Specific selection of site was noted during oviposition. However, in rare instances, eggs were laid on the upper surface also. Ovipositing females were found constructing silken web across the midrib and major lateral veins prior to the deposition of the eggs. This webbing activity was seen to coincide with oviposition also (Plate I, Fig. 10). During oviposition, the females slightly lowered the hysterosoma for extruding the egg. Subsequently, the female was found moving away from the site. A tendency of depositing the eggs in close proximity was observed and hence the eggs deposited were usually found in colonies.

The eggs were smooth, round and white in colour when freshly laid (Plate I, Figs. 4 & 6). With progress in the incubation period, a change in colour to yellow and later to orange red was observed. Eye spots were prominent as red spots by the end of incubation. An increase in the size of the egg and a slight change in shape from round to oval was also noted at the time of hatching.

The pre-oviposition period i.e., the period prior to the initiation of

oviposition activity, was recorded to be 2.57 ± 0.04 days at 25 ± 2ºC & 80 ± 5% RH, 1.6 ± 0.01 days at 30 ± 2ºC & 70 ± 5% RH and 1.25 ± 0.08 days at 35 ± 2ºC & 60 ± 5% RH on *A. tricolor* (Table X). While their respective durations on *V. unguiculata* were 2.62 ± 0.04, 1.8 ± 0.08 and 1.42 ± 0.07 days. The oviposition activity therefore, was initiated from the 2nd or 3rd day of adult emergence (Tables XI).

The oviposition periods observed on *A. tricolor* were 9.1 ± 0.23 days, 7.5 ± 0.17 days and 7.45 ± 0.16 days (Table X) and on *V. unguiculata*, 9.7 ± 0.15 days, 7.05 ± 0.22 days and 8.1 ± 0.07 days respectively for the temperature-humidity conditions *viz.*, 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH (Table XI). The post-oviposition periods that followed oviposition on *A. tricolor* for the above three temperature-humidity combinations were 2.3 ± 0.29 days, 2.4 ± 0.16 days and 2.2 ± 0.08 days respectively while that on *V. unguiculata* were 3.0 ± 0 days, 2.6 ± 0.14 days and 2.2 ± 0.11 days respectively (Tables X & XI). During this period, the adult female became inactive and lethargic. Feeding activity was found minimised. The post-oviposition period was followed by the death of the individuals. The durations on *A. tricolor* were recorded to be comparatively lower than those on *V. unguiculata*.(Plate II, Figs. 1 to 2).

Fecundity or the number of eggs laid by a gravid female *T. neocaledonicus* during its life time was minimum during the 1st and 2nd days of oviposition on *A. tricolor* as well as on *V. unguiculata* under laboratory conditions. However, a subsequent but gradual increase was observed from the 3rd day onwards until it reached its peak level on the 4th or 5th day of oviposition. A decline from the 5th or 6th

day onwards, reaching a minimum at the end of oviposition was a trend commonly observed on both the host plants studied. For temperature-humidity conditions *viz*., 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH, fecundity on *A. tricolor* recorded was 27.6 ± 1.7 (Mated - 32.0 ± 1.2 & Virgin - 23.2 ± 1.1), 34.5 ± 1.5 (Mated - 38.0 ± 1.8 & Virgin - 31.0 ± 0.7) and 41.8 ± 1.4 (Mated - 45.4 ± 0.9 & Virgin - 38.2 ± 1.1) (Table XII to XIV; Plate III, Fig.1) respectively. On *V. unguiculata*, the respective fecundity range was observed to be 31.2 ± 1.5 (Mated - 35.2 ± 1.1 & Virgin - 27.2 ± 0.9), 43.7 ± 1.3 (Mated - 46.8 ± 1.1 & Virgin - 40.6 ± 1.0) and 48.7 ± 1.6 (Mated - 52.6 ± 1.1 & Virgin - 44.8 ± 1.6 for the three temperature-humidity conditions studied (Table XV to XVII; Plate III, Fig.2).

The longevity or the life span of the mite on *A. tricolor* was 14.0 ± 0.36 days (Mated - 13.0 ± 0.2 days & Virgin - 14.9 ± 0.2 days), 11.5 ± 0.26 days (Mated - 11.3 ± 0.3 days & Virgin - 11.7 ± 0.4 days) and 10.9 ± 0.18 days (Mated - 10.6 ± 0.2 days & Virgin - 11.2 ± 0.2 days) at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables XII to XIV). While on *V. unguiculata*, the durations for the temperature-humidity conditions analysed were respectively 15.3 ± 0.15 days (Mated - 15.4 ± 0.2 days & Virgin - 15.2 ± 0.2 days), 11.4 ± 0.3 days (Mated - 11.7 ± 0.4 days & Virgin - 11.2 ± 0.4 days) and 11.7 ± 0.18 days (Mated - 11.6 ± 0.2 days & Virgin - 11.8 ± 0.3 days) (Tables XV to XVII). The mite survived longer on *V. unguiculata* than on *A. tricolor* as observed during the current study.

1.2 Hatching

Initiation of hatching was marked by an increase in size of the egg. Subsequently, the egg assumed an ovoid shape. These changes were observed at the end of the 4th to 5th day of incubation on *A. tricolor* and at the end of the 3rd to 5th day of incubation on *V. unguiculata* (Tables XVIII to XXIII). Soon a transverse slit appeared near the apical region of the egg which continued to either sides, followed by the thrusting movements of the larva. The thrusting action of the propodosoma and movements of the basal segments of the legs assisted the larva in moving out of the egg shell (Plate I, Fig. 12). Discarded egg cases consisting of an intact anterior half and a damaged posterior half could be seen distributed on infested leaf surfaces. The process of hatching required 15-20 minutes for all the temperature-humidity conditions and on all host plants studied.

1.3 Duration of Developmental Stages:

1.3.1 Incubation Period

As depicted in tables XVIII to XXIII, the incubation period showed slight variation with respect to host plants and alterations in temperature and humidity conditions and host plants. The period of incubation of *T. neocaledonicus* on *A. tricolor* at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH were recorded to be 5.17 ± 0.11, 4.44 ± 0.08 and 4.25 ± 0.07 days respectively (Table XVIII to XX; Plate IV, Figs. 1 to 3). On *V. unguiculata*, *T. neocaledonicus* took comparatively lesser duration to complete its incubation period which were recorded respectively as 4.58 ± 0.03, 3.17 ± 0.07 and 3.56 ± 0.06 days

for the different temperature – humidity combinations studied (Table XXI to XXIII; Plate V, Figs. 1 to 3).

1.3.2 Larval Period

The newly hatched larva (Plate I, Fig. 4) was small, hexapod, white in colour and devoid of pigmentation. It remained motionless for a short duration after hatching and then initiated feeding. While feeding, the larva inserted its stylets into the leaf tissue and actively sucked the tissue fluid. As feeding proceeded, a change of colour to pale yellow and later to light green was noted. The active period of the larva on *A. tricolor* lasted for 3.14 $\pm$ 0.09, 2.56 $\pm$ 0.03 and 2.29 $\pm$ 0.07 days respectively at 25 $\pm$ 2°C & 80 $\pm$ 5% RH, 30 $\pm$ 2°C & 70 $\pm$ 5% RH and 35 $\pm$ 2°C & 60 $\pm$ 5% RH (Tables XVIII to XX; Plate IV, Figs. 1 to 3). On *V. unguiculata*, the durations of larval period were 2.4 $\pm$ 0.06, 1.9 $\pm$ 0.05 and 2.42 $\pm$ 0.03 days for the temperature-humidity conditions *viz.*, 30 $\pm$ 2°C & 70 $\pm$ 5% RH and 35 $\pm$ 2°C & 60 $\pm$ 5% RH respectively (Tables XXI to XXIII; Plate V, Figs. 1 to 3).

1.3.3 Protonymphal period

Protonymph (Plate I, Fig. 5) was larger than the larva and had eight pairs of legs. It was pale yellowish green in colour and more active than the larva. Soon after emergence, the protonymph initiated feeding as a result of which the pale yellowish green colour changed to bright green. The durations of protonymphal period on *A. tricolor* at 25 $\pm$ 2°C & 80 $\pm$ 5% RH was recorded as 2.62$\pm$0.04 days, at 30 $\pm$ 2°C & 70 $\pm$ 5% RH, 2.35 $\pm$ 0.06 days and at 35 $\pm$ 2°C & 60 $\pm$ 5% RH, 2.14 $\pm$ 0.04 days (Tables XVIII to XX; Plate IV, Figs. 1 to 3). The active period of

protonymph on *V. unguiculata* extended for 2.1 ± 0.05 days at 25 ± 2ºC & 80 ± 5% RH, 1.6 ± 0.04 days at 30 ± 2ºC & 70 ± 5% RH and 1.54 ± 0.04 days at 35 ± 2ºC & 60 ± 5% RH (Tables XXI to XXIII; Plate V, Figs. 1 to 3). The protonymphal active period was followed by quiescence and subsequent moulting into the deutonymphal stage.

1.3.4 Deutonymphal period

Deutonymph or the last instar was larger in size (Plate I, Figs. 2, 6 & 7) and closely resembled the adult. Female and male deutonymphs could be clearly distinguished by the shape of the hysterosoma which was broader in the former and narrower in the latter. Feeding activity was followed by quiescence (Plate I, Figs. 2, 6 & 7) and moulting (Plate I, Fig. 7) as in earlier stages. The duration of the active deutonymphal life on *A. tricolor* was completed in 2.89 ± 0.04 days, 2.52 ± 0.02 days and 2.5 ± 0 days at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables XVIII to XX; Plate IV, Figs. 1 to 3). While the durations on *V. unguiculata* showed a slight decline up to 2.6 ± 0.03 days, 2.04 ± 0.03 days and 2.06 ± 0.03 days respectively at the 3 temperature-humidity conditions studied (Tables XXI to XXIII; Plate V, Figs. 1 to 3).

1.3.5 Quiescent periods

` A period of zero activity or quiescence was observed in the life of *T. neocaledonicus* at the end of active period of each developing stage. During this period, the individual ceased feeding and other visible life activities, became lethargic and selected a secluded area to enter into an inactive stage called quiescent

phase. While in quiescence, all the legs were withdrawn beneath the hysterosoma and the individual appeared ovoid in shape (Plate I, Figs. 2, 6 & 7). After a few hours, the body turned shiny and turgid. Prior to moulting, the cuticle became transparent in nature. In the life history of *T. neocaledonicus*, three quiescent phases, known as the first, second and third quiescence were noted, each at the end of the active larval, protonymphal and deutonymphal stages respectively. On *A. tricolor*, the Ist, IInd and IIIrd quiescence took around 1day, 0.6 day and 0.5 day for completion at 25 $\pm$ 2^{o}C & 80 $\pm$ 5% RH, 30 $\pm$ 2^{o}C & 70 $\pm$ 5% RH and 35 $\pm$ 2^{o}C & 60 $\pm$ 5% RH respectively (Tables XVIII to XX; Plate IV, Figs.1 to 3). The durations of the three quiescent phases on *V. unguiculata* were I day at 25 $\pm$ 2^{o}C & 80 $\pm$ 5% RH and 0.5 day at 30 $\pm$ 2^{o}C & 70 $\pm$ 5% RH and 35 $\pm$ 2^{o}C & 60 $\pm$ 5% RH respectively (Tables XXI to XXIII; Plate V, Figs.1 to 3). Thus the period of quiescence did not show much variation on different hosts and temperature-humidities either.

1.3.6 Moulting

Moulting, the process of emergence of an instar from the cuticle of the preceding instar facilitated by the splitting of the old cuticle along a definite line (or lines) of weakness was observed at the end of each quiescent phase of the larva, protonymph and deutonymph. Expansion of the body was a notable change observed at the onset of moulting. This was followed by the appearance of a horizontal split at the mid dorsal region between the second and third pairs of legs. The split further proceeded to either sides and finally met ventrally. A backward thrust exerted by the emerging individual helped to widen the split and emergence of the posterior

part of the body. It was followed by further backward crawling of the individual, resulting in the detachment of gnathosoma and legs from the moulting skin. The entire process required about 10-12 minutes for completion with no significant change in duration at different temperature-humidity conditions. Moulting skin, covering the anterior two pairs of legs was found intact whereas the posterior part was found split up into pieces, rarely remained intact after the emergence of the nymph (Plate I, Figs. 2 & 7).. The exuviae were often observed in groups over the leaf surface.

1.3.7 Adult Stages

Newly emerged male was creamy yellow in colour characterized by elongated legs. Eye spots were prominent and red in colour. Sexually mature male was smaller than female with a tapering hysterosoma (Plate I, Figs. 8 to 9). Adult male was very active and often moving in search of quiescent female deutonymph. Adult female was larger than the male with short legs. Feeding was initiated immediately after moulting and at this stage; they appeared light red in colour. As feeding progressed, the colour changed to dark red (Plate I, Figs. 1, 2, 6, 7 &10)

1.4 Mating

The process of sperm transfer was found achieved through copulation in this species. Mating occurred immediately after the moulting of the female deutonymph. In the laboratory cultures, males emerged comparatively earlier than the females. Soon after emergence, they were found moving in search of female deutonymphs in quiescence. As soon as a male encountered a female deutonymph ready for

moulting, the male rested close to the female, with his forelegs extending over the dorsum of the latter. When a split appeared on the cuticle of the female, the male was found pulling the posterior half of the cuticle and helping the female to come out of the exuvium (Plate I, Fig. 8). In several occasions, mating occurred even before completion of the moulting of the female deutonymph. During copulation, the male crawled beneath the female hysterosoma, lifting up the posterior end of the latter. Meanwhile, the male gripped himself firmly on the leaf surface by means of his hind legs. Posterior tip of the male hysterosoma was then held in a characteristic curved position, protruding the club shaped aedeagus upwards to the vagina of the female (Plate I, Figs. 8 to 9). Mating lasted for 2 to 3 minutes. At the end of the process, the male retracted the aedeagus and moved backwards. Then he moved away in search of a new female. A male was found inseminating an average of 10-12 females during his lifetime. The female copulated only once in her lifetime.

1.5 Parthenogenetic versus sexual development

T. neocaledonicus successfully performed both sexual and parthenogenetic reproduction. The sequence of events involved in the development from egg to the adult stage was similar in both types of reproduction. However, all the progeny comprised of males in the case of parthenogenetic development while in the sexual reproduction both males and females were produced with a sex ratio of 1:10. The durations of the various developmental stages in both the types of reproduction showed slight difference and were also found influenced significantly by variations in temperature-humidity conditions and host plants studied.

Observation

The duration of development of *T. neocaledonicus* on *A. tricolor* at 25 ± 2ºC & 80 ± 5% RH averaged 16.83 ± 0.2 days (Sexual - 17.2 ± 0.12 & Parthenogenetic -15.8 ± 0.2 days), at 30 ± 2ºC & 70 ± 5% RH was 13.8 ± 0.15 days (Sexual - 14.0 ± 0.13 & Parthenogenetic - 13.2 ± 0.08 days) and at 35 ± 2ºC & 60 ± 5% RH, 12.85 ± 0.14 days (Sexual - 13.1 ± 0.12 & Parthenogenetic - 12.3 ± 0.12 days) (Tables XVIII to XX; Plate VIII, Figs. 1 to 2). On *V. unguiculata*, the durations recorded at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 14.73 ± 0.07 days (Sexual - 14.8 ± 0.06 & Parthenogenetic - 14.4 ± 0.08 days), 10.25 ± 0.08 days (Sexual - 10.4 ± 0.07 & Parthenogenetic - 9.9 ± 0.08 days) and 11.1 ± 0.09 days (Sexual - 11.2 ± 0.08 & Parthenogenetic - 10.7 ± 0.08 days) respectively (Tables XXI to XXIII; Plate VIII, Fig.1 to 2). However, parthenogenetic development required relatively shorter duration compared to sexual development.

A comparison of the total duration of life cycle of *T. neocaledonicus* on *A. tricolor* under different temperature-humidity conditions enabled to record shorter duration of development at 35 ± 2ºC & 60 ± 5% RH and a longer duration at 25 ± 2ºC & 80 ± 5% RH (Plate VI, Figs. 1 to 2). At the same time, *T. neocaledonicus* produced more generations on *V. unguiculata* at 30 ± 2ºC & 70 ± 5% RH (Plate VII, Figs. 1 to 2) within a short span of time proving *V. unguiculata* as a more preferred host for the mite.

Results of life history studies showed that males were usually lesser in number when compared to that of females. At all 3 sets of temperature-humidity

conditions provided in the laboratory, sex ratio was found be 1-2:10, which coincided with the sex ratio, evidenced through field samplings of the mites.

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

In the genus *Tetranychus*, empodium of the female is distally split into 3 pairs of ventrally directed hairs. Empodium of tarsus I is widely separated. Dorsal body setae are long and slender with pointed tips. Aedeagus bent upwards. Only 1 pair of para-anal setae present.

Egg (Plate I, Fig. 4)

Measurements: Diameter 116 – 120 µm

The eggs were spherical, smooth, transparent and creamy white in colour when freshly laid (Plate I, Fig. 4). The colour of the eggs then changed to pale yellow and later to orange. The eggs appeared bright orange in colour and a portion of gnathosoma, eye spots and legs of the larvae could be easily perceived through the egg case, few hours prior to hatching.

Larva (Plate I, Fig. 4; Plate IX, Figs. 1 to 2)

Colour: Pale yellow
Measurements: Length: 210 – 228 µm
Width : 128 – 168 µm

Dorsal region (Fig. 1)

Observation

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

Ventral region (Fig. 2)

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

Protonymph (Plate I, Fig. 5; Plate IX, Figs. 3 to 4)

Colour:	Yellowish green
Measurements:	Length: 246 – 282 µm
	Width : 182 – 237 µm

Dorsal region (Fig. 3)

Striations present; rostrum narrow and protruding; stylets long, parallely running forward, extended far beyond the anterior margin of the rostrum; peritreme as in the larva; propodosoma broader posteriorly; pedipalp 4 segmented and terminates in a sensillus; dorsal setae 12 pairs, long, thin and smooth.

Ventral region (Fig. 4)

Setae MV_1 and MV_2 present; 1 pair long, smooth and tapering post-genital setae (*POG*) present; anal area well demarcated with 2 pairs of anal and 2 pairs of para-anal setae; 4 pairs of legs, number of setae on tarsus of legs 1-4: 12, 12, 14 and 14.

Deutonymph (Plate I, Fig. 2; Plate X, Figs. 1 to 2)

Colour: Pale red

Measurements: Length: 332 – 364 µm

Width : 200 – 246 µm

Dorsal region (Fig. 1)

Striations on whole body surface including legs; rostrum stout and broad; stylets discernible; peritreme curved downward with a hook like tip; anterior region of propodosoma more straightened; dorsal setae longer than setae of ventral side; 13 pairs of dorsal setae, 1 pair added anew, all dorsal setae smooth and pointed, seta P_2 longest and D_2 shortest.

Ventral region (Fig. 2)

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

Adult Female (Plate I, Figs. 1, 7 & 10; Plate X, Figs. 3 to 4)

Colour: Bright red

Measurements: Length: 382 – 410 µm

Width : 202 – 301 µm

Dorsal region (Fig. 3)

Striations clearly marked; propodosoma rounded anteriorly; stylets basally originated; pedipalp stout, four segmented, terminating in small and strong

sensillum; peritreme distally curved; 13 pairs of long, smooth and pointed setae on dorsal region.

Ventral region (Fig. 4)

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

Leg

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

Adult Male (Plate I, Fig. 8; Plate XI, Figs. 1 to 2)

Colour: Creamy yellow

Measurements: Length: 364 – 387 µm

Width : 191 – 205 µm

Adult male differs from the female in the following features.

Body elongated and tapering posteriorly; aedeagal knob (Plate I, Figs. 8 & 9) berry like and the anterior rounded projection better developed than the rounded posterior projection.

Leg

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

2. Post embryonic development of *T. ludeni* Zacher

2.1 Oviposition

Adult females exhibited a general preference to the upper surface of the leaves though no specific selection of site for depositing eggs was noticed. Ovipositing females constructed silken webs prior to the deposition of the eggs. In several occasions, females were found depositing eggs at random on the webbing. The process of oviposition was similar to that of *T. neocaledonicus*. The eggs deposited were solitary and scattered on leaf surface (Plate XII, Fig. 2). The eggs were spherical and transparent when freshly laid. In the following day, they turned pale yellow in colour and finally to orange on the third day. Prior to hatching, part of gnathosoma, eye spots and legs of the larva could be seen through the egg case.

The pre-oviposition period of *T. ludeni* was recorded to be 1.9 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH, 0.5 ± 0 days at 30 ± 2ºC & 70 ± 5% RH and 1 ± 0 day at 35 ± 2ºC & 60 ± 5% RH. The oviposition periods at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were respectively 5.7 ± 0.26 days, 11.5 ± 0.38 days and 10.9 ± 0.75 days. While the respective durations of post-oviposition periods were 0.6 ± 0.12, 0.5 ± 0 and 0.8 ± 0.22 for the 3 different temperature-humidity combinations studied (Table XXIV; Plate XIII, Fig. 1).

Fecundity was recorded minimum on the 1st and 2nd days of oviposition under laboratory conditions. On the 4th or 5th days (mid- days) of oviposition, the fecundity attained the maximum level and it showed a gradual decline from the 6th day onwards, reaching the minimum on the final day of oviposition. Fecundity of *T. ludeni* recorded for the temperature-humidity conditions *viz.*, 25 ± 2ºC & 80 ± 5%

RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH on *M. deeringiana* was 28.3 ± 2.2 (Mated 33.4 ± 2.8 & Virgin 23.2 ± 1.1), 83.6 ± 3.4 (Mated 91.2 ± 3.6 & Virgin 75 ± 2.6) and 74.5 ± 2.8 (Mated 81.8 ± 1.7 & Virgin 67.2 ± 2.3) respectively (Tables XXV to XXVII; Plate XIII, Fig.2).

Longevity showed slight change in durations at 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH which were recorded respectively as 12.6 ± 0.37 days (Mated – 12 ± 0.35 days & Virgin - 13.2 ± 0.58 days) and 12.7 ± 0.95 days (Mated - 12.7 ± 1.3 days & Virgin - 12.7 ± 1.5 days). While the same showed slight decline at 25 ± 2ºC & 80 ± 5% RH and was recorded as 8.0 ± 0.3 days (Mated - 8.1 ± 0.48 days & Virgin - 8.0 ± 0.4 days) (Tables XXV to XXVII).

2.2 Hatching

The beginning of the process was marked by an increase in the size of the egg at the equatorial region. Consequently, a small slit appeared at this region which gradually got extended to either sides. Later, a few wrinkles appeared at the split end of the egg case. Fluid discharge from the egg was also noted. Following this, the split got widened gradually by the wriggling movements of the larva resulting in the exposure of the hysterosoma of the larva. Further thrusting action of the individual exposed the third pair of legs also which were soon anchored on the leaf surface. Then the entire larva slipped out the anterior 2 pairs of legs and the gnathosoma leaving behind the egg case. The whole process was completed within a period of 10 to 12 minutes for all the temperature-humidity conditions studied.

2.3 Duration of developmental stages

2.3.1 Incubation period

The incubation period of *T. ludeni* on *M. deeringiana* was observed to range from 3.81 ± 0.07 at 25 ± 2ºC & 80 ± 5% RH, 2.64 ± 0.06 days at 30 ± 2ºC & 70 ± 5% RH and 2.89 ± 0.06 days at 35 ± 2ºC & 60 ± 5% RH (Tables XXVIII toXXX; Plate XIV Fig. 1 to 3).

2.3.2 Larval period

The newly hatched larva (Plates XII, Fig. 3) could be easily distinguished by its small size and the presence of 3 pairs of legs. It was the smallest among the life stages. The larva just after hatching was creamy white in colour except for the distinctly visible reddish eye spots. After emergence, the larva remained inactive for 5 to 10 minutes and then initiated feeding. Feeding characteristics resembled that of the larva of *T. neocaledonicus.* As feeding proceeded, the colour of the larva turned into greenish yellow. The active larval period lasted for 1.37 ± 0.06 days at 25 ± 2ºC & 80 ± 5% RH, 1.06 ± 0.03 days at 30 ± 2ºC & 70 ± 5% RH and 1.1 ± 0.04 days at 35 ± 2ºC & 60 ± 5% RH (Tables XXVIII to XXX). At the end of the active period, the larva entered into an inactive stage called the first quiescence which was followed by moulting and emergence of the protonymph (Plate XIV, Figs. 1 to 3).

2.3.3 Protonymphal period

Protonymph (Plate XII Fig. 4) or the first stage nymph was an active instar characterized by the presence of 4 pairs of legs. It was larger in size, pale yellow in

colour with greenish spots on its dorsolateral region. Feeding started at about 5 to 10 minutes after moulting from the quiescent stage. The active protonymphal period extended for 1.5 ± 0 days at 25 ± 2ºC & 80 ± 5% RH, 1.08 ± 0.06 day at 30 ± 2ºC & 70 ± 5% RH and 1.2 ± 0.07 days at 35 ± 2ºC & 60 ± 5% RH (Tables XXVIII to XXX). At the end of the active period, the protonymph entered into the second quiescent phase, followed by the process of moulting into the deutonymph (Plate XIV, Figs. 1 to 3).

2.3.4 Deutonymphal period

The deutonymph or the second stage nymph was slightly larger in size (Plate XII, Fig. 6) than the protonymph. This instar resembled the adult but was smaller in size, darker in colour and differing in the pattern of setation. The feeding activity of deutonymph started 5 to 10 minutes after moulting and continued till it attained third quiescence. The deutonymphal period on *M. deeringiana* was completed in 2.46 ± 0.03 days, 1.87 ± 0.04 days and 1.94 ± 0.03 days at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables XXVIII to XXX; Plate XIV, Figs. 1 to 3).

2.3.5 Quiescent Periods

T. ludeni entered into an inactive stage called quiescent phase at the end of active period of each developing stage. During this period, the third pair of legs was found folded beneath the hysterosoma while the first two pairs were directed forwards (Plate XII, Fig. 5). An interesting feature noted in this species was the tendency of aggregation during the larval and nymphal quiescent periods. The larva

entering quiescence selected a suitable site under the webbing and moved in close proximity and gradually became stationary close to each other. Subsequently, other larvae and nymphs were found moving to seek positions close to their preceders. In an aggregation of quiescent instars, direct body contact between neighboring individuals was a common feature. The colony of quiescent individuals was found acquiring more or less a circular form due to participation of individuals from all directions and this structure remained intact until the completion of moulting. The respective durations of the three quiescent phases of *T. ludeni* on *M. deeringiana* at 25 ± 2ºC & 80 ± 5% RH were 1.58 ± 0.06, 1.29 ± 0.06 & 1.08 ± 0.06, at 30 ± 2ºC & 70 ± 5% RH 0.87 ± 0.06, 1.00 ± 0 & 1.00 ± 0 and at 35 ± 2ºC & 60 ± 5% RH 0.96 ± 0.03, 1.00 ± 0 & 1.00 ± 0 days (Tables XXVIII to XXX; Plate XIV, Figs. 1 to 3).

2.3.6 Moulting

The process of moulting of individuals to the successive nymphal or adult stage marked the termination of aggregation. Moulting in *T. ludeni* resembled that of *T. neocaledonicus*. It was but a gradual process completed within 20 to 25 minutes duration.

2.3.7 Adult Stages

Freshly moulted adult can be distinguished to their sexes with ease. The adult male was much smaller in size, pale yellow in colour and spindle shaped (Plate XII, Fig. 8). Males moved faster than females and were found in less number compared to female (1-2:10). The adult female was much larger than the male, reddish in colour with cylindrically shaped abdomen (Plate XII, Fig. 7).

2.4 Mating

Copulation (Plate XII, Fig. 9) in this species occurred immediately after the final moult of the female deutonymph. The mating behaviour of the adults closely resembled the process explained in the case of *T. neocaledonicus*. But in *T. ludeni*, the same female was found engaged in multiple mating with different males, which was not observed in *T. neocaledonicus.*

2.5 Parthenogenesis versus Sexual development

Like *T. neocaledonicus*, *T. ludeni* also performed both sexual and parthenogenetic reproduction. However, the series of events involved in both the species was similar in both types of reproduction. Also, all the progeny were found to be males in the case of parthenogenetic development while in the sexual reproduction both males and females were produced with a sex ratio of 1-2:10. The durations of the various developmental stages in both the types of reproduction were found influenced significantly by variations in temperature-humidity conditions.

The total duration of development on *M. deeringiana* was found to be 12.85 $\pm$ 0.19 days (Sexual - 13.25 $\pm$ 0.24 days & Parthenogenetic - 12.46 $\pm$ 0.19 days) at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 9.54 $\pm$ 0.18 days (Sexual - 10.04 $\pm$ 0.13 days & Parthenogenetic - 9.04 $\pm$ 0.13 days) at 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 10 $\pm$ 0.17 days (Sexual - 10.54 $\pm$ 0.08 days & Parthenogenetic - 9.46 $\pm$ 0.1 days) at 35 $\pm$ 2ºC & 60 $\pm$ 5% RH (Tables XXVIII to XXX). The parthenogenetic development required comparatively shorter duration for the 3 temperature-humidity combinations considered (Plates XV to XVI).

2.6 Morphological description of the life stages of *T. ludeni* Zacher, 1913

Egg (Plate XII, Fig. 2)

Measurements: Diameter 131.2 – 134.1 µm

Eggs were spherical in shape, smooth and transparent when freshly laid. The colour of the egg turned yellow and later to orange, prior to hatching. Eye spots could be clearly perceived as a pair of dark red spots through the egg case few hours before hatching was initiated.

Larva (Plate XII, Fig. 3; Plate XVII, Figs. 1 to 2)

Colour: Pale yellow with greenish spots

Measurements Length: 205.11 – 208.91 µm

Width : 140.42 – 145.32 µm

Dorsal region (Fig. 1)

Rostrum slightly protruding; stylets short; peritremes almost straight with blunt apex; Setae P_1 shortest and P_2 longest among propodosomal setae; hysterosoma with 9 pairs of setae, all setae smooth, elongated and pointed.

Ventral region (Fig. 2)

Medioventral setae MV_1 and MV_2 present; genital area indistinct; anal region marked by a longitudinal opening, 2 pairs of anal and 1 pair of para-anal setae present, anal setae short and smooth, para-anal setae long and smooth.

Protonymph (Plate XII, Fig. 4; Plate XVII, Figs. 3 to 4)

Colour: Pale yellow

Measurements Length:350.38 – 356.22 µm

Width: 192 – 200 µm

Dorsal region (Fig. 3)

Rostrum protruded, slightly longer; peritremes directed posteriorly with curved apex; seta P_1 much shorter; 9 pairs of hysterosomal setae, seta D_4 and L_4 moved more anteriorly.

Ventral region (Fig. 4)

Genital area indistinct, 1 pair of long, smooth and pointed post genital seta (*POG*) present; anal area similar to larva.

Deutonymph (Plate XII, Fig. 6; Plate XVII, Figs. 5 to 6)

Colour: Reddish brown

Measurements**:** Length:353 – 362.86 µm

Width: 195 – 201.54 µm

Dorsal region (Fig. 5)

Peritremes arched and apex curved laterally; 3 pairs of propodosomal and 10 pairs of hysterosomal setae present, seta D_5 short, smooth, pointed and added anew.

Ventral region (Fig. 6)

3 pairs of medio-ventral setae present, all smooth, elongated and pointed; 1 pair of pre genital setae (*PRG*) and a pair of post genital setae (*POG*) present, *PRG* longer than *POG*; anal region distinct with 2 pairs of anal and 1 pair of para-anal setae.

Adult female (Plate XII, Fig. 7; Plate XVIII, Figs. 1 to 2)

Colour: Red

Measurements: Length:365 – 400.18 µm

Width: 250 – 320 µm

Dorsal region (Fig. 1)

Gnathosoma large and protruded anteriorly; peritremes backwardly directed and curved inwards; palpus with terminal sensillum 1.5 times as long as broad, dorsal sensillum long and slender; dorsal idiosomal setae longer than the interval between their longitudinal bases; seta P_1 shortest and P_2 longest among propodosomal setae; dorsal striae on propodosoma bilobed; all hysterosomal setae long and pointed, seta D_5 shorter.

Ventral region (Fig. 2)

Setae MV_1, MV_2 and MV_3 present; seta *PRG* thicker than *POG* and situated far anterior to genital opening, seta an_1 short and slender; single pair of para-anal setae present.

Leg

Tibia I with 1 sensory and 9 tactile setae, tarsus I with 1 sensory and 4 tactile setae proximal to duplex setae; tibia II with 2 sensory and 5 tactile setae, tarsus II with 2 sensory and 4 tactile setae proximal to duplex setae.

Adult Male (Plate XII, Fig. 8; Plate XVIII, Figs. 3 to 4)

Colour: Pale yellow

Measurements: Length:340 – 372 µm

Width: 208 – 219 µm

Adult male differs from the female in the following features:

Body elongated, idiosoma slender and pointed posteriorly; setae P_1, P_2 and P_3 shorter than that of female; terminal sensillum of palpus 3 times as long as wide, dorsal sensillum slender; peritreme at the distal end hooked; dorsal idiosomal setae thin, slender, 2 times longer than their mutual distance at base; aedeagus bent upwards at right angle, terminating distally with a small knob, aedeagal knob very small with no posterior angulations.

Leg

Tibia I with 2 sensory and 10 tactile setae, tarsus I with 2 sensory and 5 tactile setae proximal to duplex setae; tibia II with 1 sensory and 6 tactile setae, tarsus II with 1 sensory and 4 tactile setae proximal to duplex setae.

3. Postembryonic development of the carmine spider mite, *T. cinnabarinus* (Boisduval)

3.1 Oviposition

The females were found depositing eggs in groups, though the eggs were separate from each other. They were mostly laid on the underside of the leaf surface or attaching to the webbing spun by them extensively, prior to oviposition. The eggs were spherical, shiny and yellow coloured when freshly laid. Gradually, the colour changed to bright orange, few hours before hatching. Oviposition pattern was similar to *T. neocaledonicus* and *T. ludeni.*

The period of pre-oviposition of *T. cinnabarinus* on *C. papaya* at 25 ± 2ºC & 80 ± 5% RH was recorded to be 1 ± 0 day, while that at 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 0.5 ± 0 day. On *D. lablab*, a slight increase up to 1.25 ± 0.08 day was observed at 25 ± 2ºC & 80 ± 5% RH though the durations were same as in the case of *C. papaya* at 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH. The respective durations of oviposition on *C. papaya* at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 10 ± 0.1 days, 8.65 ± 0.15 days and 6.45 ± 0.12 days. While on *D. lablab*, the oviposition periods were 9.45 ± 0.17 days, 8.05 ± 0.14 days and 6.1 ± 0.07 days respectively for the 3 temperature-humidity combinations studied. The post-oviposition periods recorded on *C. papaya* were 2.15 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH and 0.5 ± 0 day at 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH. A slight decrease in duration *viz.*, 1.8 ± 0.24 days , 0.65 ± 0.07 and 0.5 ± 0 days could be observed respectively at

25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH on *D. lablab* (Tables XXXI to XXXII; Plate XX, Figs. 1 to 2).

The maximum number of eggs were laid between the 2nd and 4th days of the oviposition period. This trend was common in both mated and virgin females. However, the average fecundity was found more in the case of mated females at all 3 temperature- humidity combinations and on different hosts. The total number of eggs laid per female on *C. papaya* were 23.5 ± 1.4 (Mated - 27.0 ± 1.3 & Virgin - 20.0 ± 0.7) at 25 ± 2ºC & 80 ± 5% RH, 40.7 ± 1.8 (Mated - 45.2 ± 1.6 & Virgin - 36.2 ± 1.3) at 30 ± 2ºC & 70 ± 5% RH and 33.2 ± 3.2 (Mated - 41.0 ± 1.9 & Virgin - 25.6 ± 3.6) at 35 ± 2ºC & 60 ± 5% RH. On *D. lablab,* fecundity recorded at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 25.2 ± 1.59 (Mated - 29.4 ± 1.1 & Virgin - 21.0 ± 1.2), 42.5 ± 2.1 (Mated - 47.8 ± 1.9 & Virgin - 37.2 ± 1.5) and 33.9 ± 3.5 (Mated - 41.6 ± 3.5 & Virgin - 26.2 ± 3.2) respectively (Tables XXXIII to XXXVIII; Plate XXI, Figs. 1 to 2).

Longevity of the females on *C. papaya* was 13.1 ± 0.13 days (Mated - 13.1 ± 0.2 days & Virgin - 13.2 ± 0.2 days) at 25 ± 2ºC & 80 ± 5% RH, 9.6 ± 0.15 days (Mated - 9.7 ± 0.2 days & Virgin - 9.6 ± 0.25 days) at 30 ± 2ºC & 70 ± 5% RH and 6.2 ± 0.54 days (Mated - 6.1 ± 0.62 days & Virgin - 6.3 ± 0.96 days) at 35 ± 2ºC & 60 ± 5% RH. The respective durations of longevity were comparatively shorter on *D. lablab* at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH *viz.,* 12.4 ± 0.19 days (Mated & Virgin - 12.4 ± 0.3 days), 9.2 ± 0.13 days (Mated - 9.3 ± 0.2 days & Virgin - 9.1 ± 0.19 days) and 6.8 ± 0.24 days (Mated - 6.4

± 0.37 days & Virgin - 7.2 ± 0.20 days) (Tables XXXIII - XXXVIII).

3.2 Hatching

Hatching was initiated at the end of final day of incubation by the marked appearance of a slit, which progressed to either sides of the egg, resulting in the separation of the egg shell into equal upper and lower halves. Formation of the slit required 5 to 6 minutes. It was hastened by the active movement and thrusting action of the emerging larva which favoured protrusion of its legs and mouth parts. Later, the larva was found struggling out of the egg shell by a backward movement using its hind legs. The entire process was completed within 12 – 15 minutes irrespective of the variations in the temperature-humidity conditions and host plants studied.

3.3 Duration of developmental stages

3.3.1 Incubation period

The incubation period was found to vary slightly with respect to change in temperature-humidity combinations and host plants in *T. cinnabarinus* as reflected in tables XXXIX to XLIV. The respective durations on *C. papaya* at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 3.58 ± 0.10, 2.9 ± 0.04 and 2.7 ± 0.07 days (Tables XXXIX to XLI; Plate XXII, Figs. 1 to 3) while the durations of the same on *D. lablab* were 3.5 ± 0.04, 2.71 ± 0.07 and 2.67 ± 0.07 days respectively (Tables XLII to XLIV; Plate XXIII, Figs. 1 to 3).

3.3.2 Larval period

The larva was small, hexapod and yellowish with slight sexual dimorphism

especially at the hysterosomal region. The larva remained motionless for a short duration after hatching and then initiated feeding. During active feeding, the larva penetrated its stylets into the leaf tissue and sucked the tissue fluid. As feeding progressed, a change in colour of the hysterosoma from yellow to red was noted. Active life of the larva on *C. papaya* at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH could be recorded as 1.7 ± 0.07, 1.12 ± 0.06 and 0.91 ± 0.06 days respectively (Tables XXXIX to XLI; Plate XXII, Figs. 1 to 3). On *D. lablab* the durations were recorded respectively as 1.7 ± 0.07, 1 ± 0 and 0.58 ± 0.06 days (Tables XLII to XLIV; Plate XXIII, Figs. 1 to 3). Resembling the other tetranychid larvae described earlier, the larva of *T. cinnabarinus* also passed through the first quiescent phase, which subsequently moulted into the 1st nymphal stage or the protonymph.

3.3.3 Protonymphal period

The protonymph differed from the larva by its slightly larger size, reddish brown colouration and possession of 4 pairs of legs (Plate Fig.). The protonymph was more active than the larva. Feeding activity, quiescence and emergence were similar to those of the larva. The active period of the protonymph on *C. papaya* lasted for 1.29 ± 0.07, 1 ± 0 and 0.75 ± 0.08 days respectively at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH (Tables XXXIX to XLI; Plate XXII, Figs. 1 to 3). The respective durations of protonymphal period on *D. lablab* were 1.25 ± 0.08, 0.79 ± 0.07 and 0.73 ± 0.08 days for the temperature-humidity combinations studied (Tables Tables XLII to XLIV; Plate XXIII,

Figs. 1 to 3).

3.3.4 Deutonymphal period

Deutonymphal stage (Plate Fig.) showed marked resemblance with the adult stage, except for the smaller size, paler colour and difference in setation. Sexual dimorphism was quite obvious at this stage. The hysterosoma of the female was markedly robust due to ovarian development while that of the male tapered towards the anal region. Deutonymph exhibited voracious feeding which progressed till quiescence. The active deutonymphal period was observed to be 1 ± 0 day at 25 ± 2ºC & 80 ± 5% RH on *C. papaya* and *D. lablab.* A slight difference in duration of 0.75 ± 0.07 and 0.9 ± 0.07 days was recorded on *C. papaya* and 0.71 ± 0.07 and 0.7 ± 0.08 days on *D. lablab* for the temperature-humidity conditions *viz.*, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables XXXIX to XLIV; Plates XXII to XXIII, Figs. 1 to 3).

3.3.5 Quiescent periods

Like *T. neocaledonicus* and *T. ludeni*, *T. cinnabarinus* too became lethargic at the end of active larval and nymphal stages. The feeding activity of the life stages got diminished and they settled at a suitable site, preferably near the mid rib or major veins on the leaf surface. The individual penetrated its stylets into the leaf tissue and remained sedentary throughout the quiescent period. The legs were retained beneath its body. As the quiescence approached its final stage, the cuticle turned transparent. The durations of Ist, IInd and IIIrd quiescent phases on *C. papaya*

were 1.45 ± 0.04, 1.37 ± 0.06 and 1.8 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH, 0.67 ± 0.07, 0.70 ± 0.07 and 0.75 ± 0.07 days at 30 ± 2ºC & 70 ± 5% RH and 0.5 ± 0 day for all the stages at 35 ± 2ºC & 60 ± 5% RH (Tables XXXIX to XLI; Plate XXII, Figs. 1 to 3). At 25 ± 2ºC & 80 ± 5% RH, the respective durations of quiescence on *D. lablab* were 1.3 ± 0.07, 1.2 ± 0.07 and 1.5 ± 0 days, at 30 ± 2ºC & 70 ± 5% RH, 0.5 ± 0, 0.83 ± 0.07 and 0.75 ± 0.08 day and at 35 ± 2ºC & 60 ± 5% RH, 0.5 ± 0 day for all the 3 quiescent stages (Tables XLII to XLIV; Plate XXIII, Figs. 1 to 3).

3.3.6 Moulting

At the end of each quiescent phase, the individual emerged out into the successive instar by the process of moulting. A crack appeared at the dorsal region below the propodosoma which widened by the forceful movements of the individual. The moulting individual subsequently detached itself from the exuviae and resumed its normal life activities. The entire process was similar to that of *T. neocaledonicus* and *T. ludeni* and required about 25 minutes for completion.

3.3.7 Adult Stages

Adult male was very active, slightly smaller than the female with a wedge shaped hysterosoma, bearing a black spot on either lateral side. (Plate Fig.). The adult females were larger, reddish and more or less elliptical in shape. The emergence of females after moulting immediately followed copulation and active feeding prior to the initiation of oviposition. Males either wandered actively, searching for females for mating or engaged in feeding activity.

3.4 Mating

The males which emerged earlier than the females were found waiting close to quiescent female deutonymphs. As soon as the female deutonymph initiated moulting the male assisted in peeling off of the exuvium of the moulting stage. When the female became receptive to males, it stopped moving. Immediately the male crawled beneath the body of the female and bent its posterior part of hysterosoma upwards to reach the ventral side of female hysterosoma. Sperm transfer was made possible by the male through its extruded aedeagus into the female genital pore. The males then retracted and moved in search of new females. Males mated frequently with a few minutes interval, taking 17 to 24 seconds with an average of 20 seconds. The females died within hours after egg laying. An interesting observation was the cannibalistic behaviour of *T. cinnabarinus* males on females of the same species.

3.5 Parthenogenesis versus Sexual development

As recorded in the spider mites studied earlier, the females of *T. cinnabarinus* exhibited two types of reproduction – sexual and parthenogenetic. The eggs laid by mated females developed into both males and females while those of virgin females developed only into males. The total duration of development showed variation with temperature-humidity conditions and host plants.

The durations of development of *T. cinnabarinus* on *C. papaya* at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH averaged 12.16 $\pm$ 0.15 days (Sexual - 12.4 $\pm$ 0.14 & Parthenogenetic - 11.5 $\pm$ 0 days), at 30 $\pm$ 2ºC & 70 $\pm$ 5% RH was 7.95 $\pm$ 0.14 days (Sexual - 8.55 $\pm$

0.09 & Parthenogenetic - 7.4 ± 0.12 days) and at 35 ± 2ºC & 60 ± 5% RH 6.62 ± 1.8 days (Sexual - 6.83 ± 0.16 & Parthenogenetic - 6.0 ± 0 days) (Tables XXXIX to XLI; Plates XXII & XXIV). On *D. lablab*, the durations recorded at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH were 11.37 ± 0.17 days (Sexual - 11.8 ± 0.15 & Parthenogenetic - 10.8 ± 0.12 days), 7.33 ± 0.13 days (Sexual - 7.5 ± 0.12 & Parthenogenetic - 6.8 ± 0.17 days) and 6.27 ± 0.15 days (Sexual - 6.4 ± 0.13 & Parthenogenetic - 5.7 ± 0.25 days) respectively (Tables XLII to XLIV; Plates XXIII & XXV). However, parthenogenetic development required comparatively shorter duration compared to sexual development. Further, mortality rate was observed to be higher at 35 ± 2ºC & 60 ± 5% RH on both the host plants studied (Plate XXVI, Figs. 1 to 2).

3.6 Morphological description of the life stages of *T. cinnabarinus* (Boisduval, 1867)

Egg (Plate XIX, Figs. 1,8 & 10)

Measurements: Diameter 109 – 118 µm

Freshly deposited eggs were spherical, shiny and yellow coloured. The colour of the eggs gradually changed to pale yellow and bright orange few hours before hatching. Through the translucent egg case, red eye spots could be clearly seen.

Larva (Plate XIX, Fig. 3 & 6; Plate XXVII, Figs. 1 to 2)

Colour: Pale yellow

Measurements: Length: 144 – 156 µm

Width : 114 – 121 µm

Dorsal region (Fig.1)

Transparent and oval in shape; rostrum elongated and protruding; peritremes elongate with curved apex; stylets short; 12 pairs of elongated hysterosomal setae present; seta P_1 shortest among propodosomal setae, all setae elongated and pointed.

Ventral region (Fig.2)

Medioventral setae MV_1 and MV_2 present; anal area shows presence of a longitudinal opening; 2 pairs of anal and 1 pair of para-anal setae, para-anal setae slightly longer than anal setae; 3 pairs of legs.

Protonymph (Plate XIX, Figs. 4 & 6; Plate XXVII, Figs. 3 to 4)

Colour: Reddish brown

Measurements Length: 175 – 190 µm

Width : 149 – 158 µm

Dorsal region (Fig.3)

Rostrum protruding; stylets longer; peritremes elongate with curved apex; seta P_1 much shorter; 12 pairs of hysterosomal setae present.

Ventral region (Fig.4)

Setae MV_1 and MV_2 present; 1 pair of smooth post genital setae (*POG*) present; anal area distinct with 2 pairs of anal and 1 pair of para-anal setae; 4 pairs of legs.

Deutonymph (Plate XIX, Fig. 6; Plate XXVII, Figs. 5 to 6)

Colour: Red

Measurements: Length: 270 – 294 µm

Width : 251 – 262 µm

Dorsal region (Fig.5)

Peritremes elongate with arched apex; 3 pairs of propodosomal and 9 pairs of hysterosomal setae present; dorsal setae longer than ventral setae.

Ventral region (Fig.6)

Setae MV_3 added a new, MV_1 and MV_2 present, all smooth, long and pointed; 1 pair of pre-genital setae (*PRG*) and 1 pair of post-genital setae (*POG*) present; anal area distinct with 2 pairs of anal and 1 pair of para-anal setae.

Adult female (Plate XIX, Figs. 1, 2, 8 & 11 ; Plate XXVIII, Figs. 1 to 2)

Colour: Carmine red

Measurements: Length: 345 – 371 µm

Width : 276 – 291 µm

Dorsal region (Fig.1)

Palpus with terminal sensillum 2 times as long as broad; Propodosoma rounded anteriorly; pedipalp 5 segmented; 13 pairs of long, smooth and pointed setae on dorsal side.

Ventral region (Fig.2)

3 pairs of medio-ventral setae present, MV_1, MV_2 and MV_3 simple and pointed; anal area distinct with 2 pairs of anal and 1 pair of para-anal setae, anals short and

para-anals long; well developed genital area with 1 pair of *PRG* and 1 pair of *POG*.

Leg

Tibia I with 1 sensory and 9 tactile setae, tarsus I with 1 sensory and 3 tactile setae proximal to duplex setae; tibia II with 7 tactile setae, tarsus II with 1 sensory and 4 tactile setae proximal to duplex setae.

Adult Male (Plate XIX, Fig. 12; Plate XXVIII, Figs. 3 to 4)

Colour:	Greenish yellow	
Measurements:	Length:	324 – 330 µm
	Width:	201 – 217 µm

Adult male differs from the female in the following features: Smaller and slender; axis of aedeagal knob forming a strong angle with axis of shaft, posterior angulation being equal to anterior angulation.

Leg

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

4. Postembryonic development of the citrus brown mite, *E. orientalis* (Klein)

4.1 Oviposition

Adult females were found depositing eggs in proximity, randomly on the upper surface of the leaf (PlateXXIX, Figs. 3 & 5). Hence, the eggs deposited were found in colonies. No specific site preference was noted during oviposition, although more eggs were laid along the mid rib of the leaves. Prior to the deposition of eggs, the adult female after making a firm grip on the leaf surface with her first pair of legs, slowly extruded the egg by raising the posterior part of her hysterosoma. Subsequently, the female exhibited random movement over the newly deposited egg and secreted an adhesive coating over the egg.

Freshly laid eggs were disc shaped and translucent. At the end of the first day of oviposition, a dark brown spot appeared on one side of the egg. The colour of the egg then changed to yellowish brown during the second day and later to orange on the third day. The eye spots appeared as a pair of dark red spots, few hours prior to hatching.

The pre-oviposition period of *E. orientalis* on *M. oleifera* could be recorded as 1.1 $\pm$ 0.067 days at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH and 0.5 day at 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH. Oviposition period recorded for the temperature-humidity conditions *viz.*, 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH on *M. oleifera* comprised 8.2 $\pm$ 0.24, 6.4 $\pm$ 0.16 and 7.7 $\pm$ 0.15

days respectively. The respective post-oviposition period of the mite observed constituted 1.75 ± 0.25, 0.6 ± 0.067 and 0.4 ± 0.07 days for the three temperature-humidity conditions studied (Table XLV: Plate XXX, Fig. 1).

Fecundity was recorded minimum during the 1st and 2nd days of oviposition under laboratory conditions. During the 4th or 5th days of oviposition, the fecundity attained the maximum level and it showed a gradual decline from the 6th day onwards, reaching the minimum on the final day of oviposition. Fecundity recorded for the temperature-humidity conditions *viz.*, 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH on *M. oleifera* was 27.1 ± 2.0 (Mated - 31.0 ± 1.7 & Virgin - 23.2 ± 2.9), 33.9 ± 2.4 (Mated - 38.0 ± 2.6 & Virgin - 29.8 ± 3.3) and 30.0 ± 2.1 (Mated - 35.2 ± 1.9 & Virgin - 25.0 ± 1.7) respectively. On *M. oleifera* the respective longevity range was observed to be 11.1 ± 0.39 days (Mated - 10.6 ± 0.6 days & Virgin - 11.5 ± 0.45 days), 7.5 ± 0.14 days (Mated - 7.4 ± 0.24 days & Virgin - 7.6 ± 0.19 days) and 8.6 ± 0.14 days (Mated - 8.6 ± 0.19 & Virgin - 8.6 ± 0.24) for the three temperature-humidity conditions studied (Tables XLVI to XLVIII; Plate XXX, Fig.2).

4.2 Hatching

The process of hatching was initiated by the appearance of a semicircular slit at the end of the final day of incubation. Prior to the initiation of hatching, inflation of the egg and subsequent development of a hyaline area beneath the upper part of the egg shell could be noted. The slit formed continued to either side followed by wriggling movements of the larva. These movements widened the slit, separating

the egg shell into an upper and a lower half. This enabled the larva to protrude its first two pairs of legs through the slit. This was followed by the thrusting action of the upper part of the egg shell and protrusion of the larval mouth parts. Later, the larva was found struggling out of the egg shell through a backward kick using its hind legs. Since the division was not complete, the two halves of the egg shell were held together along a small length. Such discarded egg cases could be located at the hatching sites. The entire process of hatching was completed within 10 to 15 minutes for all the temperature-humidity conditions studied.

4.3 Duration of developmental stages

4.3.1 Incubation period

As represented in tables XLIX to LI and plate XXXI, the incubation period showed slight variation with respect to alterations in temperature-humidity conditions. The respective duration of incubation on *M. oleifera* at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH could be noted as 4.25 $\pm$ 0.07 days, 3.04 $\pm$ 0.04 days and 3.12 $\pm$ 0.06 days (Tables XLIX to LI; Plate XXXI, Figs. 1 to 3).

4.3.2 Larval period

The newly hatched larva (Plate XXIX Fig. 6) was small, hexapod and bright orange in colour. Soon after hatching, it remained motionless for a short span of time after which, it initiated feeding. During feeding, the larva inserted its stylets into the leaf tissue and actively sucked the sap. As feeding proceeded, a change of colour from orange red to pale greenish yellow was noted. Throughout the active

period, the larva moved randomly over the leaf surface and sucked the tissue fluid from different regions. The active larval period on *M. oleifera* was noted to be 0.77 ± 0.05 day, 1.12 ± 0.06 days and 1.33 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables XLIX to LI).

At the end of larval active period, the feeding activity got ceased and the individual became lethargic. The larva settled at a suitable site on the upper surface of the leaf and initiated its first quiescence and subsequent moulting phase.

4.3.3 Protonymphal period

Protonymph (Plate XXIX Fig. 6) was larger in size, pale white in colour with greenish black spots and could be easily distinguished from the larva by its octapod nature. Feeding was initiated soon after emergence, as a result of which the colour of the protonymph changed to dark green. Active feeding was followed by second quiescence and moulting phases respectively. The active protonymphal period on *M. oleifera* extended for 1 ± 0 day at 25 ± 2ºC & 80 ± 5% RH, 0.85 ± 0.04 day at 30 ± 2ºC & 70 ± 5% RH and 0.92 ± 0.03 day at 35 ± 2ºC & 60 ± 5% RH (Tables XLIX to LI).

4.3.4 Deutonymphal period

Deutonymph represented the final instar before attaining the adult status. It was much larger in size (Plate XXIX, Fig.4 & 6) and formed the most active stage among all the other life stages of the mite. Sexual dimorphism was quite obvious at this stage. The hysterosoma of the male nymph was narrow and tapering posteriorly

while that of the female was comparatively larger and rounded in shape than the male deutonymph. Feeding activity, quiescence and moulting were similar as in earlier stadia. The total duration of deutonymphal period lasted for 1.94 ± 0.03 days, 1.33 ± 0.07 days and 1.6 ± 0.04 days respectively at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH (Tables XLIX to LI).

4.3.5 Quiescent Periods

A period of total inactivity as observed in the other tetranychid species discussed earlier, was seen in *E. orientalis* also at the end of the active period of larva and subsequent nymphal stages. Like the earlier species, feeding and other activities were found ceased followed by the settling down of the mite on a suitable site on the leaf blade. The pattern of quiescence was similar to that of the former 3 species of tetranychids. The respective durations recorded for the Ist, IInd and IIIrd quiescent stages of *E. orientalis* on *M. oleifera* were 0.77 ± 0.05 day, 1.17 ± 0.07 days and 1.2 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH, 0.5 ± 0 day, 0.67 ± 0.03 day and 0.75 ± 0 day at 30 ± 2ºC & 70 ± 5% RH and 0.6 ± 0.04 day, 0.89 ± 0.04 day and 1 ± 0 day at 35 ± 2ºC & 60 ± 5% RH (Tables XLIX to LI).

4.3.6 Moulting

The process of moulting followed every quiescent stage and resulted in the release of the subsequent instar. The process began with the development of a narrow slit across the dorsum at the propodosoma. Subsequently the slit got widened by the movements of the individual. At this stage, the anterior pair of legs and mouth parts of the emerging instar protruded out of the moulting skin. The active

movements of the individual resulted in its emergence, leaving behind the exuviae on the leaf surface. This pattern of moulting resembled the process observed in the other spider mites. However, the process required 10-15 minutes for completion.

4.3.7 Adult Stages

Newly emerged male was slightly reddish in colour and characterized by elongate legs. Eye spots were prominent and red. Sexually mature male was smaller than the female with a tapering hysterosoma. Adult male was very active and often found moving in search of quiescent female deutonymphs. Adult female was larger than the male with short legs and posteriorly rounded hysterosoma (Plate XXIX, Fig. 3 & 5). The female was comparatively sluggish in nature and greenish-red in colour with black spots on the dorsum of the hysterosoma. Feeding was initiated soon after moulting and at this stage, they appeared light red in colour. As feeding progressed, the colour changed to dark red.

4.4 Mating

Sexual reproduction by mating occurred in *E. orientalis* soon after the emergence of the female deutonumphs. Males were the sexually active partners who were found actively moving in search of receptive females. On several occasions fighting among males for a single female ready to emerge from quiescence were observed. The successful male mated with the emerging virgin female. During the process, the male crawled beneath the female and curved its hysterosoma towards the genitalia of the female and inserted its aedeagus to transfer its sperms. The females were found mating only once while males copulated several times. Mating was completed in 2 minutes.

4.5 Parthenogenesis versus Sexual development

Like *T. neocaledonicus, T. ludeni and T. cinnabarinus, E. orientalis* performed parthenogenetic reproduction in addition to the normal sexual

reproduction. The series of events involved in the development from egg to the adult stage followed the pattern as discussed in the earlier 3 species. Males alone were produced in parthenogenetic development while in the sexual reproduction both males and females were produced with a sex ratio of 1-2:10. The durations of the various developmental stages were found influenced significantly by variations in temperature-humidity conditions in both the types of reproduction.

The total duration of development on *M. oleifera* was observed to be 12.37 ± 0.19 days (Sexual - 12.91 ± 0.18 days & Parthenogenetic - 11.8 ± 0.19 days) at 25 ± 2ºC & 80 ± 5% RH, 8.27 ± 0.14 days (Sexual - 8.67 ± 0.10 days & Parthenogenetic - 7.87 ± 0.14 days) at 30 ± 2ºC & 70 ± 5% RH and 9.48 ± 0.09 days (Sexual - 9.75 ± 0.06 days & Parthenogenetic - 9.2 ± 0.04 days) at 35 ± 2ºC & 60 ± 5% RH (Tables XLIX to LI; Plates XXXII to XXXIII). Parthenogenetic development required comparatively shorter duration.

4.6 Morphological description of the life stages of *E. orientalis*, (Klein, 1936)

The genus *Eutetranychus* includes large sized individuals which are globular in shape. Propodosomal shields are lacking and the characteristic duplex setae are absent. Tarsi usually lack empodia. Claws are short, pad like and with tenent hairs.

Egg (Plate XXIX, Figs. 1 & 5)

Measurements: Diameter 118 – 123 µm

The eggs were disc shaped and translucent when freshly laid. The colour of the egg changed to yellowish brown and finally to orange, prior to hatching. Eye spots could be clearly perceived as a pair of dark red spots through the egg case, few hours before hatching was initiated.

Larva (Plate XXIX, Fig. 6; Plate XXXIV, Figs. 1 to 2)

Colour: Bright orange

Measurements: Length: 176 – 180 µm

Width : 117 – 120 µm

Dorsal region (Fig.1)

Oval in shape; posterior end slightly tapering; rostrum slightly protruding; peritremes with bulbous apex; 3 pairs of propodosomal setae and 10 pairs of elongated hysterosomal setae present; seta P_1 situated much anteriorly near the anterior margin of the propodosoma, P_2 & P_3 close to each other; dorsocentral setae D_1 & D_2 inserted widely apart and D_3, D_4 & D_5 close to each other; tubercles of posterior setae more pronounced, all setae elongated and set with minute hairs.

Ventral region (Fig.2)

2 pairs of medioventral setae present; genital area indistinct; anal region weakly developed with 2 pairs of anal and 2 pairs of para-anal setae, anal setae minute and pointed, para-anal setae slightly longer than anal setae, slender and pointed, both pairs of para – anal setae posterior to anal setae, all ventral setae smooth; 3 pairs of legs.

Protonymph (Plate XXIX, Fig. 6; Plate XXXIV, Figs. 3 to 4)

Colour: Greenish black

Measurements Length: 300 – 315 µm

Width : 200 – 218 µm

Dorsal region (Fig.3)

Posterior end more or less round; peritremes with blunt apex; seta P_1 moved slightly posterior and P_2 slightly centrad, so that P_1, P_2 & P_3 almost at equal distances; seta D_1 highly reduced in length, D_2 to D_3 slightly shorter; posterior setae more spaciously arranged; tubercles not as prominent as in larva.

Ventral region (Fig.4)

Setae MV_1 and MV_2 present; genital area indistinct, 1 pair of postgenital setae (POG) present; anal area well demarcated with 2 pairs of anal and 2 pairs of para-anal setae, anal setae short and smooth, para-anal setae long, smooth and pointed; 4 pairs of legs.

Deutonymph (Plate XXIX, Fig. 4 & 6; Plate XXIV, Figs. 5 to 6)

Colour:	Greenish red	
Measurements:	Length:	340 – 350 µm
	Width :	260 – 271 µm

Dorsal region (Fig.5)

Peritreme similar to that of protonymph; seta P_2 slightly shorter than P_1 and P_3; dorsocentral setae D_1 to D_4 much short and spatulate, D_5 long; all the lateral setae and humeral setae elongated; all setae with minute hairs on their surface.

Ventral region (Fig.6)

Setae MV_3 added anew; 1 pair of pre-genital setae *PRG* added anew, setae *PRG* situated far anteriorly near the hind coxae; anal area similar to that of

protonymph; all ventral setae smooth and pointed

Adult female (Plate XXIX, Fig. 3 & 5; Plate XXXV, Figs. 1 to 2)

Colour:	Greenish red	
Measurements:	Length:	370 – 410 µm
	Width :	262 – 320 µm

Dorsal region (Fig. 1)

Gnathosoma sunken within the propodosoma; propodosoma rounded anteriorly, dorsal striae on propodosoma more or less parallel and lobed; stylets slender and elongated; peritremes almost straight ending in a pair of small spatulate structures; seta P_1 situated close to the anterior margin of propodosoma, seta P_3 longest among propodosomal setae; dorsal setae short, broad, barbed in nature and set on small tubercles; setae D_1, D_2, D_3 and D_4 short and spatulate, all other setae slightly longer and club shaped, set on distinct tubercles and barbed in nature.

Ventral region (Fig. 2)

Three pairs of medio-ventral setae present, MV_1, MV_2 and MV_3 slender, elongated and pointed; well developed genital area marked by an indistinct opening bordered by closely set striae, 1 pair of *PRG* far anterior to genital area and near to MV_3 and 1 pair of *POG* lateral to genital opening; a pair of genital setae present anterolateral to the genital opening; anal area distinct with a longitudinal slit, 2 pairs of anal and 2 pairs of para-anal setae present, anal setae short and smooth and para-anal setae long, smooth and pointed, setae an_1 and an_2 lateral to anal opening; setae h_2 and h_3 posterolateral to an_1 and an_2.

Leg

Six segmented having coxa, trochanter, femur, genu, tibia and tarsus, tibia I with 2 sensory and 3 tactile setae, tarsus I with 1 sensory and 14 tactile setae; tibia II with 1 sensory and 5 tactile setae.

Adult Male (Plate XXXV, Figs. 2 to 3)

Colour:	Greenish red	
Measurements:	Length:	360 – 387 µm
	Width: 210 – 224 µm	

Adult male differs from the female in the following features: Smaller and slender; terminal sensillum of palp tarsus 3 times as long as wide, dorsal sensillum long and slender; dorsal idiosomal setae set on small tubercles. Striations on the body clearly visible as figured. Aedeagus hook like with distal bent longer than dorsal margin of shaft which is slightly concave.

Leg

Tibia I with 5 sensory and 8 tactile setae, tibia II with 5 tactile and 3 sensory setae, tarsus I with 1 sensory and 11 tactile setae, tarsus II with 1 sensory and 11 tactile setae.

5. Postembryonic development of *O. biharensis* (Hirst)

5.1 Oviposition

Adult females laid eggs irrespective of being fertilized or unfertilized on both surfaces of the leaf. The eggs were deposited singly mostly near the anterior region of the leaf close to the mid rib (Plate XXXVI, Figs. 2, 4, 6 & 8). Oviposition process closely followed the pattern described in earlier species. Newly deposited eggs were orange coloured, spherical and shiny. The eggs became brownish with age and the red eye spots clearly visible prior to hatching.

The adult female laid eggs after the lapse of a certain period called the pre-oviposition period. This period of *O. biharensis* on *M. esculenta* lasted for 1.9 ± 0.07 days at 25 ± 2ºC & 80 ± 5% RH, 1 day at 30 ± 2ºC & 70 ± 5% RH and 0.5 day at 35 ± 2ºC & 60 ± 5% RH. The respective oviposition periods of the mite were observed to be 5.7 ± 0.26, 10.9 ± 0.75 and 11.5 ± 0.38 days for the three temperature-humidity conditions studied. The post-oviposition period recorded for the temperature-humidity conditions *viz.*, 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH on *M. esculenta* was 0.6 ± 0.12, 0.8 ± 0.22 and 0.5 day respectively (Table LII; Plate XXXVII, Fig.1).

Fecundity showed an increase on successive days of oviposition, reaching the peak levels on the 4th or 5th day and a gradual decrease from the 6th day onwards under laboratory conditions. On *M. esculenta* the respective fecundity was observed to be 34.2 ± 2.9 (Mated - 42.6 ± 1.7 & Virgin - 25.8 ± 1.4), 37.6 ± 3.1 (Mated - 44.6 ± 4.2 & Virgin - 30.6 ± 1.6) and 47.0 ± 3.29 (Mated - 54.8 ± 3.4 & Virgin - 39.2 ±

2.6) at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH. Longevity recorded for the three temperature-humidity conditions studied included 12.2 ± 0.32 days (Mated - 11.6 ± 0.4 days & Virgin - 12.8 ± 0.4 days), 10.1 ± 0.18 days (Mated - 9.9 ± 0.3 days & Virgin - 10.3 ± 0.2 days) and 8.75 ± 0.08 days (Mated - 8.6 ± 0.1 days & Virgin - 8.9 ± 0.1 days) respectively (Table LIII to LV; Plate XXXVII, Fig.2).

5.2 Hatching

Increase in the size of the egg was a notable change, few hours before the hatching process was initiated. This was followed by slit formation and the separation of the egg case by the forceful movements of the emerging larva. The mouth parts and the first pair of legs protruded out of the egg shell in the beginning followed by the emergence of the last two pairs of legs. Soon after hatching the larva moved away in search of food. Discarded egg cases could be seen on the leaf surface as transparent spherical structures (Plate XXXVI, Figs. 2 to 3). The hatching process took 10 minutes to complete with no significant change at different temperature-humidity conditions provided.

5.3 Duration of developmental stages

5.3.1 Incubation period

Incubation period was shortest (2.71 ± 0.07 days) at 35 ± 2ºC & 60 ± 5% RH and maximum (3.79 ± 0.07 days) at 25 ± 2ºC & 80 ± 5% RH. At 30 ± 2ºC & 70 ± 5% RH, the incubation period was 2.83 ± 0.03 days (Tables LVI to LVIII; Plate XXXVIII, Figs. 1 to 3).

5.3.2 Larval period

The newly emerged larva (Plates XXXVI, Fig.5) was small, spherical and reddish orange in colour. The larva possessed 3 pairs of pale orange coloured legs. Change in body colour was noted with progress in feeding to dark red with dark spots on the dorsal body surface. The larva exhibited random movements on both surfaces of the leaf actively sucking the leaf sap. On *M. esculenta*, the active larval life lasted for 0.87 ± 0.06 day, 0.67 ± 0.03 day and 0.54 ± 0.03 day at 25 ± 2ºC & 80 ± 5% RH, 30 ± 2ºC & 70 ± 5% RH and 35 ± 2ºC & 60 ± 5% RH respectively (Tables LVI to LVIII; Plate XXXVIII, Figs. 1 to 3).

As discussed in earlier species, the larvae of *O. biharensis* also passed through the 1st quiescent phase and subsequently moulted into the protonymph.

5.3.3 Protonymphal period

The protonymph (Plates XXXVI Fig. 1 & 6) was larger in size, reddish-orange coloured and octapod in nature with reddish-orange legs. As soon as it emerged, feeding was initiated and the nymph developed dark blotches on its dorsal surface. All the protonymphs passed through a resting stage or the so called 2nd quiescent phase before moulting into the deutonymph. Males and females of this species could be distinguished at this stage. The duration of active protonymphal period on *M. esculenta* was shorter at 35 ± 2ºC & 60 ± 5% RH extending for 1 day and longer at 25 ± 2ºC & 80 ± 5% RH being 1.67 ± 0.07 days. At 30 ± 2ºC & 70 ± 5% RH, the duration was 1.19 ± 0.07 days (Tables LVI to LVIII; Plate XXXVIII, Figs. 1 to 3).

5.3.4 Deutonymphal period

The largest among the nymphal instars, the deutonymph was orange red coloured at the time of emergence (Plate XXXVI Figs.1 & 8). The colour later darkened upon feeding and appearance of dark blotches on the dorsum was also noted. The hysterosoma of the male and female deutonymph showed marked differences which were tapering posteriorly in the former and rounded in the latter. A similar pattern of feeding activity, quiescence and moulting were observed as in earlier stages. The respective durations of deutonymphal period were 1.29 $\pm$ 0.07 days, 1.19 $\pm$ 0.04 days and 1.08 $\pm$ 0.03 days respectively at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH (Tables LVI to LVIII; Plate XXXVIII, Figs. 1 to 3).

5.3.5 Quiescent Periods

A period of zero activity or quiescence was observed at the end of the active period of each developing stage, as observed in the case of other tetranychid species. The individual ceased all its visible life activities and became inactive. Selection of concealed or secluded areas especially near the petiole, mid rib or in between the leaf veins in order to settle down in quiescence was a notable feature. During quiescence, the body assumed oval shape and developed a pale white covering (Plate XXXVI Fig.7). All the legs were in retracted condition below its body and stylets in pierced state in the leaf tissues. At the end of quiescent phase, the cuticle turned transparent and developed a slit on the dorsal region preparing itself for the moulting process. No significant changes in the duration could be recorded for the

Ist, IInd and IIIrd quiescent stages of *O. biharensis* on *M. esculenta*. At 25 ± 2^{o}C & 80 ± 5% RH, 30 ± 2^{o}C & 70 ± 5% RH and 35 ± 2^{o}C & 60 ± 5% RH, the quiescence was completed in 0.5 day (Tables LVI to LVIII; Plate XXXVIII, Figs. 1 to 3).

5.3.6 Moulting

The process of moulting followed a similar trend as described in the case of other tetranychid species. Appearance of a dorsal slit marked the initiation of the process. This was followed by widening of the slit towards either side until it met ventrally. The division was complete and hence the moulting skins were observed as two separate pieces on the leaf surface (Plate XXXVI Figs.2 to 3). The individual released from the exuviae moved away from the site in order to resume its normal life activities. The entire process was completed in 15 minutes for all the different temperature-humidity conditions considered.

5.3.7 Adult Stages

Adult male was slightly reddish-orange in colour with elongate orange legs and tapering hysterosoma (Plate XXXVI Figs.10 to 11). Sexually mature male was smaller than the female and moved very actively moving in search of quiescent female deutonymphs for copulation or engaged in feeding. Adult female was larger than the male, red coloured with short orange legs and posteriorly rounded hysterosoma (Plate XXXVI Figs.10 to 11). Feeding was initiated soon after moulting and as feeding progressed, the colour changed to dark red.

5.4 Mating

As soon as the male emerged, it was found wandering in search of quiescent female deutonymphs. Upon encounter with such deutonymphs, it placed its anterior pair of legs over the dorsum and awaited the female's emergence. When the female began moulting, the male was found helping it to cast off the moulting skin. During the act of copulation, the male was found moving under the posterior ventral surface of the female, arching its opisthosomal part in such a way that the aedeagus could enter the genital aperture of the female. Mating lasted for 2 minutes. A single male mated with several females, though females were receptive to a single male only.

5.5 Parthenogenesis versus Sexual development

Like the previous cases, the female of *O. biharensis* exhibited sexual as well as parthenogenetic reproduction. As a rule, the progeny of fertilized females produced individuals of both the sexes in the ratio 3 males:10 females whereas the progeny of unfertilized females produced males only. On *M. esculenta*, the durations recorded at 25 ± 2°C & 80 ± 5% RH, 30 ± 2°C & 70 ± 5% RH and 35 ± 2°C & 60 ± 5% RH were 9.12 ± 0.09 days (Sexual - 9.37 ± 0.08 days & Parthenogenetic - 8.87 ± 0.08 days), 7.37 ± 0.12 days (Sexual - 7.75 ± 0.09 days & Parthenogenetic - 7.0 ± 0.06 days) and 6.83 ± 0.10 days (Sexual - 7.17 ± 0.05 days & Parthenogenetic - 6.5 days) respectively (Tables LVI to LVIII; Plate XXXIX, Fig.1). At all the temperatures and relative humidity conditions, parthenogenetic development took comparatively shorter time than the sexual development

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

Genus *Oligonychus* is characterized by the possession of pad like claws with tenent hairs. Empodium is claw like in appearance, with proximoventral hairs set at right angles to the empodium. Two pairs of anal and a single pair of para-anal setae are present.

Egg (Plate XXXVI, Figs. 4, 6 & 8)
Measurements: Diameter 125 – 132 µm

Eggs spherical, reddish-orange in colour when freshly laid. The colour of the egg changed to golden brown and finally to dark brown before hatching. Red eye spots clearly visible through the translucent egg case few hours before hatching.

Larva (Plate XXXVI, Fig. 5; Plate XLIV, Figs. 1 to 2)

Colour:	Reddish-orange
Measurements:	Length: 170 – 211 µm
	Width : 120 – 147 µm

Dorsal region (Fig.1)

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

Ventral region (Fig.2)

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

Protonymph (Plate XXXVI, Figs. 1 & 6; Plate XLIV, Figs. 3 to 4)

Colour:	Reddish orange	
Measurements	Length:	250 – 305 µm
	Width :	145 – 198 µm

Dorsal region (Fig. 3)

Striations present; rostrum protruding; stylets parallely proceeding forwards; peritremes distally curved; propodosoma more or less narrow; 12 pairs of dorsal setae, all setae long and thin.

Ventral region (Fig. 4)

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

Deutonymph (Plate XXXVI, Figs. 1 & 8; Plate XLIV, Figs. 5 to 6)

Colour:	Orange red	
Measurements:	Length:	310 – 347 µm
	Width:	207 – 252 µm

Dorsal region (Fig. 5)

Transverse striations with slight variations in different body regions; rostrum stout and long; peritremes directed backwards and curved into a hook distally; seta P_1 comparatively shorter than P_2 and P_3; hysterosomal setae D_5 added

anew, all setae except D_5 long and pointed.

Ventral region (Fig. 6)

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

Adult female (Plate XXXVI, Figs. 9 & 11; Plate XLIII, Fig. 1 to 2, Plate XLV, Figs. 1 to 2)

Colour:	Brick red	
Measurements:	Length:	360 – 374 µm
	Width :	256 – 268 µm

Dorsal region (Plate XLV, Fig. 1)

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

Ventral region (Plate XLV, Fig. 2)

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

Leg (Plate XLIII, Figs.3 to 4)

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

Adult Male (Plate XXXVI, Figs. 10 to 11; Plate XLV, Figs. 3 to 4)

Colour: Reddish orange

Measurements: Length: 357 – 390 µm

Width: 162 – 173 µm

Adult male differs from the female in the following features: Slender elongated body with long reddish legs; Aedeagus long and slender with axis of the distal enlargement parallel to the shaft.

Leg

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

Chapter V
Discussion

Vegetables constitute an important source of nutritive minerals, fibers, vitamins and anti-oxidants brimming with many other protective ingredients which are essential for body building and maintenance. The term 'vegetable' generally means the edible parts of plants. They provide more food within a short period from a limited area. During the present national emergency, vegetable growing has its own value both in general agricultural production and as kitchen gardening as these are short duration crops having the capacity to produce more food per unit area. A spectacular field of mite activity leading to depletion of plant quality is their potential to rise to the pest status. This extraordinary ability of the spider mites to colonise vegetable plants, replenish the available nutrients and cause serious injuries has raised the importance of these mites as pests in terms of the degree of damage. Therefore, this would obviously necessitate control programme augmenting regulation of these pests well below the problem level. In this context, introduction of biological control programmes seems to be quite promising. Implementation of a successful biocontrol method demands a concrete and reliable data on the biology of the mite in question as well as the temparature-relative humidity conditions favourable for their outbreak as a dreadful pest. Hence, a detailed investigation on the feeding and breeding biology and the influence of the temparature and relative humidity on the life cycle of 5 serious tetranychid pest mites has been focussed in greater detail.

Chapter V
Discussion

Mites have emerged as a prominent faunal element on almost all the 40 species of vegetable plants surveyed, of which prostigmatids showed predominance in terms of species composition followed by mesostigmatids represented by predatory mites. Other groups including oribatids made a nominal representation. Taxonomic analysis of the prostigmatid fauna envisaged the presence of 3 superfamilies; Tetranychoidea, Tarsonemoidea and Eriophyoidea in almost all of the collection sites.

The recovery of rich and varied faunal complexities of spider mites from the vegetable crops affords adequate evidence to consider their potential of infestation under natural conditions. A total of 5 species of tetranychid mites belonging to 3 genera were selected for further biological studies within the limit of the objectives of the current study. A worth mentioning aspect of the study was that these spider mites were comparatively scanty in the case of plants sprayed with pesticides whereas the same plants without pesticides harboured quite a good number of them.

A comparison of the site wise incidence of the species of spider mites shared interesting trend in their distribution pattern. Occurrence of atleast 3 species from 19 out of 25 localities screened, well proved the potential of this group to infest vegetable crops. This would suggest the possible micro and macro habitats provided by the vegetable plants for the flourishing of spider mites. Most of the locality sampled were open vegetable fields. Probably the erect leaves and micro and macro habitats provided by the extensively grown vegetable plants favoured distribution of spider mites without any interspecific differences.

Chapter V
Discussion

The current study also added knowledge on the host range of the spider mites studied. Each of the host plant examined during the study revealed the occurrence of more than one species of mite. However, analysis of the host range of each species within the limit of the study suggests 21, 20, 20, 9 and 5 species of host plants respectively for *T. ludeni, T. neocaledonicus, T. cinnabarinus, E. orientalis* and *O. biharensis.* However, infestation was observed to attain peak levels during the months of February to April/May for *T. neocaledonicus, T. cinnabarinus, E. orientalis* and *O. biharensis* (Lal and Mukharji, 1980; Dhooria and Butani, 1983; Gupta, 1985; Pande and Sharma, 1986) with an exception of *T. ludeni* which appeared at high levels from May to July (Puttaswamy and ChannaBasavanna, 1981a). This would probably suggest their tendency to avoid competition eventhough they occurred at moderate to scanty levels during the rest of the year. During the monsoon season, the mites were scanty on the leaves of the various vegetable crops, though their abundance was noted in the lower vegetation like grasses and weeds. This comprised almost all species of mites including the soil mites. It leads to the conclusion that these mites were compelled to leave their normal niche in order to escape from the washing effect of heavy rain and had to take shelter in such protected niches. At the same time the increased population of the predators in these areas during the monsoon season may be due to the abundance of their prey species around the area. The occurrence of the former 4 species at similar seasons of the year may be attributed to their ability to co-exist despite similarity in their feeding trends.

Chapter V
Discussion

A study of the relative abundance of the spider mites under study revealed the occurrence of *T. ludeni* in almost all the localities screened followed by *T. cinnabarinus, T. neocaledonicus, O. biharensis* and *E. orientalis*. The active nature of the former group depicted by the earlier workers (Moutia, 1958; Meyer and Rodriguez, 1966; ChannaBasavanna, 1971; Jeppson *et al.*, 1975; Puttaswamy and ChannaBasavanna, 1980a, b & c, 1981b; Manjunatha and Puttaswamy, 1989; Ghoshal *et al.*, 2006; Sangeetha and Ramani, 2007a, 2008a & 2009) would have been one of the factors that favoured them in dominating these habitats. The relative abundance of spider mite species was noted on the plants which were under mordern cultural practices like frequent fertilizer application and irrigation than those species grown in comparatively barren land. This observation is in agreement with the suggestion of Sadana (1985) that the use of fertilizer and better crop management practise enhanced the power of increased reproductive potential of these mites. Sarkar and Somchoudhury (1981) and Puttaswamy and ChannaBasavanna (1982a) also reported the enhanced pest status of plant feeding mites on high yielding varieties of crops under improved cultural practices. The reason for the abundance of infestation may be related to the fact that the mordern fertilizers increase the availability of rich food supply with high nutritive value to the mite pests from plants.

An interesting aspect that emerged from the study of relative abundance was the tendency of *T. ludeni* to compete with *T. neocaledonicus* for the host plant infested by both of them. Following initial infestation on a host plant both species

spread gradually to all other leaves. A tendency of restricting itself to a small area of the leaf and then gradually spreading to other areas as shown by *T. neocaledonicus* appeared contrary to *T. ludeni* which explored and spread all over the leaf area at a faster rate. The slow dispersal from the area of initial infestation appreared to explain the slow increase in numbers of *T. neocaledonicus* cohabiting with *T. ludeni* initially. This observation is in support of earlier findings concerning the reciprocal effects of cohabitation by these two mites by Puttaswamy and ChannaBasavanna (1980c) and many other pairs of spider mites (Newcomer and Yothers, 1929; Webster, 1948; Chapman and Lienk, 1950; Lienk and Chapman, 1951; Foott, 1962, 1963), suggesting the possibility of competition between them.

Results of field observation on distribution pattern revealed that the spider mites under study could infest almost all age groups of host leaves except the newly sprouted and very tender ones. The petiole and the tender stem of the plants remained unaffected. Inspite of such preference for leaves, the mites exhibited profound variation in their distribution pattern among the leaves. Accordingly, the middle aged leaves were found mostly favoured by all the species, as their population densities were high on these leaves. Probably the biochemical constituents of these leaves at this age provided the ideal nutritional components for the development of these mites. Leaves that were too old (Dhooria, 1985) or too young (Sobha and Haq, 1999) harboured comparatively lower population of adults eventhough eggs could be seen on younger leaves. This could be a preventive measure against loss of eggs due to leaf dehiscence. The particular absence of

spider mites on younger leaves suggested their preference to the less turgid tissues of mature leaves. This observation is in accordance with that of Jeppson *et al.,* (1975) who also remarked *O. coffeae* as a less turgidity preferring species. The apical 1-3 tender leaves generally revealed a total absence of the mites. Total avoidance of most tender leaves may be attributed to the non availability of specific nutritional components required for the survival and population build up of these spider mites. On the leaf blade, the spider mites were often found occuring in the joining regions of leaf veins. The shallow concavity available in such regions appeared to provide some shelter for their oviposition as well as serve to prevent their direct exposure to sunlight. Moreover, the veins and veinlets enable to provide a firm grip to these mites during oviposition (Banu and ChannaBasavanna, 1972; Dhooria, 1982) preventing their dislodgement from the leaf surfaces. This indicated a high degree of thigmokinesis, thereby favouring the earlier findings of Jeppson *et al.,* (1975).

The spider mite species selected for study represented the category of leaf suckers. Feeding activities of these sucking forms enabled to produce conspicuous injury to the host plant, manifested through chlorosis of the leaves. This category was entirely represented by all the 5 species of tetranychids. It was observed that infestation by *T. ludeni* and *E. orientalis* initiated on the upper surface of the leaf. This appears to support the observations of Banu and ChannaBasavanna (1972), Lal (1977) and Dhooria (1985) who observed *E. orientalis* invariably on the upper leaf surface of different host plants. While *T. neocaledonicus* and *T. cinnabarinus,* in all

stages preferred lower surface of the leaf blade (Sobha and Haq, 1999; Sangeetha and Ramani, 2007a). Probably, the dorsoventral disposition of the host leaves would have favoured feeding of these mites on one side of the leaf. On the contrary, *O. biharensis* colonised both the leaf surfaces simultaneously. Difference in feeding trends in these spider mites could be a mechanism to avoid competition especially when more than one species occur together on the same host plant. However, infestation by the former 4 species readily spread to the other surface of the leaf or petiole when the feeding niches on preferred leaf surface were completely exhausted (Banu and ChannaBasavanna, 1972; Gupta, 1985; Sangeetha and Ramani, 2007a & b). This revealed intraspecific competition among the members of the colony. Also, the incidence of mites was more pronounced on the exposed upper layer of the canopy than the lower ones.

Webbing behaviour is a character recognised in some genera like *Tetranychus*, *Oligonychus*, *Eotetranychus* and *Schizotetranychus* (Hazan *et al.*, 1974, 1975; Saito 1977a, 1977b and 1979b; Gerson, 1979; Saito, 1983; Duncan and Lindquist, 1989). The complicated nature of the webbing produced by the above genera seems to be identical with that of the present species. Webbing was found to serve as a protective device for the eggs and immatures as they remained totally confined within the canopy of the webbing. Webs were proved to safeguard the viability of eggs also, as removal from the web, often resulted in reduced hatchability (Hazan *et al.*, 1974). Apart from this, webbing was also found acting as a means of transport for the individuals within or between the host plants. In

addition, webbing was reported to serve as carrier of sex pheromone and increase the potential of the species to compete with other non-spinning phytophagous mites. The webs served as a place for excretion (Saito, 1983; Oku, 2008) and also enhanced the accumulation of dust particles on the leaves, impairing the fast movement of the predatory mites. This might have resulted in the avoidance of the host plants by the latter. This finding substantiated the reports of Griffiths and Fischer (1950) who reported the favourable effect of inert dusts on spider mite population and the adverse effects on the population of their natural enemies. Plants with the web laiden debris were seen to be paler in colour than their relatives without the dusts. This suggests that in addition to the direct disservices, the spider mites can even affect the metabolism of the host indirectly by reducing the quantum of light reaching the surface of the leaves thereby reducing the photosynthetic activity. This inference supports the view of Sadana (1985) who remarked that dust entangling the spider mite webs impaired photosynthesis by preventing the sunlight reaching the leaf surfaces.

Spider mites produce large quantities of black coloured faecal pellets which normally appear to be a reflection of their feeding tendency. However, *T. neocaledonicus* produced violet faecal pellets on *A. tricolor*, which could be attributed to the colour of the host leaves on which the mite was feeding. A special feature observed in the current study was the production of two types of faecal pellets by all the life stages of *T. ludeni* suggesting the lack of influence of age on the type of faecal pellet produced. The excreta of this species constituted black and

white pellets with a central core of oval granules glued together and covered by a transparent membrane. Analysis of the reason behind the production of two types of faecal pellets, its nature and origin needs further indepth studies. *T. kanzawai* was reported to produce two types *viz.*, black and yellow faecal pellets (Oku, 2008) where the viscous yellow pellets (Wiesmann, 1968) reduced chances of egg predation by predatory mites by preventing the foraging activity of the latter. The black pellets are excreta and the yellow pellets could be considered to deter predators, as they are suggested to be secreted not excreted for actively deterring predators (Oku, 2008).

Egg deposition as a common feature, has been observed during the process of feeding and webbing and the deposited eggs were often found entangled in the web along with the faecal pellets. Egg cases and moulting skins of the various developing stages were also found attached to the webs which facilitated accumulation of dust particles and formation of a thick layer over the leaf surface. The above observations seem to support the earlier findings in several tetranychid representatives (Sumangala and Haq, 2000; Reddall *et al.*, 2004; Sangeetha and Ramani, 2007b).

Spider mites are known to induce various types of damages ranging from simple mechanical injury of the cells to complex physiological alterations to their host plants. Some of the major mechanical injuries include flattened epidermal cells, collapse or reduction in cells of pallisade and spongy parenchyma, loss of cell contents, coagulation of protoplasts, damage and loss of chloroplasts, alterations to

stomatal apparatus and other visible contents in cells of mesophyll tissue (Geijskes, 1938; Blair, 1951; Avery and Briggs, 1968b; Jeppson *et al.,* 1975; Tanigoshi and Davis, 1978; Mothes and Seitz, 1982; Tomczyk and Kropczynska, 1985, Bondada *et al.*, 1995; Nachman and Zemek, 2002; Skaloudova *et al.*, 2006). In addition, apparently unattacked cells were affected by the formation of chloroplasts with cup shaped thylakoids (Tanigoshi and Davis, 1978). Injuries at the physiological level include reduction in photosynthesis and transpiration rates, vegetative growth and productivity (Sances *et al.,* 1982; Royalty and Perring, 1989; Welter, 1989; Nihoul *et al.,* 1992, Reddall *et al.,* 2004). Biochemical studies of spider mite feeding injury (Boulanger, 1958; Leigh, 1963; Avery and Briggs, 1968a; Avery and Lacey, 1968; Storms, 1971) have led to the conclusion that fundamental metabolic pathways such as dissimilation, assimilation and water balance are disturbed before visible changes in the leaf occurs (Hall and Ferree, 1975; Reddall *et al.,* 2004).

Feeding injury induced by *T. neocaledonicus* on their respective host leaves was invisible to naked eyes in the initial stage and marked by the appearance of white spots at the point of suction of sap from the plant cells. These spots could be distinguished from the feeding spots produced by *T. ludeni, T. cinnabarinus, E. orientalis* and *O. biharensis* which were respectively represented as pale etiolated spots, pale yellow spots, light yellowish brown spots and yellowish brown patches. The symptoms of injury produced by *T. ludeni* were more conspicuous even during the early stages of infestation. The attack by *O. biharensis* on *M. esculenta* was so severe that the whole plantation appeared to be crinkled. Various reasons may be

attributed to this. There might have occurred a loss of considerable amount of water due to high rate of evaporation through the feeding punctures produced on the leaves. Loss in the chlorophyll content as well as nutrients and cell contents might have caused the initiation of development of bronzing, crinkling and ultimate drying up of the plants. Further, *T. neocaledonicus* and *T. cinnabarinus* feed on the underside of the leaves which are major sites of photosynthesis (Tomczyk and Kropczynska, 1985; Welter, 1989). The effects of mite feeding at the leaf level were so severe that mite infestation increased leaf resistance to CO_2 uptake thereby decreasing the rate of photosynthesis (Brito *et al.*, 1986).

The difference in the morphological responses of the 5 species may be attributed to variation in chemical constituents of the salivary secretion injected by these species during feeding. Prolonged and excessive feeding by *T. neocaledonicus* resulted in acute chlorosis and premature leaf abscission while the leaves infested by *T. ludeni* appeared to be bleached following chlorosis. Heavy infestation by *T. cinnabarinus* resulted in crumpling, curling or twisting of leaves. However, bronzing, depigmentation and drying of leaves were characteristic of *E. orientalis* infestation when leaves infested severely by *O. biharensis* encompassed crinkling, drying and defoliation. An overall assessment of the damage strategies of these 5 species enabled to reach a conclusion that the attack by these mites affected the growth and vigour of their host plants (Reddy and Baskaran, 2006). However, observations made by Candolfi *et al.* (1993) appeared to be contrary in that the

authors failed to observe any negative effect on plant vigour and yield even at much higher infestation levels of *P. ulmi* on grapevine leaves.

Cytological alterations resulting from feeding of *O. biharensis* on *M. esculenta* using electron microscopy showed reduction in the number of cells and chloroplasts, alterations in cell structure, increase in space in the spongy layer, extensive disruption of the mesophyll cells and even reduction of chloroplasts in adjacent unpunctured cells. These findings were in agreement with the descriptions of Geijskes (1938), Blair and Groves (1952), Avery and Briggs (1968 a & b) on *P. ulmi,* Tanigoshi and Davis (1978), Kielkiewicz (1985) and Park and Lee (2002). Cells punctured by the mite do not participate further in the metabolic processes of the plant. Further, reduction of photosynthetically active organelles in apparently unattacked cells resulted in a decrease in the rate of photosynthesis and metabolic activities, although the cells themselves were not injured by mechanical influence of the mite (Mothes and Seitz, 1982). The present study supports the cytological results of mite feeding on different plants (Tanigoshi and Davis, 1978). Because of the small size of *O. biharensis*, it seemed impossible to answer metabolic and energetic questions which arose from feeding injury on host plants. Subsequent investigations combining plant and mite reactions and their mutual effects are demanded.

Quantitative analysis of physiological injuries caused by the 5 species of spider mites were made through estimation of chlorophyll content of host leaves. Data on chlorophyll estimation of *V. unguiculata* leaves proved a notable loss in chlorophyll content (a & b) due to the feeding activity of *T. neocaledonicus* which

accounted upto 47% and 48% respectively. The loss in chlorophyll a and b reached upto 35% and 43% in the case of *T. ludeni* on *M. deeringiana*, 41% and 51% in the case of *T. cinnabarinus* on *D. lablab*, 36% and 35% for *E. orientalis* on *M. oleifera* and 29% and 46% for *O. biharensis* on *M. esculenta* leaves respectively. The results proved significant at 1% or 5% levels on various hosts. A very high loss in chlorophyll content could be recorded by Haq (1997) on okra leaves infested by *T. macfarlanei* (55% to 68%), Sumangala and Haq (2000) on *Eichhornia crassipes* infested by *T. ludeni* (20% to 54%) and Park and Lee (2002) on cucumber leaves infested by *T. urticae* (55% to 80%). Results obtained by Iatrou *et al.* (1995), Nachman and Zemek (2002) on *T. urticae* feeding on *Phaseolus vulgaris* leaves and Sangeetha and Ramani (2007b) on *M. oleifera* infested by *T. neocaledonicus* further substantiated the fact that leaf chlorophyll content decreased with increase in mite density and duration of feeding. But the observations of Sances *et al.*, (1979) who demonstrated that total chlorophyll content was not reduced significantly even at relatively high mite densities appeared to be contrary to the results of the present study. Despite this, the results of the present study helped to support the findings of Bounfour *et al.* (2002) who through measurements of chlorophyll fluorescence and chlorophyll contents of raspberry leaves injured by spider mites, concluded that spider mite feeding primarily injures the plastoquinone pool, which plays a major role in electron transport during photosynthesis. The chlorophyll content of the leaves is regarded as one of the parameters determining the photosynthetic efficiency of the plant (Maithra and Sen, 1988; Ekanayake *et al.*, 1996 & 1998; Oyetunji *et al*., 1998; Lahai *et al.*, 2003). Moreover, these leaves were found glued

with faecal pellets, egg cases and exuviae of various life stages in innumerable numbers. Such leaves along with the profuse webbing of the mites facilitated settling of dust particles, producing a separate coating over the leaf surface. This coating imparts a cumulative effect on the retardation of photosynthesis by preventing the absorption of light by the residual chlorophyll left unfed by the mites (Sumangala and Haq, 2000). In addition, feeding activity of the individuals induced heavy loss of water from the leaf tissue. The overall impact of the above processes had resulted in the total destruction of the photosynthetic machinery of the plant leading to its final collapse. These results have clearly established the potentiality of the leaf sucking forms in damaging the host plants (Ekanayake *et al.*, 1996 & 1998; Bounfour *et al.*, 2002; Lahai *et al.*, 2003; Reddall *et al.*, 2004; Sangeetha and Ramani, 2007b).

Analysis of the feeding response of 2 species of mites *viz.*, *T. neocaledonicus* and *O. biharensis* was extended to the estimation of total phenolics of their host leaves. Phenols, the aromatic compounds with hydroxyl groups are wide spread in plant kingdom, the role of which in the metabolism of the plant has not been adequately explained, though are believed to offer resistance to pests and diseases. Because certain phenolics have the ability to precipitate plant proteins and render them indigestible, they have been considered as defense compounds. A significant increase in phenol content was observed respectively on *V. unguiculata* and *M. esculenta* leaves following *T. neocaledonicus* and *O. biharensis* infestation suggesting the innate response of the plants against mite attack. Ananthakrishnan *et*

al. (1992) recorded a similar increase in the production of phenolics in *M. esculenta*, castor and eucalyptus during pest attack and concluded that increase in total phenols induced resistance in hosts against herbivory. Such an increase in phenolic content due to spider mite feeding in 'Conica' leaves was reported earlier (Puchalska, 2006), estimating upto 50% reduction in photosynthesis rate after 3 weeks of heavy infestation by *O. ununguis*. Accumulation of phenolic compounds in plant tissues is reported to be one of the causes of photosynthesis suppression (Puchalska, 2006). Hence it is feasible to suggest that spider mites cause drastic reduction in photosynthesis by making mechanical damage aggravated by biochemical alterations.

Studies on the protein profile of *M. esculenta* leaves infested by *O. biharensis* in order to outline a basic understanding of the biochemical changes occuring in the host leaves revealed the occurrence of identical bands in the mite-infested as well as uninfested leaves. A slight decrease in the protein concentration in the mite infested leaves as observed in the current study suggests that apparently there occured no qualitative change in the protein profile as a result of infestation. That is, neither de novo synthesis of proteins occured nor was there a selective depletion of any protein. Contradicting the present observation, spider mite infestation was already known to induce drastic changes in host plants, leading to the production of volatile compounds (Takabayashi *et al.*, 1994; Bouwmeester *et al.*, 1999) to attract natural predators and thus to promote plant defence. In the present study, no additional bands could be visualised upon gel electrophoresis of extracts of

infested leaves though the concentration of protein bands showed a decrease in intensity. Probably, endogenous degradation of existing proteins might have occurred, following mite infestation. The amino acid thus liberated might have been utilized for other metabolic needs or transported away from the leaf tissue. It is undoubtful that the infestation of *M. esculenta* leaves by *O. biharensis* imposes a severe stress on the host plant in as much as it depletes the protein content of the leaves. However, the studies undertaken were preliminary and therefore, indepth studies on this aspect are inevitable to substantiate the results.

An overall assessment of the feeding strategies through qualitative and quantitative analysis of morphological, anatomical and biochemical aspects of infestation by 5 species of spider mites made during the present study helped to supplement better results on the impact of their feeding on host plants. Comparison of the nature and extent of damage produced by these mites to the host plants has disclosed the supremacy of the above mites over the others. In addition, tetranychids are capable of altering the balance of growth regulators (Avery and Lacey, 1968; Storms, 1971) by injecting toxic materials into the host plants (Avery and Briggs, 1968 a & b). Such physiological hazards appeared to be more effective when compared to the mechanical injury induced by them.

Information gathered on the developmental aspects of the spider mites studied depicted a common pattern of developmental processes as in other tetranychid mite species. The development involved a larval and 2 nymphal instars

before attaining the adult status. Each of the instar after the larval stage was proceeded by quiescent and moulting processes.

Mites in general, exhibit certain degree of site selection for oviposition. Majority of the tetranychid species were found depositing eggs adjacent to the midrib of the leaves of the host plant (Banu and ChannaBasavanna, 1972; Barrion and Corpuz-Raros, 1975; Sangeetha and Ramani, 2007). However, *T. neocaledonicus* and *T. cinnabarinus* were found depositing eggs in groups on the lower surface of the leaves. This habit of laying eggs on the underside and attached to the webbing would definitely ensure better chances of protection from desication as well as washing effects of rain (Sobha and Haq, 1999; Sangeetha and Ramani, 2007a). *T. ludeni* and *E. orientalis* showed no specific preference during oviposition. The eggs were laid in a very random fashion, all over the leaf lamina. The silken web in *T. ludeni* (Puttaswamy and ChannaBasavanna, 1980b), waxy secretion and sparse webbing in *E. orientalis* (Banu and ChannaBasavanna, 1972) probably served adequate protection to the eggs and the subsequent instars, which may be the possible reason for the randomised deposition of eggs. Ovipositing females of *O. biharensis* preferred areas close to the mid rib and major veins of the leaf though they showed no preference for the leaf surface. Such habit of laying eggs in secluded habitat may offer better chances of protection of eggs.

Temperature as well as relative humidity (RH) are known to influence the development and reproduction of several species of tetranychid mites (Boudreaux, 1958; Das and Das, 1967; Lal, 1977; Puttaswamy and ChannaBasavanna, 1980a;

Boyne and Hain, 1983; Congdon and Logan, 1983; Pande and Sharma, 1986; Bonato *et al.*, 1990; Childers *et al.*, 1991; Bonato *et al.*, 1995b; Liu and Tsai, 1998; Bonato, 1999; Bounfour and Tanigoshi, 2001; Zhang *et al.*, 2001 a & b; Fu, *et al.* 2002; Kasap, 2003; Badii *et al.*, 2003; Sakunwarin *et al.* (2003); Gotoh *et al.*, 2004; Kasap, 2004; Geraldo, *et al.*, 2004; Sangita and Bhardwaj, 2004; Ji *et al.*, 2005 a & b; Ghoshal *et al.*, 2006; Sangeetha and Ramani, 2008b). The 5 species of spider mites considered in the present study showed variation in the durations of their development as influenced by temperature, relative humidity and host plants.

The pre-oviposition period of *T. neocaledonicus* was recorded to be around 2.57, 1.6 and 1.25 days on *A. tricolor* at 25ºC & 80% RH, 30ºC & 70% RH and 35ºC & 60% RH respectively. While on *V. unguiculata*, the respective durations were 2.62, 1.8 and 1.42 days. The durations were found to decrease with increase in temperature and decrease in RH. The maximum pre-oviposition period of 2.62 days was therefore noted for *T. neocaledonicus* when fed on *V. unguiculata*, followed by 2.57 days on *A. tricolor* and at 25ºC & 80% RH. Differences in the duration at 1% significance level was noted by Puttaswamy and ChannaBasavanna (1982b) in *T. neocaledonicus* infesting tapioca, mulberry, castor and *Amaranthus*. Reports of other workers on pre-oviposition periods of *T. neocaledonicus viz.*, 1.83 $\pm$ 0.19 days (Mallik and ChannaBasavanna, 1983), 2.5 $\pm$ 0.15 days (Ghoshal *et al.*, 2006) and 1.5$\pm$ 0.12 days (Sangeetha and Ramani, 2007a) were almost in agreement with the results of the present study. Also, the pre-oviposition periods of mated females were comparatively lower than that of virgin females, probably because the former got

fertilised as soon as they emerged from the preceeding quiescence. While the durations of pre-oviposition (0.5 day) and post-oviposition periods (0.5 day) of *T. ludeni* on *M. deeringiana* were recorded lowest and that of oviposition the highest (11.5 days) at 30ºC & 70% RH. The observations on the respective durations made by Puttaswamy and ChannaBasavanna (1981b) on brinjal leaves were 0.98 day, 10.85 days and 2.3 days. However, at 19.3 ºC - 28.4 ºC and 53% - 88% RH, the pre-oviposition, oviposition and post-oviposition periods were 1.54 days, 12.75 days and 3.61 days respectively (Puttaswamy and ChannaBasavanna, 1980b).

Apart from the studies on the influence of temperature and relative humidity, influence of 2 species of host plants *viz., C. papaya* and *D. lablab* on the biology of *T. cinnabarinus* was considered in detail. However, the duration of pre-oviposition and post-oviposition periods of *T. cinnabarinus* did not show much variation (0.5 day) at 30ºC & 70% RH and 35ºC & 60% RH on both the host plants. At the same time, Nandagopal and Gedia (1995) recorded 1.12 days and 1.22 days of pre-oviposition and post-oviposition respectively for the mite at 30ºC & 80% RH. The pre-ovipositional and post-ovipositionl characteristics of *E. orientalis* on *M. oleifera* were found to be high at very low temperature and high humidity conditions. The respective durations were 1.1 and 1.75 days for pre-oviposition and post-oviposition at 25ºC & 80% RH. At higher temperatures, the durations were found to decrease to less than 1 day. Similar results were recorded for the mite by Dhooria (1985). The durations of pre-oviposition and post-oviposition of *O. biharensis* on *M. esculenta* showed a gradual decline with increase in temperature. Lowest durations for the

respective periods were recorded at 35ºC & 60% RH (0.5 day each) while extended durations were noted at 25ºC & 80% RH (1.8 and 1.5 days).

The durations of oviposition period of *T. neocaledonicus* was reported to be 4.7 days on *R. mucronata* (Ghoshal *et al.*, 2006), 8.4 days on *M. oleifera* (Sangeetha and Ramani, 2007a), 8-10 days on lady's finger (Ray and Rai, 1981) and 13-19 days on French bean (Manjunatha and Puttaswamy, 1989). On *A. tricolor* and *V. unguiculata*, it was found to range from 7.5-9 days and 7-9.7 days depending on temperature and relative humidity. Similar observations on the effect of temperature on the life history of *T. evansi* were recorded by Bonato (1999). Similarly, respective durations of post-oviposition ranged from 2.2-2.3 days on *A. tricolor* and 2.2-3 days on *V. unguiculata*. Contrary to these results, many authors reported comparatively lower duration for the post-oviposition period of this mite (Manjunatha and Puttaswamy, 1989; Ghoshal *et al.*, 2006 and Sangeetha and Ramani, 2007a). The results suggests that apart from temperature and humidity, host plants also exert a considerable influence on the biology of plant mites (Rasmy, 1978; Jesioter, 1980; Puttaswamy and ChannaBasavanna, 1981 b & c, 1982b; Dhooria, 1982; Sharma and Kushwaha, 1984; Dhooria, 1985; Tomczyk and Kropczynska, 1985; Manjunatha *et al.*, 1991; Karmakar *et al.*, 1994; Sarkar *et al.*, 1998; Gotoh and Higo, 1997; Bonato *et al.*, 2000; Kerguelen and Hoddle, 2000; Thongtab *et al.*, 2002; Kasap, 2003; Kasap, 2004; Czajkowska and Puchalska, 2006; Vasquez *et al.*, 2008). The oviposition period of *T. ludeni* was very low at 25ºC & 80% RH (5.7 days) and high at 30-35ºC & 55-70% RH (10.9-11.5 days). The above

results have clearly indicated that high temperatures and low humidities were more favourable for *T. ludeni*.

The oviposition period of *T. cinnabarinus* seemed to be affected by prevailing temperature and relative humidity. A progressive increase in the duration was observed with decrease in temperature and increase in RH. The duration of oviposition was similar on *C. papaya* and *D. lablab* at all the temperature-humidity combinations studied. Similarly at 30ºC, no differences occurred in the daily oviposition rates at 70% RH. The oviposition period was much reduced at 35ºC and 60% RH. This resulted from greater mortality of adults at 35ºC and 60% RH. The duration of egg laying period in the females of *E. orientalis* significantly decreased from 8.2 days to 7.7 days with increase in temperature and a corresponding decline in humidity conditions. This was higher than those recorded by Dhooria (1985) when Rasmy (1977) noted no much variation in the oviposition periods for the mite. Studies on the period of oviposition of *O. biharensis* on *M. esculenta* showed that the temperature-humidity combinations of 25ºC & 80% RH promoted extension of oviposition periods to 8.8 days, though rearing of mites at these conditions led to poorest fecundity. Shortest duration of oviposition with maximum fecundity was recorded at 35ºC & 60% RH (7.7 days).

The number of eggs produced during the life time of a female tetranychid mite may vary greatly among species and also with hosts, temperature and relative humidity. It is not surprising to note that even individuals of the same species show variation in the number of eggs produced by them. Fecundity of *T. neocaledonicus*

on *A. tricolor* and *V. unguiculata* was highest at 35ºC & 60% RH (41.8 & 48.7) and lowest at 25ºC & 80% RH (27.6 & 31.2). However, significantly higher fecundity of the mite was recorded by Puttaswamy and ChannaBasavanna (1981c) for *A. tricolor* (95.08) and *A. viridis* (147.42) at 23-26ºC & 74-81% RH. The number of eggs laid by individual female mite on *V. unguiculata* was higher than on *A. tricolor*, though was much lower than that of earlier reports on other host plants (Gupta *et al*., 1974; Ray and Rai, 1981; Manjunatha and Puttaswamy, 1989; Kasap, 2004). While on *M. oleifera*, the same mite was reported to lay 27-45 eggs which supported the results of the current study (Sangeetha and Ramani, 2007a & Sangeetha *et al.*, 2007). The number of eggs deposited by *T. ludeni* was affected by both temperature and relative humidity levels. The highest number of eggs (83.6 eggs/female/day) was laid at 30ºC & 70% RH. The lowest number (28.3 eggs/female/day) was deposited at 25ºC & 80% RH. Irrespective of temperature, the number of eggs laid by an individual was maximum at 70% relative humidity levels. The number of eggs laid per female per day was reduced at higher humidities (80% RH) since high humidities reduced egg production capacity of adults irrespective of temperature ranges. These results are in agreement with the findings of several authors (Boudreaux, 1958; Puttaswamy and ChannaBasavanna, 1980a & b) on tetranychids.

Humidity though had little influence on the pre-oviposition and post-oviposition periods of *T. cinnabarinus*, higher humidity proved to have negative impact on the egg laying capacity as shown by adult females. A decrease in the fecundity was recorded at low temperatures and higher humidity. Rate of egg

production on *C. papaya* was 23.5, 40.7 and 33.2/female/day respectively at 25ºC & 80% RH, 30ºC & 70% RH and 35ºC & 60% RH. While on *D. lablab*, the respective fecundity was 25.2, 42.5 and 33.9/female/day.. (Nandagopal and Gedia, 1995; Biswas *et al.*, 2004; Sangeetha and Ramani, 2008b).

The number of eggs laid by *E. orientalis* varied from 27.1 to 33.9 at temperature-humidities ranging from 25ºC & 80% to 35ºC & 60% RH. Lowest fecundity was recorded at 25ºC & 80% RH and 35ºC & 60% RH due to high rate of adult female mortality which prevented the species from laying more eggs. Lal (1977) and Dhooria (1985) recorded fecundity of the mite to range from 10-36 and 2.58-29.87 respectively. A combination of 30ºC & 70% RH proved to be the optimum conditions for high fecundity of *E. orientalis* in the present study. High mortality for the mite at 35ºC was reported by Gupta (1985) and Banu and ChannaBasavanna (1972). However, Lal (1977) observed doubling in fecundity with increase in temperature from 23.61 ºC to 28.64 ºC. Data recorded on the fecundity of *O. biharensis* revealed that the average number of eggs laid per female at 35ºC & 60% RH (47 eggs) was significantly higher as compared with that of the females reared at 30ºC & 70% RH (37.6 eggs). The lowest number of eggs was laid at 25ºC & 80% RH (34.2 eggs). This was in support of the findings of Ji *et al.* (2005b) who reported highest fecundity of *O. biharensis* at 35ºC (71.6 eggs/female). While on cultivars of litchi, *O. biharensis* deposited 34 - 68.8 eggs which were significantly much higher to that recorded in the present study (Chen *et al.*, 2005).

Chapter V
Discussion

Longevity of the mites was often found influenced by several factors, of which temperature, humidity, host plants and mating appear to be vital. Comparison of the life span of mated and virgin females of *T. neocaledonicus* has shown shorter duration on *A. tricolor* (10.9 days) and *V. unguiculata* (11.7 days) at 35ºC & 60% RH. Durations recorded by several authors on different hosts at different temperatures and humidities fell in the range of 24-50 days in the case of mated and virgin individuals (Puttaswamy and Reddy, 1980, Puttaswamy and ChannaBasavanna, 1981c; Manjunatha and Puttaswamy, 1989; Ghoshal *et al.*, 2006). This has established negative influence of mating and higher temperature on the longevity of these individuals. Similar observation on *T. neocaledonicus* was made by Ray and Rai (1981) on lady's finger and Sangeetha and Ramani (2007a) on *M. oleifera*. Rate of daily egg production was yet another factor that influenced the longevity of these individuals. Probably, high frequency of oviposition reduced the life expectancy of the females as observed in the present study. Longevity of *T. ludeni* was observed to be highest (12.7 days) at 35ºC & 60% RH and lowest (8 days) at 25ºC & 80% RH on *M. deeringiana.* This appears to be the usual trend under field conditions where *T. ludeni* lived longer at higher temperatures and low relative humidities (Puttaswamy and ChannaBasavanna, 1980a).

The longevity of *T. cinnabarinus* was shorter on *D. lablab* (6.8 days) and *C. papaya* (6.2 days) at 35ºC & 60% RH due to low survival rate of the adults. However, the conditions for longer life was observed at 25ºC - 30ºC & 70% - 80% RH. The overall trend was that the mite, *T. cinnabarinus* lived longer at low -

moderate temperatures and humidities. The life span of females of *E. orientalis* on *M. oleifera* varied from 7.5 days to 11.1 days depending on the temperature and relative humidities provided. Longevity was highest (11.1 days) at 25ºC & 80% RH, while 30ºC & 70% RH recorded lowest (7.5 days) life span for the adults. Mean longevity of 2-5.8 days and 6-12 days for the mite was recorded by Dhooria (1985) and Gupta (1985) respectively. In the case of *O. biharensis* on *M. esculenta*, 35ºC & 60% RH was the least suitable temperature and relative humidity in terms of lowest longevity (8.74 days) followed by 30ºC & 70% RH (10.1 days) and 25ºC & 80% RH (12.2 days). Similar trend was observed by Ji *et al.* (2005a), who recorded lowest longevity at 35ºC (19 $\pm$ 3.11 days) and highest of 98.9 $\pm$ 20.77 days at 15ºC.

The duration of development from egg to adult stage *T. neocaledonicus* was longer on *A. tricolor* (16.83 days) at 25ºC & 80% RH. The same species completed its development at a comparitively shorter span of time (14.73 days) on *V. unguiculata*. Both the species however took lowest developmental time of 12.85 days and 10.25 days respectively at 35ºC & 60% RH and 30ºC & 70% RH. The durations as reported by earlier workers seem to coincide with the current duration. The statement of Praslicka and Huszar (2004) that higher the temperature, faster was the development of *T. urticae* on different hosts supported the current findings of *T. neocaledonicus.* Further, the authors recorded the optimum temperature as 35ºC. The results obtained on the preference of *T. neocaledonicus* on 2 hosts reflected *V. unguiculata* to be the more susceptible host for the mite than *A. tricolor* owing to shorter developmental time, higher fecundity, adult longevity and feeding responses.

Also, the temperature-humidty combination of 35ºC & 60% RH was found to be favourable for the production of maximum number of generations. While studies made on the effect of temperature by Gupta *et al.* (1972) indicated 30 ºC as the most favoured temperature for the mite. The mean egg to adult period of *T. ludeni* on *M. deeringiana* was recorded to be a maximum of 12.85 days at 25ºC & 80% RH and minimum of 9.54 days at 30ºC & 70% RH. This duration appeared to be on a higher side as compared to 222 hours (Mallik and ChannaBasavanna, 1983) and 10.16 days (Singh *et al.,* 1989) in *T. ludeni.*

Developmental duration of *T. cinnabarinus* was found to be affected mainly by temperature, with relative humidities playing a minor part. The optimum temperature for development as observed in the current study was 30ºC & 70% RH on *D. lablab* (7.33 days) and *C. papaya* (7.95 days) for the mite. Similar results on *T. cinnabarinus* were recorded by Jeppson *et al.* (1975). At 35ºC & 60% RH, *T. cinnabarinus* could survive only for a limited period of time. This resulted from greater mortality of pre-adults and lower survival of adults at 35ºC & 60% RH. As per reports of Gupta *et al.* (1976), high temperature and high RH proved detrimental for mite population while moderate temperature and RH proved congenial for its multiplication. Population was positively correlated with RH and negatively correlated with temperature. According to Biswas *et al.* (2004) temperature reduced the developmental, reproductive period and longevity of *T. cinnabarinus* though fecundity increased with increase in temperature. Significant differences in duration of development was not observed on both the hosts, but *T. cinnabarinus* performed

better on *D. lablab* than on *C. papaya* in terms of net reproductive rates and adult survival rates.

Comparison of data regarding development of *E. orientalis* at 25ºC & 80% RH, 30ºC & 70% RH and 35ºC & 60% RH revealed that the mean duration of development was shorter (8.27 days) while fecundity was higher when the species was reared at 30ºC & 70% RH, followed by those reared at 35ºC & 60% RH (9.48 days) and 25ºC & 80% RH (12.37 days). To summarise the results, 25ºC & 80% RH was least suited for the mite owing to lowest fecundity and longest developmental time. High temperature and low humidity were best preferred to by the mite (Lal and Mukharji, 1980). Contrary to these observations, Jeppson *et al.* (1975) suggested 21ºC & 59-70% RH as the best suited conditions for *E. orientalis* beyond which the conditions were unfavourable for mite development. Among the different conditions, development of *O. biharensis* on *M. esculenta* was much faster at 35ºC & 60% RH (6.83 days). But, 25ºC & 80% RH was not found suitable as the mean duration of development of all life stages was comparatively higher on it. Highly significant and positive correlation was recorded among adult, immature stages and eggs with temperature. Further, higher temperature accelerated the developmental rates and reduced the durations of developmental stages. Temperature exerted a significant effect on all developmental stages of *O. coffeae* (Haque *et al.*, 2007). Accordingly, at higher temperatures, the development of *O. coffeae* occurred rapidly. This seems to explain why this spider mite multiplies and attains pest status during the drier and hotter months of the year in Kerala.

Chapter V
Discussion

In all the 5 species of spider mites, the number of females outnumbered males on all hosts and at various combinations of temperature and relative humidities. In the present study, a maximum of 10 females to 1 male was found in the population of spider mites reared on different host plants. Observation on the life cycle of the spider mites at temperatures above 40ºC recorded high mortality of the life stages. Even though the spider mites were delicate and desicated after a short exposure to high temperature, the hatchability of their eggs was not considerably retarded and more than 70% eggs hatched into larvae. This may be due to the comparatively thick membranes of the egg whereas the larva and nymphs were found to be shrivelled out on subjecting to higher temperatures.

The hatching characteristics of the 5 species followed a more or less similar trend involving the formation of an equatorial slit on the egg case and culminating in the separation of the case into two halves. The entire process averaged 10 – 20 minutes in duration. Moulting of the quiescent individuals was initiated by the formation of a horizontal slit at the dorsal region of the propodosoma followed by the slow backward movement of the individual. This pattern of moulting was clearly followed by all 5 species of spider mites studied. These findings are in support with earlier reports on tetranychid mites (Siddig and Elbadry, 1971; Banu and ChannaBasavanna, 1972; Gupta, 1985; Sangeetha and Ramani, 2007a).

Mating marks the success of reproductive potential, which is crucial to the survival of a species. Mating, as a common feature was observed in all the tetranychid species studied during the current investigation. The phenomenon of

sperm transfer was direct, achieved through copulation. The males emerged earlier than the females and found guarding the quiescent female deutonymphs and copulating with the female immediately after the emergence of the latter. These observations are in agreement with the behavioural activities observed in the case of *T. urticae* (Penman and Cone, 1972), *T. evansi* (Qureshi *et al.,* 1969), *P. citri* (Beavers and Hampton, 1971) and *E. orientalis* (Banu and ChannaBasavanna, 1972). Therefore the process appears to be common among different genera of tetranychid mites. Indepth studies on the mediation of the male attraction towards the female deutonymphs (Cone *et al.,* 1971a; Hazan *et al.,* 1973; Penman and Cone, 1974) have attributed the role of sex pheromones in the process. As the process appears to be similar in other species of mites studied, the production of sex pheromone by the females may be considered as a common feature among the members of the tetranychidae. Male preference for virgin and mated females of *T. kanzawai* was tested by Oku *et al.* (2005) who suggested the probability of the use of odours by males to discriminate the mating status of females. They added that the males preferred virgin females who were more gregarious and remained on the leaves for longer time than the mated ones so as to increase the mating opportunities. Generally, a single copulation was reported in the case of females, while males were known to copulate many times (Banu and ChannaBasavanna, 1972, Nandagopal and Gedia, 1995; Sangeetha and Ramani, 2007a).

A special type of reproductive behaviour in tetranychids called parthenogenesis has been reported by several authors. The instance of arrhenotoky

in particular has been reported in several spider mite species by Nandagopal and Gedia (1995). During the present study, mated females of all the species were found to lay eggs which developed into both males and females. However, the eggs deposited by virgin females always developed into males only. This has clearly indicated the occurance of normal sexual reproduction as well as parthenogenesis in all the 5 species studied. Probably, the occurrence of dual reproductive means may enhance the male population which is otherwise found low in field conditions.

An interesting observation emerged during the present study was the cannibalistic habit of the males of *T. cinnabarinus* on the females of the same species after their death immediately after egg laying. Predatory habit in tetranychid mites was already reported in species like *cinnabarinus*, the males of which devoured the females of *T. hypogea* (Nandagopal and Gedia, 1995). However, cannibalistic trend seems to be a new behavioural alteration so far unreported among phytophagous mites. This behaviour of switching of feeding trends of males from phytophagy to predation or even to cannibalism appears to be an interesting deviation from the general trend and therefore needs further studies for understanding its relevance.

The biological phenomenon of aggregation as observed in many groups of organisms, serving various life activities of the species in question, was a feature noted in *T. ludeni*. Repeated occurrence of the process at the time of each quiescent period has indicated the significance of the phenomenon in the ontogeny of the species. Hence, further studies on the aggregation behaviour of this species

particularly, of the larval and nymphal instars are warranted. More studies on the mediation of pheromones in this behaviour will help in unveiling the exact nature of the relationship among the members of the species.

A progressive decrease in duration of the active periods of life stages was a common feature observed in all the 5 species of these mites at different temperature-humidity combinations and different host plants. However, quiescent periods showed not much significant change in duration. But conditions of extremely high relative humidity (80% RH) caused all life stages of *T. cinnabarinus* to extend their period of quiescence. Similar observations were made by Jeppson *et al.*, (1975). The total duration of sexual development was found shortest in the case of *T. cinnabarinus* on *D. lablab* at 35ºC and 60% RH which was 6.4 days and highest in the case of *T. neocaledonicus* on *A. tricolor* which was 17.2 days. Again the total duration of parthenogenetic development was found shortest in the case of *T. cinnabarinus* on *D. lablab* at 35ºC and 60% RH which was 5.7 days and highest in the case of *T. neocaledonicus* on *A. tricolor* at 25ºC and 80% RH which was 15.8 days. This would suggest that among the 5 species, *T. cinnabarinus* possesses maximum number of generations in the field at 35ºC and 60% RH. The maximum number of generations of *T. neocaledonicus* was observed at 35ºC and 60% RH on *V. unguiculata*, *T. ludeni* at 30ºC and 70% RH on *M. deeringiana*, *T. cinnabarinus* on *D. lablab* at 35ºC and 60% RH, *E. orientalis* on *M. oleifera* at 30ºC and 70% RH and *O. biharensis* on *M. esculenta* at 35ºC and 60% RH. Such variations in the

number of generations were observed at different temparature-humidity conditions as evidenced by the studies on same or other species of tetranychids.

Results of the morphological studies on the developmental stages enabled to distinguish the immatures of the above 5 tetranychid mite species. Further, the life stages of the genus *Eutetranychus* could be easily differntiated on the basis of the nature of their dorsal setae. They were short barbed and set on distinct tubercles, while that of genus *Tetranychus* were long, pointed, smooth and without tubercles. Further, the presence of empodium and claw set the members belonging to genus *Oligonychus* well apart from the other 2 genera. The number and position of hysterosomal setae showed variation in the different life stages of the species studied. This supports the importance of chaetotaxy in the recognition of species even in the larval and nymphal stages.

A progressive increase in body size and number of body setae from larva to deutonymph was noted in all the 5 species studied. The progressive change in the ventral setal complements of the individuals of all the species appeared to be identical. In all the species, the larvae possesed only 2 pairs of medioventral setae and lacked the pre-genital and post-genital setae. Developnment of the genital area and setae alone was attained at this stage. However, full setal compliment of 13 setae was observed at the larval stage itself in *E. orientalis.* In the rest, the complete dorsal setal compliment was attained only at the deutonymphal stage. These points have indicated a progressive trend in the morphological changes of the mite species studied.

Chapter V
Discussion

Of all the different temperature - humidity conditions provided, the temperature-humidity combinations of 30ºC & 70% RH and 35ºC & 60% RH were found to be best suited for the successful survival and development of all the spider mite species studied on different hosts. This combination is almost in agreement with the temperature and humidity conditions prevalent during summer months when the population density of each mite has attained the peak level in the field. This clearly suggests that temperature and relative humidity exerts a direct influence on the developmental process of the spider mites. Thus, the study elucidates the fact that warmer temperature and low relative humidity available during the summer months in our state would ensure ideal conditions for the rapid population build up of these mites. Vegetable plants, being the most valuable crops of our nutritional concern, this has to be considered seriously, as these major mite pests would become a great threat to our vegetable crops..

Further, an interesting and cognitive aspect that emerged from the study was the incidence of *E. orientalis* on *M. oleifera* and *T. ludeni* on *M. deeringiana,* both of which are new records of host plants, so far unreported from India. The above results clearly indicate the possibility of new host arenas yet to be explored thereby necessitating further attention to be focussed on this aspect.

Chapter VI
Summary

Agriculture plays an important role to determine the economy of Kerala. Being primarily an agricultural state, contribution of Kerala to the vegetable crop industry is a crucial one. However, despite the rich diversity of pests on these crops, knowledge on their faunal composition particularly of mites as pests and other related details remains very much limited. In this context, the present study, though throws light only on the tetranychid fauna of selected few can be considered as a basic framework for further research along this line.

In the present investigation, association of 5 most common and dominant species of spider mites of local importance with a few economically important vegetable crops was studied in detail. The study further elucidated the biological parameters of the spider mites and provided an account of the influence of 3 different temperature-relative humidity combinations on the life history of the mites. Further, the study shed light on the feeding habits of the selected species and helped assess the damage potential qualitatively and quantitatively, unravelling the relative abundance, host range, seasonal distribution and the population distribution pattern of the selected species of spider mites on the leaves of the host plant.

Aerial parts of the plants, especially the leaves and leaflets that showed mite infestation were collected with the help of a scissors and transferred to polythene bags, labelled and transported to the laboratory. The collected samples were

examined individually under a stereo zoom microscope. Live mites were either transferred to 70% alcohol for further processing or to fresh leaves for biological studies. Rearing of species of interest for indepth studies on feeding was made by culturing them on artificially set up experimental and control plots. Studies on the life history parameters were initiated by raising laboratory cultures of the mites by rearing them on leaves of their respective host plant as food. The cultures were maintained at different sets of temperature-humidity conditions *viz.*, 25 $\pm$ 2ºC & 80 $\pm$ 5% RH, 30 $\pm$ 2ºC & 70 $\pm$ 5% RH and 35 $\pm$ 2ºC & 60 $\pm$ 5% RH and daily observations were made on the mode of feeding, damage and breeding of the mites. The damage potential was evaluated by adopting different approaches like estimation of loss of chlorophyll content, estimation of phenol content, estimation of protein profile and transmission electron microscopic studies. Post-embryonic studies of the selected species were made and illustrations of the developmental stages were provided with morphological descriptions supported by camera lucida drawings. The various aspects of the study have been presented in appropriate chapters with special emphasis on the survey of acarine fauna associated with 40 species of vegetable crops cultivated in different localities covering 6 districts of Kerala, biological studies of 5 species of spider mites belonging to 3 different genera showing potentiality as major pests.

Survey of the acarine fauna revealed the occurrence of members belonging to 3 orders, Prostigmata, Mesostigmata and Oribatida. Prostigmata confirmed maximum acarine inquilines figured by 3 superfamilies, Tetranychoidea,

Tarsonemoidea and Eriophyoidea, detected in all of the 25 collection sites, thereby claiming maximum diversity, closely followed by members of Mesostigmata and Oribatida. Of the various species of Prostigmatids recovered, 5 species of mites representing family Tetranychidae belonging to 3 genera *viz.*, *Tetranychus*, *Eutetranychus* and *Oligonychus* were considered for detailed biological studies. The above 5 species were *T. neocaledonicus* Andre, *T. ludeni* Zacher, *T. cinnabarinus* (Boisduval), *E. orientalis* (Klein) and *O. biharensis* (Hirst).

The survey of host plants associated with the tetranychid fauna revealed 40 species of economically important plants, especially vegetable crops belonging to 36 genera and 22 families cultivated in agricultural fields, home yards and kitchen gardens in 25 different sites covering 6 districts of Kerala *viz.*, Malappuram, Kozhikode, Kannur, Wayanad, Palakkad and Thrissur. However, detailed studies were initiated on 7 species of host plants duly considering their availability, supreme status and severity of mite infestation on them.

Studies on the seasonal distribution of the selected species of mites during the study period revealed their presence throughout the year at peak, moderate or scanty levels. *T. neocaledonicus*, *T. cinnabarinus*, *E. orientalis* and *O. biharensis* occurred at peak levels mainly during summer from February to April or May while *T. ludeni* showed its presence at peak levels from May to July. Study of relative abundance of the spider mite species revealed variations at interspecific and intraspecific levels. Of the 5 species, *T. ludeni* was found to be the most abundant species in terms of population density, followed by *T. cinnabarinus*, *T.*

neocaledonicus and *O. biharensis* and *E. orientalis*, which happened to occur only at low to scarce levels. Data on differential distribution pattern of the spider mites evidenced the occurrence of *E. orientalis* and *T. ludeni* on the upper leaf surface, *T. neocaledonicus* and *T. cinnabarinus* on the underside while *O. biharensis* on the other hand showed equal distribution on both sides of the leaf blade.

Results of the feeding experiments conducted in the laboratory on *T. neocaledonicus* infesting *V. unguiculata* and *A. tricolor*; *T. ludeni* on *M. deeringiana*; *T. cinnabarinus* on *C. papaya* and *D. lablab*; *E. orientalis* on *M. oleifera* and *O. biharensis* on *M. esculenta* leaves reflected on active feeding by the different life stages by piercing the leaves and sucking the cell contents. Combined and extensive feeding by the mites resulted in acute chlorosis of the leaves. Estimation of the damage potential of the above species through analysis of chlorophyll content of the leaves, in terms of percentage loss of chlorophyll 'a' and 'b', respectively yielded 47.58 $\pm$ 2.1 % and 48.30 $\pm$ 2.2 % for *T. neocaledonicus*, 34.57 $\pm$ 2.2 % and 43.32 + 3.3 % for *T. ludeni*, 41.07 $\pm$ 2.1 % and 50.81 $\pm$ 1.6 % for *T. cinnabarinus*, 36.26 $\pm$ 0.99 % and 35.40 $\pm$ 2.0 % for *E. orientalis* and 29.40 $\pm$ 1.6 % and 46.03 $\pm$ 1.0 % for *O. biharensis*. Interestingly enough, this loss was found to reach 80% levels in cases of severe infestations. Analysis of total phenolics revealed an increase of about 2 - 2.5 mg phenol/100 gm plant material following *T. neocaledonicus* infestation and 10 – 12 mg phenol/100 gm plant material following infestation by *O. biharensis.* Preliminary studies on the protein profile of *M. esculenta* leaves following infestation and damage by *O. biharensis* revealed 5

prominent bands with invariably higher protein concentration on uninfested samples. This reflected a decrease in the protein concentration in the mite-infested leaves though no significant change in the protein profile could be recorded. Probably, endogenous degradation of existing proteins might have occurred.following mite infestation. Cytological alterations resulting from feeding of *O. biharensis* on *M. esculenta* using electron microscopy showed reduction in the number of cells and chloroplasts, alterations in cell structure, increase in space in the spongy layer, extensive disruption of the mesophyll cells and even reduction of chloroplasts in adjacent unpunctured cells. The overall impact of spider mite feeding had resulted in the total destruction of the photosynthetic machinery of the plant leading to its final collapse. These results thus clearly established the potentiality of the leaf sucking forms in damaging the host plants.

Post-embryonic developmental studies of the above 5 species disclosed the occurrence of a larval and 2 nymphal stages prior to attaining adulthood. Each instar was constituted by an active period followed by a quiescent period, which then moulted to successive stages of development. The process of sperm transfer was achieved through mating which occurred immediately after moulting of the female deutonymph and the process lasted for 2-3 minutes. The egg deposited by the mated females developed into both females and males whereas unmated females gave rise to male progeny alone. Thus parthenogenetic development could also be recorded in all the 5 species of spider mites.

Chapter VI
Summary

An interesting observation made during the development of *T. ludeni* was the detection of a phenomenon of aggregation during quiescent periods of the immatures. Detailed studies on the mechanism of the process indicated that the process was initiated by few individuals of the colony and the removal of these individuals disrupted the aggregation and continuation of the process. Existence of a pheromonal communication could be evidenced in the present study. The production of two types of faecal pellets by *T. ludeni* was another special feature which was not observed in the current study in any other spider mites. A yet another interesting finding emerged during the present study was the cannibalistic nature of males of *T. cinnabarinus* on the females of the same species after their death immediately after egg laying. A worth mentioning aspect of the study was the incidence of *E. orientalis* on *M. oleifera* and *T. ludeni* on *M. deeringiana*, both of which were new records of host plants, so far unreported from India. Further investigations should aim at providing undisputable evidence of new host plants yet to be explored, thereby necessitating further attention to be focussed on this aspect.

A comparison of the total duration of life cycle of *T. neocaledonicus* on *A. tricolor* under different temperature-humidity conditions enabled to record shorter duration of development (12.85 $\pm$ 0.14 days) at 35 $\pm$ 2ºC & 60 $\pm$ 5% RH and a longer duration at 25 $\pm$ 2ºC & 80 $\pm$ 5% RH (16.83 $\pm$ 0.2 days). At the same time, *T. neocaledonicus* produced more generations on *V. unguiculata* at 30 $\pm$ 2ºC & 70 $\pm$ 5% within a short span of time (10.25 $\pm$ 0.08 days) proving *V. unguiculata* as the more preferred host for the mite. The developmental period of *T. cinnabarinus* on *C.*

papaya (6.62 ± 1.8 days) and on *D. lablab* (6.27 ± 0.15 days) at 35 ± 2ºC & 60 ± 5% RH enabled to record *D. lablab* as the more susceptible host for the mite. The most favoured temperature-humidity combinations of *T. ludeni* on *M. deeringiana* was recorded to be 30 ± 2ºC & 70 ± 5% RH (9.54 ± 0.18 days), of *E. orientalis* on *M. oleifera* (8.27 ± 0.14 days) was 30 ± 2ºC & 70 ± 5% RH and of *O. biharensis* on *M. esculenta* (6.83 ± 0.10 days) was 35 ± 2ºC & 60 ± 5% RH.

The shorter developmental period averaging 6 – 12 days for the above 5 species helped them in successfully completing 2-5 generations per month during favourable conditions corresponding to the temperature-humidities as reflected from the present investigation. These conditions could be identified as the ideal conditions for the population build up of the mite in field conditions also. This seems to explain why these spider mites could multiply and attain pest status especially during the drier and hotter months of the year in Kerala.

ABUKHASHIM (N.K.) and LUFF (M.L.), 1997. – Effects of short exposure periods to low temperatures on the biology of *Tetranychus urticae*. *Acarol*., **38**(3): 255-263.

ADANGO (E.), ONZO (A.), HANNA (R.), ATACHI (P.) and JAMES (B.), 2006. – Comparative demography of the spider mite, *Tetranychus ludeni*, on two host plants in West Africa. *J. Ins. Sci*., **6**(49): 1-9.

AKIRA (K.), KENJI (C.) and FUKUSABURO (T.), 1998. – Development and population increase of two spotted spider mite *Tetranychus urticae* Koch (Green form) (Acari: Tetranychidae) on different varieties of Chrysanthemum. *Appl. Entomol. Zool*., **33**(1): 28-30.

ALI (S.M.) and SARKAR (S.K.), 1987. – Life history of red spider mite *T. bioculatus* (Wood Mason) on Mashkalari. *Bangl. J. Zool*., **15**(2): 173-176.

ALLAM (L.), HMIMINA (M.) and OUAHBI (A.), 1999. – Influence of host plant changing on the development of *Tetranychus urticae* Koch (Acari: Tetranychidae): Consequence of mite infestation in citrus fields. *J. Appl. Entomol*., **123**(10): 597-601.

AMER (S.A.A.) and RASMY (A.H.), 1994. – Biology of the two spotted spider mite *Tetranychus urticae* as affected by some resistant plants. *Acta. Phytopathol. et. Entomol. Hung*., **29**(3-4): 349-352.

ANANTHAKRISHNAN (T.N.), GOPICHANDRAN (R.) and GURUSUBRAMANIAN (G.), 1992. – Influence of chemical profiles of host plants on the infestation diversity of *Retithrips syriacus*. *J. Biosci.*, **17** (4): 483-489.

ANSARI (M.A.) and PAWAR (A.D.), 1992. – Biology of spider mite *Tetranychus ludeni* Zacher (Acari: Tetranychidae) recorded on water hyacinth. – *Plant Prot. Bull*., **42**(3): 23-31.

APONTE (O.) and MC MURTRY (J.A.), 1997. – Biology, life table and mating behaviour of *Oligonychus perseae* (Acari: Tetranychidae). *Intl. J. Acar.*, **23**(3): 199-207.

ATWA (W.A.), ABDELL – ALL (H.E.) and AFIFY (E.A.), 1987. – Morphology of *Tetranychus urticae* Koch different stages (Acari: Tetranychidae). *Ann. Agri. Sci*., **32**(1): 767-784.

AVERY (D.J.) and BRIGGS (J.B.), 1968a. – The aetiology and development of damage in joung fruit trees infested with fruit tree red spider mite, *Panonychus ulmi* (Koch). *Ann. App. Biol.*, **61**: 277-288.

AVERY (D.J.) and BRIGGS (J.B.), 1968b. – Damage to leaves caused by fruit tree red spider mite, *Panonychus ulmi* (Koch). *J. Hort. Sci.*, **43**: 463-473.

AVERY (D.J.) and LACEY (H.J.), 1968. – Changes in the growth regulator content of plum infested with fruit tree red spider mite, *Panonychus ulmi* (Koch). *J. Exp. Bot.*, **19**: 760-769.

BADII (M.H.), VARELA (S.), FLORES (A.E.) and LANDEROS (J.), 2003.– Temperature – based life history and life table parameters of Texas citrus mite on orange (Acari: Tetranychidae). *Sys. Appl. Acarol*., **8**: 25-38.

BALI (X.), 1993. – Preliminary studies on the demography of the Pacific spider mite, *Tetranychus pacificus* (Acari: Tetranychidae) on cotton. *Polish Ecol. Studies*, **19**(1 & 2): 45-58.

BANU (K.) and CHANNABASAVANNA (G.P.), 1972. – Plant feeding mites of India I. A preliminary account of the biology of the spider mite

Eutetranychus orientalis (Klein) (Acari: Tetranychidae). *Mysore J. Agri. Sci*., **6**(3): 253-268.

BARRION (A.T.) and CORPUZ – RAROS (L.A.), 1975.- Studies on citrus mites (Acarina) : Biology of *Eotetranychus cendanai* Rimando (Tetranychidae) and population trends in *Brevipalpus obovatus* Donnadieu (Tenuipalpidae). *The Phillipine Entomol.*, **3**(1) : 30-45.

BEAVERS (J.B.) and HAMPTON (R.B.), 1971. – Growth, development and mating behaviour of the citrus red mite (Acari: Tetranychidae). *Ann. Entomol. Soc. Amer*., **64**: 804-806.

BEGLYAROV (G.A.), 1959. – On the bionomics of the hawthorn mite *Tetranychus crataegi* Hirst. *Rev. Entomol*., USSR, **38**: 135-144.

BEITIA (C.F.J.) and VIVAS (G.A.), 1991. – Differences in the development of *Panonychus citri* (Mc Gregor) on leaves of several citrus species (Acari: Tetranychidae). *Agronomic (Paris)*., **11**(3): 229-233.

BISWAS (G.C.), ISLAM (W.), HAQUE (M.M.), SAHA (R.K.), HOQUE (K.M.F.), ISLAM (M.S.) and HAQUE (M.E.), 2004. – Some biological aspects of Carmine spider mite, *Tetranychus cinnabarinus* Boisd. (Acari: Tetranychidae) infesting egg plant from Rajshahi. *J. Biol. Sci*., **4** (5): 588-591.

BLAIR (C.A.) and GROVES (J.R.), 1952. – Biology of the fruit tree red spider mite *Metatetranychus ulmi* (Koch) in South – East England. *J. Hort. Sci*., **27**: 14-43.

BLAIR (C.A.), 1951. – Damage to apple leaves by the fruit tree red spider mite, *Metatetranychus ulmi* (Koch). 38th Rep. East Malling, *Res. Stn*. **1949/1950**: 152-154.

BONATO (O.) and GUTIERREZ (J.), 1996. – Reproductive strategy of two major mite pests (Acari: Tetranychidae) on cassava in Africa. *Ann. Entomol. Soc. Amer*., **89**(5): 676-680.

BONATO (O.) and GUTIERREZ (J.), 1999. – Effect of mating status on the fecundity and longevity of 4 spider mite species (Acari: Tetranychidae). *Expt. Appl. Acarol*., **23**(8): 623-632.

BONATO (O.), 1999. – The effect of temperature on life history parameters of *Tetranychus evansi* (Acari: Tetranychidae). *Expt. Appl. Acarol*., **23**(1): 11-19.

BONATO (O.), BAUMGARTNER (J.) and GUTIERREZ (J.), 1995a. – Comparison of biological and demographic parameters for *Mononychellus progresivus* and *Oligonychus gossypii* on cassava: influence of temperature. *Entomologia Experimentalis et Applicata*, **75**: 119-125.

BONATO (O.), COTTON (S.K.) and GUTIERREZ (J.), 1990. – Influence of temperature on the life history parameters of the yellow grape vine mite *Eotetranychus carpini* (Oudemans) (Acari: Tetranychidae). *Intl. J. Acar*., **16**(4): 241-245.

BONATO (O.), DIVASSA (M.S.) and GUTIERREZ (J.), 1995b. – Influence of relative humidity on life-history parameters of *Mononychellus progresivus* and *Oligonychus gossypii* (Acari: Tetranychidae). *Environ. Entomol*., **24**(4): 841-845.

BONATO (O.), SANTAROSA (P.L.), RIBEIRO (G.) and LUCCHINI (F.), 2000. – Suitability of three legumes for development of *T. ogmophallus* (Acari: Tetranychidae). *Florida Entomol.*, **83**(2): 203-205.

BONDADA (B.R.), OOSTERHUIS (D.M.), TUGWELL (N.P.) and KIM (J.S.), 1995. – Physiological and cytological studies of two-spotted spider mite, *Tetranychus urticae* K., injury in cotton. Southwest. *Entomol.*, **20:** 171-180.

BOUDREAUX (H.B.), 1958. – The effect of relative humidity on egg-laying, hatching and survival in various spider mites. *J. Ins. Physiol*., **2**: 65-72.

BOUDREAUX (H.B.), 1963. – Biological aspects of some phytophagous mites. *Ann. Rev. Entomol*., **8**: 137-154.

BOULANGER (L.W.), 1958. – The effect of European red spider mite feeding injury on certain metabolic activities on Red Delicious apple leaves – Maine *Agr. Exp, Sta. Bull*., **570**: 1-34.

BOUNFOUR (M.) and TANIGOSHI (L.K.), 2001. – Effect of temperature on development and demographic parameters of *Tetranychus urticae* and *Eotetranychus carpini borealis* (Acari: Tetranychidae). *Ann. Entomol. Soc. Amer*., **94**(3): 400-404.

BOUNFOUR (M.), TANIGOSHI (L.K.), CHEN (C.), CAMERON (S.J.) and KLAUER (S.), 2002. – Chlorophyll content and chlorophyll fluorescence in Red Raspberry leaves infested with *Tetranychus urticae* and *Eotetranychus carpini borealis* (Acari: Tetranychidae). *Environ. Entomol.*, **31**(1): 215-220.

BOUWMEESTER (H.J.), VERSTAPPEN (F.W.A.), POSTHUMUS (M.A.) and DICKE (M.), 1999. – Spider mite-induced (3*S*)–(*E*)-Nerolidol synthase activity in cucumber and Lima bean. The first dedicated step in Acyclic C_{11}-Homoterpene biosynthesis. *Plant Physiol.*, **121**(1): 173-180.

BOYLE (W.W.), 1957. – On the mode of dissemination of the two spotted spider mite. *Tetranychus telarius* (L.). *Proc. Hawaiian Entomol. Soc*., **16**: 261-268.

BOYNE (J.V.) and HAIN (F.P.), 1983. – Effect of constant temperature, relative humidity and simulated rainfall on development and survival of the spruce spider mite *Oligonychus ununguis*. *Can. Ent*., **115**: 93-105.

BRITO (R.M.), STERN (V.M.) and SANCES (F.V.), 1986. – Physiological response of cotton plants to feeding of three *Tetranychus* spider mite species (Acari: Tetranychidae). *J. Econ. Entomol.,* **79**: 1217-1220.

BROUFAS (G.D.) and KOVEOS (D.S.), 2000. – Threshold temperature for post-diapause development and degree-days to hatching of winter eggs of the European Red mite (Acari: Tetranychidae) in Northern Greece. *J. Econ. Entomol*., **93**(4): 710-713.

BUTLER (C.D.) Jr. and ABID (M.K.), 1965. – The biology of *Oligonychus platani* on Pyracantha. *J. Econ. Entomol*., **58**(4): 687-688.

CAGLE (L.R.), 1946. – Life history of the European red mite. *Va. Agr. Expt. Sta. Tech. Bull*., **98**: 19p.

CAGLE (L.R.), 1956. – Life history of the spider mite, *Tetranychus atlanticus* Mc. Gregor. *Va. Agr. Expt. Sta. Tech. Bull*., **124**: 1-22.

CANDOLFI (M.P.), WERMELINGER (B.) and BOLIER (E.F.), 1993. – Photosynthesis and transpiration of “Riesling x Sylvaner” grapevine leaves as affected by European red mite (*Panonychus ulmi* Koch) (Acari: Tetranychidae) feeding. *J. Appl. Ent*.**, 115**: 233-239.

CAREY (J.R.) and BRADLEY (J.W.), 1982. – Developmental rates, vital schedules, sex ratios and life tables for *Tetranychus urticae, T. turkestani* and *T. pacificus* (Acarina: Tetranychidae) on cotton. *Acarol*., **23**(4): 333-345.

CHANNABASAVANNA (G.P.), 1971. – The present status of our knowledge of Indian plant feeding mites. *Proc. 3rd. Intr. Congr. Acarology,* Prague: 201-204.

CHAPMAN (P.J.) and LIENK (S.E.), 1950. – Orchard mite control experiments in Western New York. *J. Econ. Entomol.,* **45**: 309-314.

CHEN (W.), FU (Y.), ZHANG (F.) and PENG (Z.), 2005.- Effect of different varieties of litchi on the development and reproduction of *Oligonychus biharensis* (Hirst). *Syst. Appl. Acarol*. **10**: 11-16.

CHIAVEGATO (L.G.), 1988. – Biology of the mite, *Panonychus citri* (Mc Gregor 1916) (Acari: Tetranychidae), a pest of citrus. *Cientifica*, **16**(1): 79-84.

CHILDERS (C.C.), ABOU – SETTA (M.M.) and NAWAR (M.S.), 1991. – Biology of *Eutetranychus banksi*: Life tables on 'marsh' grapefruit leaves at different temperatures (Acari: Tetranychidae). *Intl. J. Acar*., **17**(1): 29-35.

COLLINS (R.D.) and MARGOLIES (D.C.), 1995. – The effect of interspecific mating on sex ratios in the two spotted spider mite and the Banks grass mite (Acari: Tetranychidae). *J. Ins. Behaviour*, **8**(2): 189-206.

CONE (W.W.), MC DONOUGH (L.M.), MAITLEN (J.C.) and BURDAJEWICZ (S.), 1971a. – Pheromone studies of the two spotted spider mite I. Evidence of a sex pheromone. *J. Econ. Entomol*., **64**: 355-358.

CONE (W.W.), PREDKI (S.) and KLOSTERMEYER (E.C.), 1971b. – Pheromone studies of the two spotted spider mite 2. Behavioural response of males to quiescent deutonymphs. *J. Econ. Entomol*., **64**: 379-382.

CONGDON (B.D.) and LOGAN (J.A.), 1983. – Temperature effects on development and fecundity of *Oligonychus pratensis* (Acari: Tetranychidae). *Environ. Entomol.*, **12**: 359-362.

CZAJKOWSKA (B.) and PUCHALSKA (E.), 2006. – European larch (*Larix decidua*) and sweet chestnut (*Castanea sativa*) as host plants of spruce spider mites (*Oligonychus ununguis* Jacobi). *Biological Lett*., **43**(2): 307-313.

DAS (G.M.) and DAS (S.C.), 1967. – Effect of temperature and humidity on the development of tea spider mite, *Oligonychus coffeae* (Nietner). *Bull. Entomol. Res*., **57**(3): 433-436.

DAS (G.M.), 1959. – Bionomics of the tea red spider, *Oligonychus coffeae* (Nietner). *Bull. Entomol. Res*., **50**: 265-274.

DAS (T.K.) and GUPTA (S.K.), 1991. – Biological studies on the citrus mite, *Eutetranychus orientalis* under field condition in West Bengal, India. – In: Modern Acarology Vol I. Dusbabek (F.) and Bukva (V.) (Eds): Academic Prague and SPB Academic Publishing bv, The Hague, The Netherlands, Czechoslovak: 607-612.

DHOORIA (M.S.) and BUTANI (D.K.), 1983. – Seasonal incidence of citrus mite, *Eutetranychus orientalis* and its predators. *Indian J. Acar*., **7**: 59-62.

DHOORIA (M.S.) and SAGAR (P.), 1989. – Preliminary studies on the biology of carmine spider mite, *Tetranychus cinnabarinus* on 4 species of Japanese mint at Ludhiana, India. (G.P. Channabasavanna and C.A. Viraktamath) (Eds.), Progress in Acarology, **2**: 239-241.

DHOORIA (M.S.), 1982. – Studies on ovipositional preference, host-range and seasonal incidence of *Eutetranychus orientalis* (Acari: Tetranychidae) in Delhi. *Indian J. Acar*., **6**: 77-83.

DHOORIA (M.S.), 1985. –Development of citrus mite, *Eutetranychus orientalis* (Acari: Tetranychidae) as influenced by age and surface of leaves of different hosts. *Indian J. Acar*., **9**: 82-88.

DITTRICH (V.), 1965. – Embryonic development of tetranychids. *Boll. Zool. Agric. Bachic Ser*. 2, **7**: 101-104.

DONAHUE (D.J.) and MCPHERSON (R.M.), 1990. – Oviposition response of *Tetranychus urticae* (Acari: Tetranychidae) to direct treatment and residue of pyrethroids on soyabean. *J. Econ. Entomol. Sci*., **25**(1): 158-169.

DUNCAN (R.) and LINDQUIST (E.E.), 1989. – An unusually copious production of webbing by a willow-inhabiting spider mite, *Schizotetranychus schizopus* (Zacher). *Can. Ent.* **121**: 1037-1039.

EHARA (S.), 1964. – The Tetranychoid mites of Japan. *Acarol*., **6**: 409-414.

EKANAYAKE (I.J.) and ADELEKE (M.T.V.), 1996.– Selected procedures for Instrumentation in Ecophysiological Studies of Root Crops. Procedures Manual No. 3, Crop Improvement Division (CID), IITA, Ibadan, Nigeria, 103pp.

EKANAYAKE (I.J.), DIXON (A.G.O.) and PORTO (M.C.M.), 1996. – Performance of various cassava clones in the dry savannah region ofNigeria. In: *Tropical Tuber Crops: Problems, Prospects and Future Strategies*. (Eds.) Kump G. T., Palaniswamy, M. S., Potty, V. R., Padmaja, G., Kabeerathumara, S. and Pillai, S. V.,. Oxford & IBH Publishing Co., New Delhi, India. 207-215.

EKANAYAKE (I.J.), OKARTER (U.C.) and ADELEKE (M.T.V.), 1998.– Dry season dust alters photosynthetic characteristics of field grown cassava in the dry season in two agroecozones of Nigeria. In: *Root Crops and Poverty Alleviation*. (Eds.). Akoroda M. O. and Ekanayake I. J. Proceedings of Sixth Symposium of ISTRC-AB, Lilongwe, Malawi, 402pp.

EWING (H.E.), 1914.– The common red spider or spider mite. *Oreg. Agric. Exp. Sta. Bull*., **121**: 95p.

FERRO (D.N.) and CHAPMAN (R.B.), 1979. – Effects of different constant humidities and temperatures on two spotted spider mite egg hatch. *Environ. Entomol*., **8**(4): 701-705.

FOOTT (W.H.), 1962. Competition between two species of mites. I. Experimental results. *Can. Ent*., **94**: 365-375.

FOOTT (W.H.), 1963. Competition between two species of mites. II. Factors influencing intensity. *Can. Ent*., **95**: 45-57.

FREIBERGER (C.E.), VANDERJAGT (D.J.), PASTUSZYN (A.), GLEW (R.S.), MOUNKAILA (G.), MILLSON (M.), GLEW (R.H.), 1998.- Nutrient content of the edible leaves of seven wild plants from Niger. Plant Foods Hum. Nutr., **53**(1):57-69.

FU (Y.), ZHANG (F.), PENG (Z.), LIU (K.) and JIN (Q.), 2002. – The effect of temperature on the development and reproduction of *Tetranychus pierci* Mc. Gregor (Acari: Tetranychidae) in banana. *Sys. Appl. Acarol*., **7**: 69-76.

FUJIBAYASHI (Y.) and SEKITA (N.), 1993. – Development and diapause induction of the Kanzawa spider mite *Tetranychus kanzawai*. *Annual report of the Society of Plant Protection*, North Japan, **44**: 184-186.

GAAL (O.), MEDGYESI (G.A.) and VERECZKEY (L.). 1980. – Electrophoresis in the separation of biological macromolecules. John Wiley and Sons, Chichester. 83 – 87.

GEIJSKES (D.C.), 1938. – Waarnemingen over het fruitspint in verband met zijt bestrijding. – Tijdsch. *PlZiekt*., **44**: 49 – 80.

GERALDO (V.J.N.), FERNANDO (S.R.) da, MANOEL (G.G.C.) Jr, 2004. – Effect of different temperatures on the development and reproduction of

Tetranychus abaceae Baker & Pritchard (Acari: Tetranychidae) on *Musa sp*. cv. Prata. *Neotrop. Entomol*., **33**(2): 149-154.

GERSON (U.), 1979. – Silk production in *Tetranychus* (Acari: Tetranychidae) – In. RODRIGUEZ (J.G.) Ed. Recent Advances in Acarology, 1. Academic Press, New York: 177-188.

GHOSHAL (S.), GUPTA (S.K.) and MUKHERJEE (B.). 2006. – Life cycle of *Tetranychus neocaledonicus* Andre on *Rhizophora mucronata* Lamk, under laboratory condition at controlled temperature. *Rec. zool. Surv. India*, **106**(2): 61-65.

GOLPAYEGANI (A.Z.), SABOORI (A.), NOWZARI (J.) and KAMALI (K.). 2004. – Biology of *Amphitetranychus viennensis* (Zacher) (Acari: Tetranychidae) in Baraghan region of Karaj, Iran. *Acarol*., **14**(1-2): 69-71.

GON CALVES (M.E.C.), OLIVEIRA (J.V.), BARROS (R.) and TORRES (J.B.), 2001. – Effect of plant extracts on immature stages and adult females of *Mononychellus tanajoa* (Bondar) (Acari: Tetranychidae). *Neotrop. Entomol*., **30**(2): 305-309.

GOODWIN (S.), 1990. – Seasonal abundance and control of spider mites (Acari:Tetranychidae) infesting commercial strawberries in coastal New South Wales (Australia). *J. Aust. Entomol. Soc*., **29**(3): 161-166.

GOTOH (T.) and HIGO (Y.), 1997. – Differences in host range and reproductive compatibility among populations of *Panonychus mori* Yokoyama (Acari: Tetranychidae). *Intl. J. Acar*., **23**(2): 119-125.

GOTOH (T.) and NAGATA (T.), 2001. – Development and reproduction of *Oligonychus coffeae* (Acari: Tetranychidae) on tea. *Intl. J. Acar*., **27**(4): 293-298.

GOTOH (T.), 1987. – Life history parameters of *Panonychus ulmi* Koch (Acarina: Tetranychidae) on dwarf bamboo. *Appl. Entomol. Zool*., **22**(1): 112-114.

GOTOH (T.), 1988. – Annual life cycle of the spider mite *Eotetranychus dissectus* Ehara (Acarina: Tetranychidae) on mono apple. *Jap. J. Appl. Entomol. Zool*., **32**(3): 219-223.

GOTOH (T.), ISHIKAWA (Y.) and KITASHIMA (Y.), 2003. – Life history traits of the six *Panonychus* species from Japan (Acari: Tetranychidae). *Expt. Appl. Acarol*., **29**(3&4): 241-252.

GOTOH (T.), SUGASAWA (J.), NAGATA (T.), 1999. - Reproductive compatibility of the two spotted spider mite (*Tetranychus urticae)* infected with *Wolbachia*. *Entomol. Sci*., **2**(3): 289-295.

GOTOH (T.), SUWA (A.), KITASHIMA (Y.) and REZK (H.A.), 2004. – Developmental and reproductive performance of *Tetranychus puerariсola* Ehara and Gotoh (Acari: Tetranychidae) at four constant temperatures. *Appl. Entomol. Zool*., **39**(4): 675-682.

GRIFFITHS (J.T.) and FISCHER (F.E.), 1950. – Residues on Citrus trees in Florida. *J. Econ. Entomol.,* **43**: 298-305.

GUPTA (S.K.), 1985. - Handbook: Plant mites of India, Sri Aurobindo press, Calcutta, India. 520pp.

GUPTA (S.K.), DHOORIA (M.S.) and SIDHU (A.S.), 1972. – Effect of food and temperature on the rate of development, fecundity and longevity of *Tetranychus cucurbitae* Rahman and Sapra (Acarina: Tetranychidae). *Ind. J. Agric. Sci.*, **42**: 980-983.

GUPTA (S.K.), DHOORIA (M.S.) and SIDHU (A.S.), 1974. – Effect of food and temperature on the development, longevity and fecundity of sugarcane red spider mite *Oligonychus indicus* (Hirst). *Acarol*., **16**(3): 436-440.

GUPTA (S.K.), DHOORIA (M.S.) and SIDHU (A.S.), 1976. – Seasonal abundance of *Tetranychus telarius* (Linn.) on castor in the Punjab. *Oilseeds J*., **6**: 16-18.

HALL (F.R.) and FERREE (D.C.), 1975.– Influence of two-spotted spider mite population on photosynthesis of apple leaves. *J. Econ. Entomol.,* **68**: 517-520.

HAQ (M.A.), 1997.– *Tetranychus macfarlanei* Pritchard and Baker on Okra. *Ins. Envt*., **3**(1): 6-7.

HAQUE (M.), WAHAB (A.), NAHER (N.) and BEGUM (A.), 2007.– Developmental stages of the red spider mite, *Oligonychus coffeae* Neitner (Acari: Tetranychidae) infesting rose. *Univ. J.Zool*. Rajshahi Univ., **26**: 71-72.

HAZAN (A.), GERSON (U.) and TAHORI (A.S.), 1973. – Life history and life tables of the carmine spider mite. *Acarol*., **15**(3): 414-440.

HAZAN (A.), GERSON (U.) and TAHORI (A.S.), 1974. – Spider mite webbing 1 – The production of webbing under various environmental conditions. *Acarol*., **16**(1): 68-84.

HAZAN (A.), GERSON (U.) and TAHORI (A.S.), 1975. – Spider mite webbing II – The effect of webbing on egg hatchability. *Acarol*., **17**(2): 270-273.

HELLE (W.) and BOLLARD (H.R.), 1967. – Karyotypes and sex determination of spider mites. *Genetica*, **38**: 43-53.

HELLE (W.), 1967. – Fertilization in the two spotted spider mite. *Ent. Exp. and Appl*., **10**(1): 103-110.

HERBERT (H.J.), 1981a. – Biology, life-tables and intrinsic rate of increase of the European red mite, *Panonychus ulmi* (Acarina: Tetranychidae). *Can. Ent*., **113**(5): 65-71.

HERBERT (H.J.), 1981b. – Biology, life-tables and innate capacity for increase of the two spotted spider mite, *Tetranychus urticae* (Acarina: Tetranychidae). *Can. Ent*., **113**(5): 371-378.

HESSEIN (N.A.), 1977. – Morphology and biology of the carmine mite *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae), *Lbyan J. Agri*., **4**: 117-122.

HO (C.C.) and LO (K.C.), 1979. – Influence of temperature on life history and population parameters of *Tetranychus urticae*. *J. Agri. Res. China*, **28**(4): 261-271.

HOLTZER (T.O.), NORMAN (J.M.), PERRING (T.M.), BERRY (J.) and HEINTZ (J.C.), 1988. – Effects of micro environment on the dynamics of spider mite populations. *Exptl. Appl. Acarol*., **4**(3): 247-264.

HUAGUO (C.), LIANG (X.) and YANG (Z.), 1998. – Influence of temperature – humidity on the development of *Tetranychus kanzawai*. *Acta Entomologica Sinica*, **41**(2): 153-156.

IATROU (G.), COOK (C.M.), STAMOU (G.) and LANARAS (T.), 1995. – Chlorophyll fluorescence and leaf chlorophyll content of bean leaves injured by spider mites (Acari: Tetranychidae). *Exptl. Appl. Acarol*., **19**(10): 581-591.

IGLINSKY (W.E.) and RAINWATER (C.R). 1954. – Life history and habits of *Tetranychus desertorum* and *Tetranychus bimaculatus* on Cotton. *J. Econ. Entomol.*, **47**(6): 1084-1086.

JACKSON (P.R.), HUNTER (P.E.) and PAYNE (J.A.), 1983. – Biology of the Pecan leaf scorch mite (Acari: Tetranychidae). *Environ. Entomol*, **12**: 55-59.

JANJUA (N.A.), 1942. – On the biology of red spider mite (*Tetranychus telarius* Linn.) in Baluchistan. *Proc. Indian Acad. Sci*., **15**(B): 256-262.

JEPPSON (L.R.), KEIFER (H.H.) and BAKER (E.W.), 1975.- Mites injurious to economic plants. University of California Press. Berkley, Los Angeles, London. 614pp.

JESIOTER (L.J.) and ZBIGNUI (W.S.), 1976. – The influence of host plants on the reproduction potential of the two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae). *Ekol. Pol*., **24**(3): 407-412.

JESIOTER (L.J.), 1980. – The influence of the host plants on the reproduction potential of the two spotted spider mite, *T. urticae* Koch (Acarina: Tetranychidae) III. Responses of different populations feeding on beans, roses and carnations. *Ekol. Pol*., **28**(3): 423-432.

JI (J.), ZHANG (Y.X.), CHEN (X.) and LIN (J.Z.), 2005a. – Laboratory population life table of *Amphitetranychus viennensis* (Zacher) (Acari: Tetranychidae) at different temperatures. *Sys. Appl. Acarol*., **10**: 7-10.

JI (J.), ZHANG (Y.X.), CHEN (X.) and LIN (J.Z.), 2005b. – Laboratory population life table of *Oligonychus biharensis* (Hirst) (Acari: Tetranychidae) at different temperatures. *Acta. Arachnol. Sinica*., **14**(1): 37-41.

KARMAKAR (K.), SARKAR (P.K.), SOMCHOUDHURY (A.K.) and MUKHERJEE (A.B.), 1994. – Role of some weather parameters vis–a–vis morphological and biochemical characteristics of pigeonpea plant on the relative abundance of *Schizotetranychus cajani* (Gupta) (Acarina: Tetranychidae). *Ann. Entomol.*, **12**(1): 29-35.

KASAP (I.), 2003. – Life history of hawthorn spider mite *Amphitetranychus viennensis* (Acarina: Tetranychidae) on various apple cultivars and at different temperatures. *Expt. Appl .Acarol*., **31**(1 & 2): 79-91.

KASAP (I.), 2004. – Effect of apple cultivar and of temperature on the biology and life table parameters of two spotted spider mite *Tetranychus urticae*. *Phytoparasitica*, **32**(1): 73-82.

KERGUELEN (V.) and HODDLE (M.S.), 2000. – Comparison of the susceptibility of several cultivars of avocado to the persea mite, *Oligonychus perseae* (Acari: Tetranychidae). *Sci. Hort*. **84**: 101-114.

KIELKIEWICZ (M.), 1985. – Ultrastructural changes in strawberry leaves infested by two-spotted spider mites. *Entomol. Exp. Appl.,* **37**: 49-54.

KLOEPPER (J.W.), UBANA (R.R.), ZEHNDERA (G.W.), MURPHY (J.F.), SIKORAA (E.) and FERNANDEZA (C.), 1999. – Plant root-bacterial interactions in biological control of soilborne diseases and potential extension to systemic and foliar diseases. *Australasian Pl. Pathol.*, **28**: 21-26.

KRAINACKER (D.A.) and CAREY (J.R.), 1989. – Reproductive limits and heterogeneity of male two spotted spider mites. *Ent. Exp. Appl*., **50**(3): 209-214.

KUMAR (K.K.) and PRASAD (V.G.), 1981. – Survival and development of *Tetranychus fijiensis* on citrus reticulate leaves of different ages. In: ChannaBasavanna (G.P.) (Ed.). Proceedings of All India Symposium in Acarology, Acarol. Soci. India. Univ. Agric. Sci. Ind, : 55-58.

LAHAI (M.T.), EKANAYAKE (I.J.) and GEORGE (J.B.), 2003. – Leaf chlorophyll content and tuberous root yield of cassava in inland valley. *Afr. Crop Sci. J.*, **11** (2): 107-117.

LAING (J.E.), 1969. – Life history and life table of *Tetranychus urticae* Koch. *Acarol*., **11**(1): 32-42.

LAL (L.) and MUKHARJI (S.P.), 1978. – Biology of *Eotetranychus uncatus* (Acari: Tetranychidae) in North India. *Indian J. Acar*., **3**(1); 38-42.

LAL (L.) and MUKHARJI (S.P.), 1980. – Seasonal history of three phytophagous mites at Varanasi (Uttar Pradesh). *Indian J. Acar*., **4**(2); 61-67.

LAL (L.), 1977. – Studies on the biology of the mite *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae). *Entomon*, **2**(1): 53-57.

LAL (S.S.), 1982. – Influence of weather factors on the population of spider mites (Acari: Tetranychidae) and thrip (Thysanoptera) on cassava in Kerala. *Indian J. Acar.*, **7**: 5-10.

LEIGH (T.F.), 1963. – Considerations of distribution abundance and control of acarine pests of cotton. In: Adv. Acarol., I (Ed.) Naegele (J.A.) Cornell Univ. Press, Ithaca, NY. 14-20.

LIENK (S.E.) and CHAPMAN (P.J.), 1951. – Influence of the presence or absence of the European red mite on the two spotted mite abundance. *J. Econ. Entomol.,* **44**: 623.

LIENK (W.), 1953. – Investigations of the biology and epidemiology of the common spider mite, *Tetranychus altheae* von Hanstein with particular consideration to hop as the host. *Hofchenbriefe*., **4**: 181-232.

LIU (H.) and TSAI (J.H.), 1998. – Development, survivorship and reproduction of *Tetranychus tumidus* Banks (Acari: Tetranychidae) in relation to temperature. *Intl. J. Acar*., **24**(3): 245-252.

LIU (H.), ZHAO (Z.), WANG (J.), HE (L.) and WU (S.), 2004. – Effect of different bamboo ages on population parameters of *Schizotetranychus bambusae* Reck (Acari: Tetranychidae). *Syst. Appl. Acarol.*, **9:** 15-21.

MAITHRA (N.) and SEN (S.P.), 1988. – Photosynthetic activity of leaves and non-leaf green organs of plants belonging to different families. *Indian J. Plant Physiol.*, **31**(2): 127-133.

MAITY (S.P.) and CHAKRABARTI (S.), 1978. – Biological studies on *Panonychus citri* (Acari: Tetranychidae). *Indian J. Acar.*, **2**(2): 55-59.

MALLIK (B.) and CHANNABASAVANNA (G.P.), 1983. - Life history and life tables of *Tetranychus ludeni* and its predator *Amblyseius longispinosus* (Acari: Tetranychidae; Phytoseiidae). *Indian J. Acar.*, **8**: 1-12.

MALLIKARJUNAPPA (S.) and NAGESHCHANDRA (B.K.), 1989. – Biology of *Eutetranychus hicoriae* (Acari: Tetranychidae) on guava. *Indian J. Acar.*, **10**(1 & 2): 47-51.

MANJUNATHA (M.) and PUTTASWAMY, (1989). – Life history of *Tetranychus neocaledonicus* under green house conditions. *J. Acar.*, **11**(1 & 2): 35-40.

MANJUNATHA (M.), BHAT (N.S.), RAJU (G.T.T.) and NAGESHCHANDRA (B.K.), 1991. Influence of alternate host plants on the reproductive biology of *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae). In: Proceedings of Ist National Seminar on Acarology. Mukherjee. (A.B.), Somchoudhary (A.K.) and Sarkar (P.K.) (Eds), 347-351.

MEYER (M.K.P.) and RODRIGUEZ (M.), 1966. – Acari associated with cotton in Southern Africa. *Revistadajunta de Inves. doultramar.*, **13**:1-33.

MORAES (D.G..J.) and MC MURTRY (J.A.), 1987. – Effects of temperature and sperm supply on the reproductive potential of *Tetranychus evansi* (Acari: Tetranychidae). *Expt. Appl. Acarol*., **3**(2): 95-107.

MORAES (D.G.J.), MOREIRA (A.N.) and DELALIBERA (I) (Jr.) 1995. – Growth of the mite *Mononychellus tanajoa* (Acari: Tetranychidae) on alternative plant hosts in north eastern Brazil. *Fla. Entomol*., **78**(2): 350-354.

MOTHES (U.) and SEITZ (K.A.), 1982. – Fine structural alterations of bean plant leaves by feeding injury of *Tetranychus urticae* Koch (Acari: Tetranychidae). *Acarol.*, **23**: 149-157.

MOUTIA (L.A.), 1958. – Contribution to the study of some phytophagous acarina and their predators in Mauritius. *Bull. Ent. Res.*, **49**:59-75.

MULLER (G.F.W.), 1957. – Morphology, biology and control of the hawthorn spider mite, *Tetranychus viennensis* Zacher. *Hofchenbriefe*, **10**(1): 1-60.

MUREGA (T.N.) and KHAEMBA (B.M.), 1985. – The effects of the infestation by red spider mites, *Tetranychus* sp. (Acarina: Tetranychidae) on the growth and yield components of cotton in Eastern Kenya. *Insect Sci. Applic.*, **6**(1): 7-10.

NACHMAN (G.) and ZEMEK (R.), 2002. – Interactions in a tritrophic acarine predator-prey metapopulation system IV: Effects of host plant condition on *Tetranychus urticae* (Acari: Tetranychidae). *Expt. Appl. Acarol*., **26**: 43-70.

NANDAGOPAL (V.) and GEDIA (M.V.), 1995. – Biology of the red spider mite *Tetranychus cinnabarinus* (Boisd.) - a pest of ground nut. *Entomon*, **20**(1): 41-43.

NANDAGOPAL (V.) and GEDIA (M.V.), 1999. – Post-embryonic observations on two spotted white spider mite *Tetranychus hypogaea* Gupta - a pest of groundnut. *Entomon*, **24**(4): 359-362.

NEELU NANGIA, JAGADISH (P.S.) and NAGESHCHANDRA (B.K.), 1990. – Biology and control of *Oligonychus mangiferus* (Rahman and Sapra) (Acari: Tetranychidae) on *Terminalia spp.*, important host plant of silk worms. *Mysore. J. Agric. Sci*., **23**(3): 355-358.

NEWCOMER (E.J.) and YOTHERS (M.A.), 1929. – Biology of the European Red Mite in the Pacific North-West. *U. S. Dept. Agric. Tech. Bull.*, **89**: 70pp.

NIELSEN (F.), 1958. – Biology of the McDaniel mite *Tetranychus macdanieli* McGregor, in Utah. *J. Econ. Entomol*., **51**(5): 588-592.

NIHOUL (P.P.), HANCE (T.), IMPE (G.V.) and MARECHAL (B.), 1992. – Aspects physiologiques des degats provoques par les acarins phytophages au niveau folioles de tomates. *J. Appl. Ent.*, **113**: 487-492.

NORONHA (A.C.S.), 2006. – Biological aspects of *Tetranychus marianae* McGregor (Acari: Tetranychidae) reared on yellow passion fruit (*Passiflora edulis* Sims f. *flavicarpa* Deg.) leaves. *Rev. Bras. Zool*., **23**(2): 404-407.

OKU (K.), 2008. – Role of excreta in predator avoidance by the Kanzawa spider mite, *Tetranychus kanzawai* (Acari: Tetranychidae). *Eur. J. Entomol.*, **105**: 619-623.

OKU (K.), YANO (S.), OSAKABE (M.) and TAKAFUJI (A.), 2005. – Mating strategies of *Tetranychus kanzawai* (Acari: Tetranychidae) in relation to mating status of females. *Ann. Entomol. Soc. Amer*., **98**(4): 625-628.

OYETUNJI (O.J.), EKANAYAKE, (I.J.) and OSONUBI (O.), 1998. – Photosynthetic photochemical response of cassava (*Manihot esculenta* Crantz) to water stress and mycorrhizal inoculation. *Tropical Agri.*, **75** (2): 328-329.

PANDE (Y.D.) and SHARMA (B.L.), 1986. – Effect of temperature on the biology of red cucurbit mite *Tetranychus neocaledonicus* Andre, *Revista. Brasileira de Biologia*, **46**(3): 597-602.

PARENT (B.) and BEALIEU (A.A.), 1957.- Life history of the European red mite. *Can. Ent*., **89**(7): 328 – 333.

PARK (Y.L.) and LEE (J.H.), 2002.- Leaf cell and tissue damage of cucumber caused by two-spotted spider mite (Acari: Tetranychidae). *J. Econ. Entomol.*, 952-957.

PEAL (S.E.), 1868.- Letter for forwarding specimens and drawing of "Red spider". *J. Agric. Hort. Soc. India*, **1**: 69.

PENMAN (D.R.) and CONE (W.W.), 1972. – Behaviour of male two spotted spider mites in response to quiescent female deutonymphs and to web. *Ann. Entomol. Soc. Amer*., **65**: 1289-1293.

PENMAN (D.R.) and CONE (W.W.), 1974. – Role of web, tactile stimuli and female sex pheromone in attraction of male two spotted spider mites to quiescent female deutonymphs. *Ann. Entomol. Soc. Amer*., **67**: 179-182.

PLOURDE (D.F.), GOONEWARDENE (H.F.), KWOLEK (W.F.) and NEILSEN (N.C.), 1983. – The effect of European red mite, *Panonychus ulmi*, on chlorophyll content and chlorophyll A/B ratios of apple, *Malus domestica* Borkh., leaves in a growth chamber study (Acarina: Tetranychidae). *Intl. J. Acar*., **9**(1): 11-18.

POTTER (D.A.), 1981. – Agonistic behaviour in male spider mites: factors affecting frequency and intensity of fighting. *Ann. Entomol. Soc. Amer*., **74**: 138-143.

PRASLICKA (J.) and HUSZAR (J.), 2004. – Influence of temperature and host plants on the development and fecundity of the spider mite *Tetranychus urticae* (Acarina: Tetranychidae). *Plant Protect*. *Sci*., **40**: 141-144.

PRINGLE (K.L.), DRAYTON (A.W.) and NORTHCRAFT (P.P.D.), 1994. – Developmental biology of the carmine and green form of *Tetranychus urticae* Koch (Acari: Tetranychidae). *Afr. Entomol*., **2**(2): 127-132.

PUCHALSKA (E.), 2006. – The influence of *Oligonychus ununguis* Jacobi (Acari: Tetranychidae) on photosynthetic activity and needle damage of *Picea glauca* 'Conica'. *Biological Lett*., **43**(2): 353-360.

PUTMAN (W.L.), 1970a. – Threshold temperatures for the European red mite, *Panonychus ulmi* (Acarina: Tetranychidae). *Can. Ent*., **102**(5): 421-425.

PUTMAN (W.L.), 1970b. – Some aspects of sex in the European red mite, *Panonychus ulmi*. *Can. Ent*., **102**(5): 612-617.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1980a. – Effect of temperature and relative humidity on the development and oviposition of *Tetranychus ludeni* (Acari: Tetranychidae). *Indian J. Acar*., **4**(1): 31-40.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1980b. – Life history of *T. ludeni* (Acari: Tetranychidae) under field condition. *Indian. J. Acar*., **4**(1): 41-48.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1980c. – Competition between *Tetranychus neocaledonicus* and *T. ludeni* (Acari: Tetranychidae). *Indian J. Acar*., **4**(2): 49-54.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1981a. – Influence of weather factors and predators on the populations of the spider mite *Tetranychus ludeni* (Acari: Tetranychidae). *Indian J. Acar*., **5**: 69-79.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1981b. – Influence of host plants on the development, fecundity and longevity of *Tetranychus ludeni* Zacher (Acari: Tetranychidae). *Indian J. Acar*., **5**: 80-84.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1981c. – Influence of three *Amaranthus* species on the development, fecundity and longevity of *Tetranychus neocaledonicus* (Acari: Tetranychidae). *Colemania*, **1**(1): 35-36.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1982a. – Influence of nitrogen fertilization of the host plant on the population development of *Tetranychus ludeni* (Acari: Tetranychidae). *Indian J. Acar*., **6**(1 & 2): 64-71.

PUTTASWAMY and CHANNABASAVANNA (G.P.), 1982b. – Influence of host plants on the reproductive biology of *Tetranychus neocaledonicus* (Acari: Tetranychidae). *Indian J. Acar*., **6**(1 & 2): 72-76.

PUTTASWAMY and REDDY (D.N.R.), 1980. – *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae): a new pest on cardamom.*Acarol. Newsletter*, **10**: 6.

QURESHI (A.H.), OATMAN (E.R.) and FLESCHNER (C. A.), 1969. – Biology of the spider mite, *Tetranychus evansi* Pritchard and Baker. *Ann. Entomol. Soc. Amer*., **62**(4): 898-903.

RAHMAN (K.A.) and SAPRA (A.N.), 1946. – On the biology of the vegetable mite (*Tetranychus cucurbitae* Rahman and Sapra: family, Tetranychidae). *Indian J. Agri. Sci*., **15**(3): 124-130.

RAJAGOPALAN (K.), 1974. –First record of spider mite *Tetranychus ludeni* Zacher transmitting Dolichos Enation Mosaic Virus (DEMV). *Curr.Sci*., **43**(15): 488-489.

RASMY (A.H.) and HUSSEIN (H.E.), 1994. – Effect of age and mating on release of female sex pheromones and male response in the two-spotted spider mite. *J. Appl. Ent*., **117**: 109-111.

RASMY (A.H.), 1978. – Biology of the citrus brown mite *Eutetranychus orientalis* as affected by some citrus species. *Acarol*., **19**(2): 222-224.

RAY (R.) and RAI (L.), 1981. – Biology and Control of *Tetranychus neocaledonicus* (Acari: Tetranychidae) on lady's finger at Varanasi. In: ChannaBasavanna (G.P.) (Ed.). Proceedings of All India Symposium in Acarology, Acarol. Soci. India. Univ. Agric. Sci. Ind. : 41-46.

REDDALL (A.), SADRAS (V.O.), WILSON (L.J.) and GREGG (P.C.), 2004. – Physiological responses of cotton to two-spotted spider mite damage. *Crop Sci.*, **44**: 835-846.

REDDY (G.V.P.) and BASKARAN (P.), 2006. – Damage potential of spider mite *Tetranychus ludeni* (Acari: Tetranychidae) on four varieties of egg plant. *Intl. J. Tropical Ins. Sci.*, **26** (1): 48-56.

ROSERO (L.), TORRESS (T.M.) and ACOSTA (G.A.), 1990. – Embryological development of *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae), pest of the carnation (*Dianthus caryophyllus* L.). *Rev. Colomb. Entomol*., **16**(1): 39-49.

ROYALTY (R.N.) and PERRING (T.M.), 1989. – Reduction in photosynthesis of tomato leaflets caused by tomato russet mite (Acari: Eriophyidae). *Environ. Entomol*., **18**: 256-260.

SABA (F.), 1971. – *Tetranychus yusti*, a spider mite of potential economic importance. *J. Econ. Entomol*., **64**: 141-144.

SABA (F.), 1974. – Life history and population dynamics of *Tetranychus tumidus* in Florida (Acarina: Tetranychidae). *Florida Entomologist*, **57**(1): 47-63.

SADANA (G.L.), 1985. – Plant feeding mites of India, Kalyani Publishers, New Delhi, 99pp.

SAHA (K.), DEY (P.K.), SOMCHOUDHURY (A.K.) and SARKAR (P.K.), 1999. – Effect of temperature and relative humidity on the rate of development, longevity and fecundity of the red spider mite *Oligonychus coffeae*. *Indian J. Acar*., **15**(1 & 2): 84-88.

SAIKIA (S.), HAZARIKA (L.K.) and SHARMAH (T.C.), 1999. – Seasonal variation in the biology of *Oligonychus coffeae* on tea. *J. Acar*., **14** (1 & 2): 22-26.

SAITO (Y.), 1977a. – Study on spinning behaviour of spider mites (Acarina: Tetranychidae) I. Method for quantitative evaluation of the mite webbing, and the relationship between webbing and walking. *Jap. J. Appl*. *Ent. Zool.*, **21**: 27-34.

SAITO (Y.), 1977b. – Study on spinning behaviour of spider mites (Acarina: Tetranychidae) II. The process of silk secretion and the webbing on the various stages of *Tetranychus urticae* Koch under different environmental conditions. *Jap. J. Appl*. *Ent. Zool.*, **21**: 150-157.

SAITO (Y.), 1979a. – Comparative studies on life histories of three species of spider mites (Acari: Tetranychidae). *Appl. Entomol. Zool*., **14**(1): 83-94.

SAITO (Y.), 1979b. – Study on spinning behaviour of spider mites III. Responses of mite to webbing residues and their preferences for particular physical

conditions of leaf surfaces (Acarina: Tetranychidae). *Jap. J. Appl. Ent. Zool.*, **23**: 82-91.

SAITO (Y.), 1983. – The concept of "life types" in tetranychidae. *Acarol.*, **24**: 377-391.

SAKUNWARIN (S.), CHANDRAPATYA (A.) and BAKER (G.T.), 2003. – Biology and life table of the cassava mite, *Tetranychus truncatus* Ehara (Acari: Tetranychidae). *Sys. Appl. Acarol.*, **8**: 13-24.

SALAZAR (S.F.), CARRILLO (L.I.R.), AGUILERA (P.A.) and REBOLLEDA (R.R.), 1998. – Biological anticedents of *Tetranychus urticae* Koch (Acari: Tetranychidae) in raspberry cv. Heritage in Temuco, Chile. *Revista Chilena de Entomologia*, **25**: 15-20.

SALMON (A.G.A.), 1983. – Effect of host plant species and temperature on population increase of the citrus brown mite, *Eutetranychus orientalis* (Klein). *Bull. De la Societe' Entomologique d' Egypte*, **62**: 142-154.

SANCES (F.V.), TOSCANO (N.C.), OATMAN (E.R.), LAPRE (L.F.), JOHNSON (M.W.) and VOTH (V.), 1982. – Reductions in plant process by *Tetranychus urticae* (Acari: Tetranychidae) feeding on strawberry. *Environ. Entomol.*, **11**(3): 733-737.

SANCES (F.V.), WYMAN (D.A.) and TING (J.P.), 1979. – Physiological responses to spider mite infestations on strawberries. *Environ. Entomol.*, **8**: 711-740.

SANGEETHA (G.K.) and RAMANI (N.), 2007a. – Biological studies of *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) infesting *Moringa oleifera* Lam., *Bull. Pure Appl. Sci.*, **26A** (2): 51-57.

SANGEETHA (G.K.) and RAMANI (N.), 2007b. – Chlorophyll loss due to infestation by *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) on *Moringa oleifera* Lam. *J. Acar*., **17**(1&2): 12-14.

SANGEETHA (G.K.) and RAMANI (N.), 2008a. – Embryonic development of *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) infesting *Moringa oleifera* Lam. *J. Exp. Zool. India*, **11**(1): 25-27.

SANGEETHA (G.K.) and RAMANI (N.), 2008b. – Effect of temperature and relative humidity on oviposition and fecundity of *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) – a pest of *Moringa oleifera* Lam. *J. Exp. Zool. India*, **11**(2): 279-282.

SANGEETHA (G.K.) and RAMANI (N.), 2009. – Reproductive behaviour of *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) infesting *Moringa oleifera* Lam, Recent Trends in Animal Behaviour, New India Publishing Agency, New Delhi, 346pp.

SANGEETHA (G.K.), RAMANI (N.), SHEEJA (U.M.) and JULIE (E.), 2007. – Fecundity of the vegetable mite *Tetranychus neocaledonicus* Andre (Acari: Tetranychidae) on *Moringa oleifera* Lam. *Ins. Envt*., **13**(3): 101-102.

SANGITA (S.) and BHARDWAJ (S.P.), 2004. – Effects of temperature and relative humidity on population build up of European red mite *Panonychus ulmi* (Koch) on apple. *Ind. J. Entomol*., **66**(3): 215-221.

SARKAR (P.K.) and SOMCHOUDHURY (A.K.), 1981. – Influence of major abiotic factors on the seasonal incidence of *Raoiella indica* and *T. fijiensis* on coconut. In: Progress in Acarology, Vol 11. (Eds.) ChannaBasavanna, G.P. and Viraktamath, C.A., Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, 484pp.

SARKAR (P.K.), SAHA (K.), SOMCHOUDHURY (A.K.) and GUPTA (S.K.), 1998. – Influence of host plants on the development of mite pest *Tetranychus urticae* Koch. *Ann. Entomol*., **16**(1): 63-66.

SHANKS Jr. (C.H.) and DOSS (R.P.), 1989. – Population fluctuations of two spotted spider mite (Acari: Tetranychidae) on strawberry. *Environ. Entomol*., **18**(4): 641-645.

SHARMA (A.) and KUSHWAHA (K.S.), 1984. - Susceptibility of different varieties of brinjal to *Tetranychus neocaledonicus* (Acari: Tetranychidae). *Indian. J. Acar*., **8**(2):100-103.

SHIH (C.I.T.) and SHIUE (S.P.), 1995. – Copulation competition of male *Tetranychus urticae* Koch and *Tetranychus kanzawai* Kishida (Acari: Tetranychidae) with conspecific and heterospecific females and their isolation mechanism. *Chin. J. Entomol*. Zhonghua Kunchong, **15**(3): 239-255.

SHIH (C.I.T.), POE (S.L.) and CROMROY (H.L.), 1976. – Biology, life table and intrinsic rate of increase of *Tetranychus urticae*. *Ann. Entomol. Soc. Amer*., **69**(2): 362-364.

SIDDIG (M.A.) and ELBADRY (E.A.), 1971. – Biology of the spider mite, *Eutetranychus sudanicus*. *Ann. Entomol. Soc. Amer*., **64**: 806-809.

SINGH (P.), SOMCHOUDHURY (A.K.) and MUKHERJEE (A.B.), 1989. – The influence of natural enemy complex on the population of *Aceria litchii* (Acari: Eriophyidae). In: Progress in Acarology, **2**: 361-367.

SINGLETON (V. L. R.), ORTHOFER and LAMUELA-RAVENTOS (R.) 1999. - Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteau reagent. Methods in Enzymology, Harcourt B. **299**: 152-178.

SIRSIKAR (A.N.) and NAGABHUSHANAM (R.), 1989. – Biology of *Oligonychus tylus*, a potential mite pest of sorghum and other cereals. *J. Acar*., **11**(1 & 2): 95-99.

SKALOUDOVA (B.), KRIVAN (V.) and ZEMEK (R.), 2006. – Computer-assisted estimation of leaf damage caused by spider mites. *Computers and Electronics in Agri.*, **53**: 81-91.

SMITLEY (D.R.) and KENNEDY (G.G.), 1988. – Aerial dispersal of the two spotted spider mite (*Tetranychus urticae*) from field corn. *Expt. Appl. Acarol*., **5**(1/2): 33-46.

SOBHA (T.R.) and HAQ (M.A.), 1999. – Incidence of *Tetranychus neocaledonicus* (Acari: Tetranychidae) on *Dolichos lablab*. *J. Acarol.*, **14**(1&2): 73-76.

SOLIMAN (A.A.), ATTIAH (H.A.) and WAHBA (M.L.), 1973. – Preliminary biological studies on *Tetranychus neocaledonicus* Mare Andre. In: DANIEL (M.) and ROSICKY (B.) eds., Proc. 3rd Int. Congr. Acar. Prague 1971. The Hague, Academia, Czechoslovakia: 251-254.

SRIVASTAVA (B.K.) and MATHUR (L.M.L.), 1962. – Bionomics and control of castor mite. *Indian J. Ent*., **24**: 229-235.

STONE (C.), 1986. – An investigation into the morphology and biology of *Tetranychus lintearius* Dufour (Acari: Tetranychidae). *Expt. Appl. Acarol*., **2**(2): 173-186.

STORMS (J.J.H.), 1971. – Some physiological effects of spider mite infestation on bean plants. *Neth. J. Plant Pathol.*, **77**: 154-176.

SUMANGALA (K.) and HAQ (M.A.), 2000.– Injurious effects of *Tetranychus ludeni* (Acari: Tetranychidae) on *Eichhornia crassipes*. *Indian J. Environ. & Ecoplan.*, **3**(1): 121-126.

TAKABAYASHI (J.), DICKE (M.), POSTHUMUS (M.A.), 1994.– Volatile herbivore-induced terpenoids in plant-mite interactions: variation caused by biotic and abiotic factors. *J. Chem. Ecol.*, **20**: 1329-1354.

TAN (F.M.) and WARD (C.R.), 1977. – Laboratory studies on the biology of the Banks grass mite. *Ann. Entomol. Soc. Amer*., **70**: 534-536.

TANIGOSHI (L.K.) and DAVIS (R.W.), 1978.– An ultrastructural study of *Tetranychus mcdanieli* feeding injury to the leaves of 'Red Delicious' apple (Acari: Tetranychidae). *Intl. J. Acarol.*, **4**: 47-56.

TANIGOSHI (L.K.), HOYT (S.C.), BROWNE (R.W.) and LOGAN (J.A.), 1975.– Influence of temperature on population increase of *Tetranychus mcdanieli* (Acarina: Tetranychidae). *Ann. Entomol. Soc. Amer*., **68**(6): 972-978.

THONGTAB (T.), CHANDRAPATYA (A.) and BAKER (G.T.), 2002. – Bionomics of the citrus yellow mite, *Eotetranychus cendani* Rimando. *Sys. Appl. Acarol*., **7**: 57-68.

TOMCZYK (A.) and KROPCZYNSKA (D.), 1985. – Effects on the host plants. In: Helle, W; Sabelis, M.W. (Eds.), Spider Mites, Their Biology, Natural Enemies and Control, **1B.** Elsevier, Amsterdam, The Netherlands, 317-327.

TRINIDADE (M.L.B.) and CHIAVEGATO (L.G.), 1999. – Effects of different levels of nitrogen, phosphorus and potassium on the biological activity of *Tetranychus urticae* Koch (Acari: Tetranychidae) maintained on cultivated cotton in a nutritive solution. *Cientifica*, **27**(1 & 2): 47-56.

UBERTALLI (J.A.), 1955. – Life history of *Eutetranychus uncatus* Garman. *J. Econ. Entomol*., 47-49.

VASQUEZ (C.), APONTE (O.), MORALES (J.), SANABRIA (M.E.) and GARCIA (G.), 2008.– Biological studies of *Oligonychus punicae* (Acari: Tetranychidae) on grapevine cultivars. *Exp. Appl. Acarol*., **45**: 59-69.

WANG (J.), ZHAO (Z.) and ZHANG (J.), 2004.– The host plant-mediated impact of simulated acid rain on the development and reproduction of *Tetranychus cinnabarinus* (Acari: Tetranychidae). *J. Appl. Entomol*., **128** (6): 397-402.

WEBSTER (R.L.), 1948. – Mites of economic importance in the Pacific Northwest. *J. Econ. Entomol*., **41**: 677-683..

WELTER (S.C.), 1989. – Arthropod impact on plant gas exchange.In: (Ed.) Bernays (E.A.). Insect-Plant interactions, I, CRC Press, Boca Raton, FL, 135-150.

WESTIGARD (P.H.) and BERRY (D.W.), 1970. – Life history and control of the yellow spider mite on pear in southern Oregon. *J. Econ. Entomol*., **63**(5): 1433-1437.

WIESMANN (V.R.), 1968. – Untersuchungen uber die Verdauungsvorgange bei der gemeinen Spinnmilbe, *Tetranychus urticae* Koch. *Z. Angew. Entomol.* **61**: 457-465.

WILSON (L.J.), 1994. – Plant quality effect on the life history parameters of two spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae) on cotton. *J. Econ. Entomol*., **81**(6): 1665-1673.

WINSTON (P. W.) and BATES (D. H.), 1960. - Saturated solutions for control of humidity in biological research. *Ecol*. **41**, 232pp.

WOOD-MASON (J.), 1884. – Report of the tea mite and tea bug of Assam, London, 20pp.

WU (Q.H.) and JING, 1993. – Study on the induction of diapause in the carmine spider mite *Tetranychus cinnabarinus* (Boisduval). *Entomol*. *knowledge*, **30**(6): 335-337.

YANAGIDA (H.), YUTAKA (S.), KATARD (M.) and CHITTENDEN (A.R.), 2001. – Egg depositing behaviour as a predator avoidance tactic of *Yezonychus sapporensis* Ehara (Acari: Tetranychidae). *J. Ethol*., **19**(1): 63-66.

YOKOYAMA (K.) and ISHII (G.), 1934. – Studies on the mites attacking mulberry leaves. 2. Morphology and biology of *Panonychus mori Kishida. Jap. Bull. Sericult. Expt. Sta*. *Japan*, **8**(9): 425-454.

YOUNG (S.S.Y.), WRENSCH (D.L.) and KONGCHUENSIN (M.), 1986. – Control of sex ratio by female spider mites. *Entomologia Experimentalis et Applicata*, **40**(1): 53-60.

ZHANG (Y.), ZHANG (Z.), LIN (J.) and JI (J.), 2001a.- Observations on the behaviour and life history of *Schizotetranychus tenuinidus* (Acari: Tetranychidae) inhabiting bamboo leaves in Fujian, China. *Sys. Appl. Acarol*., **8**: 13-20.

ZHANG (Y.), ZHANG (Z.), LIN (J.), JI (J.) and HOU (A.), 2001b.- Observations on the life history of *Schizotetranychus bambusae* (Acari: Tetranychidae) infesting bamboo leaves in Fujian, China. *Sys. Appl. Acarol*., **6**: 13-20.

TABLE XII – Fecundity of *T. neocaledonicus* on *A. tricolor* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	1	1	4	5	9	4	2	1	1	Dead	28	M	12.5
2	1	3	5	6	4	3	1	1	1	1	26	V	15
3	1	1	2	3	3	3	3	2	1	1	20	V	15.5
4	2	3	5	6	7	4	2	1	1	Dead	31	M	12.75
5	2	3	4	7	3	2	1	1	1	0	24	V	14.5
6	1	3	4	5	6	2	1	1	1	0	25	V	14.25
7	1	1	2	3	5	3	2	2	1	1	21	V	15.5
8	3	4	6	7	8	3	2	1	1	Dead	35	M	12.75
9	3	4	5	7	9	2	1	1	0	0	32	M	13.5
10	2	4	4	8	10	3	2	1	0	0	34	M	13.5
Range	**1 - 3**	**1 - 4**	**2 - 6**	**3 - 8**	**3 - 10**	**2 - 4**	**1 - 3**	**1 - 2**	**0 - 1**	**0 - 1**	**M 28 - 35 V 20 - 26**		**M12.5-13.5 V14.2-15.5**
Mean ± SEM	**1.7 ± 0.26**	**2.7 ± 0.39**	**4.1 ± 0.41**	**5.7 ± 0.54**	**6.4 ± 0.82**	**2.9 ± 0.23**	**1.7 ± 0.21**	**1.2 ± 0.13**	**0.8 ± 0.13**	**0.3 ± 0.15**	**27.6 ± 1.7 M 32.0±1.2 V 23.2±1.1**		**14.0 ± 0.36 M 13.0±0.2 V 14.9±0.2**

TABLE XIII – Fecundity of *T. neocaledonicus* on *A. tricolor* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	1	2	5	10	4	3	3	1	29	V	12
2	1	4	5	12	6	2	1	0	31	V	11.5
3	2	4	7	14	7	4	2	0	40	M	10.5
4	1	3	7	13	4	3	1	0	32	V	10.5
5	2	4	6	11	4	2	2	2	33	V	13
6	2	4	5	13	6	3	1	1	35	M	11.5
7	1	2	6	10	7	4	2	2	34	M	12
8	2	3	6	13	7	3	2	1	37	M	12
9	2	5	7	13	9	6	2	0	44	M	10.5
10	1	2	7	12	5	2	1	0	30	V	11.5
Range	**1 - 2**	**2 - 5**	**5 - 7**	**10 - 14**	**4 - 9**	**2 - 6**	**1 - 3**	**0 - 2**	**M 34 - 44 V 29 - 33**		**M 10.5-12 V 10.5-13**
Mean ± SEM	**1.5 ± 0.17**	**3.3 ± 0.33**	**6.1 ± 0.28**	**12.1 ± 0.43**	**5.9 ± 0.53**	**3.2 ± 0.39**	**1.7 ± 0.21**	**0.7 ± 0.26**	**34.5 ± 1.5 M 38.0±1.8 V 31.0±0.7**		**11.5 ± 0.26 M 11.3±0.3 V 11.7±0.4**

TABLE XIV – Fecundity of *T. neocaledonicus* on *A. tricolor* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	5	6	7	9	5	3	2	1	38	V	11.5
2	6	6	9	15	4	3	1	0	44	M	10.5
3	4	5	8	12	3	1	1	1	35	V	11
4	7	7	10	14	6	2	1	0	47	M	10
5	5	7	9	13	3	1	1	1	40	V	11.5
6	5	6	10	15	2	2	2	1	43	M	11.5
7	6	8	9	13	4	3	2	0	45	M	10.5
8	6	7	7	13	3	1	0	0	37	V	10.5
9	6	7	11	15	4	3	2	0	48	M	10.5
10	4	5	10	12	4	3	2	1	41	V	11.5
Range	**4 - 7**	**5 - 8**	**7 - 11**	**9 - 15**	**2 - 6**	**1 - 3**	**0 - 2**	**0 - 1**	**M 43 - 48** **V 35 - 41**		**M 10-11.5** **V10.5-11.5**
Mean ± SEM	**5.4 ± 0.3**	**6.4 ± 0.3**	**9.0 ± 0.42**	**13.1 ± 0.58**	**3.8 ± 0.36**	**2.2 ± 0.39**	**2.2 ± 0.29**	**0.5 ± 0.17**	**41.8 ± 1.4** **M 45.4±0.9** **V 38.2±1.1**		**10.9 ± 0.18** **M 10.6±0.2** **V 11.2±0.2**

TABLE XV – Fecundity of *T. neocaledonicus* on *V. unguiculata* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	1	1	2	6	9	5	4	2	1	1	32	M	15.5
2	1	2	2	5	12	6	4	2	2	1	37	M	15.75
3	2	2	4	5	9	4	3	2	1	1	33	M	15.5
4	1	1	2	3	8	7	3	2	1	0	28	V	14.75
5	1	1	3	5	9	5	3	2	1	0	30	V	14.75
6	1	1	3	4	8	4	2	1	1	1	26	V	15.5
7	2	3	3	7	12	5	3	2	1	0	38	M	14.5
8	1	2	3	5	7	4	2	1	1	1	27	V	15.5
9	1	1	2	4	6	5	3	1	1	1	25	V	15.75
10	1	1	3	4	11	9	3	2	1	1	36	M	15.75
Range	**1 - 2**	**1 - 3**	**2 - 4**	**3 - 7**	**6 - 12**	**4 - 9**	**2 - 4**	**1 - 2**	**1 - 2**	**0 - 1**	**M 32 - 38 V 25 - 30**		**M14.5-15.7 V14.7-15.7**
Mean ± SEM	**1.2 ± 0.13**	**1.5 ± 0.22**	**2.7 ± 0.21**	**4.8 ± 0.36**	**9.1 ± 0.64**	**5.4 ± 0.5**	**3.0 ± 0.21**	**1.7 ± 0.15**	**1.1 ± 0.1**	**0.7 ± 0.15**	**31.2 ± 1.5 M 35.2±1.1 V 27.2±0.9**		**15.3 ± 0.15 M 15.4±0.2 V 15.2±0.2**

TABLE XVI – Fecundity of *T. neocaledonicus* on *V. unguiculata* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	2	4	8	12	7	5	2	0	40	V	11.5
2	2	5	10	16	8	5	2	2	50	M	12
3	1	5	9	15	8	4	0	0	42	V	10.5
4	3	7	10	16	6	3	1	0	46	M	12
5	2	6	8	14	8	3	2	0	43	V	12
6	2	6	11	18	8	3	1	0	49	M	10.5
7	1	5	9	15	7	5	2	1	45	M	11
8	2	5	10	14	7	3	2	1	44	M	13
9	3	6	9	12	6	1	0	0	37	V	10
10	1	4	8	13	6	5	4	0	41	V	12
Range	**1 - 3**	**4 - 7**	**8 - 11**	**12 - 18**	**6 - 8**	**1 - 5**	**0 - 4**	**0 - 2**	**M 44 - 50 V 37 - 43**		**M 10.5 - 13 V 10 - 12**
Mean ± SEM	**1.9 ± 0.23**	**5.3 ± 0.3**	**9.2 ± 0.32**	**14.5 ± 0.6**	**7.1 ± 0.28**	**3.7 ± 0.42**	**1.6 ± 0.37**	**0.4 ± 0.2**	**43.7 ± 1.3 M 46.8±1.1 V 40.6±1.0**		**11.4 ± 0.3 M 11.7±0.4 V 11.2±0.4**

TABLE XVII – Fecundity of *T. neocaledonicus* on *V. unguiculata* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	2	7	11	19	10	4	2	1	56	M	11
2	2	5	8	14	8	5	3	2	47	V	12.5
3	3	6	10	15	9	4	3	2	52	M	11.5
4	3	4	8	14	6	3	1	1	40	V	11
5	3	7	10	16	7	4	2	1	50	M	11.5
6	3	5	9	13	6	4	3	2	45	V	11.75
7	3	5	10	13	8	5	3	2	49	V	12.5
8	4	3	8	17	10	5	2	2	51	M	11.5
9	4	7	11	16	8	4	3	1	54	M	12.5
10	4	6	8	13	6	3	2	1	43	V	11.5
Range	**2 - 4**	**3 - 7**	**8 - 11**	**13 - 19**	**6 - 10**	**3 - 5**	**1 - 3**	**1 - 2**	**M 50 - 56 V 40 - 49**		**M 11–12.5 V 11-12.5**
Mean ± SEM	**3.1 ± 0.23**	**5.5 ± 0.43**	**9.3 ± 0.4**	**15.0 ± 0.63**	**7.8 ± 0.5**	**4.1 ± 0.23**	**2.4 ± 0.22**	**1.5 ± 0.17**	**48.7 ± 1.6 M 52.6±1.1 V 44.8±1.6**		**11.7 ± 0.18 M 11.6±0.2 V 11.8±0.3**

TABLE XVIII - Duration (in days) of development of *T. neocaledonicus* on *A. tricolor* 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 develop-ment
1	5	3	1	2.5	1	2.75	1	16.25	M	P
2	5.5	3	1	2.75	1	2.75	1	17	F	S
3	5	3.5	1	2.5	1	3	1	17	M	S
4	4.5	3	1	2.5	1	2.75	1	15.75	M	P
5	5.5	2.75	1	2.75	1	3	1	17	M	S
6	5	2.75	1	2.75	1	3	1	16.5	M	S
7	5.5	3.5	1	2.5	1	3	1	17.5	F	S
8	5.5	3.5	1	2.75	1	2.75	1	17.5	F	S
9	4.5	2.75	1	2.5	1	2.75	1	15.5	M	P
10	5.5	3	1	2.5	1	3	1	17	F	S
11	5.5	3.5	1	2.75	1	3	1	17.75	F	S
12	5	3.5	1	2.75	1	3	1	17.25	F	S
Range	**4.5 – 5.5**	**2.75 – 3.5**	**1**	**2.5 – 2.75**	**1**	**2.75 – 3**	**1**	**15.5 – 17.75**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**5.17±0.11**	**3.14±0.09**	**1 ± 0**	**2.62±0.04**	**1 ± 0**	**2.89±0.04**	**1 ± 0**	**16.83 ± 0.2 S-17.2±0.12 P-15.8±0.2**		

TABLE XIX - Duration (in days) of development of *T. neocaledonicus* on *A. tricolor* 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 develop-ment
1	4.5	2.5	0.75	2.25	0.75	2.5	0.75	14	F	S
2	4.5	2.75	0.75	2	0.75	2.5	0.75	14	F	S
3	4.75	2.5	0.75	2.5	0.5	2.5	0.75	14.25	F	S
4	4.75	2.75	0.75	2.5	0.75	2.5	0.75	14.75	F	S
5	4.5	2.5	0.5	2.5	0.5	2.5	0.5	13.5	M	S
6	4.5	2.5	0.75	2.5	0.75	2.5	0.75	14.25	F	S
7	4.75	2.5	0.75	2.25	0.5	2.5	0.75	14	F	S
8	4	2.5	0.5	2.25	0.5	2.75	0.5	13	M	P
9	4.5	2.5	0.5	2	0.5	2.5	0.75	13.25	M	P
10	4.5	2.5	0.5	2.5	0.5	2.5	0.75	13.75	M	S
11	4	2.75	0.5	2.5	0.75	2.5	0.5	13.5	M	S
12	4	2.5	0.75	2.5	0.5	2.5	0.5	13.25	M	P
Range	**4 – 4.75**	**2.5 – 2.75**	**0.5 – 0.75**	**2 – 2.5**	**0.5 – 0.75**	**2.5 – 2.75**	**0.5 – 0.75**	**13 – 14.75**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**4.44±0.08**	**2.56±0.03**	**0.64±0.03**	**2.35±0.06**	**0.60±0.04**	**2.52±0.02**	**0.67±0.03**	**13.8 ± 0.15 S-14.0±0.13 P-13.2±0.08**		

TABLE XX - Duration (in days) of development of *T. neocaledonicus* on *A. tricolor* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	4	2.5	0.5	2	0.5	2.5	0.5	12.5	M	P
2	4.5	2.5	0.5	2.25	0.75	2.5	0.75	13.75	F	S
3	4	2.5	0.75	2	0.5	2.5	0.5	12.75	M	S
4	4.5	2	0.5	2.25	0.5	2.5	0.5	12.75	M	S
5	4.5	2.5	0.75	2.25	0.5	2.5	0.5	13.5	F	S
6	4	2	0.5	2	0.5	2.5	0.5	12	M	P
7	4.5	2.5	0.5	2	0.5	2.5	0.5	13	F	S
8	4.5	2	0.75	2.25	0.5	2.5	0.5	13	F	S
9	4	2.5	0.5	2.25	0.75	2.5	0.5	13	M	S
10	4.5	2.5	0.5	2.25	0.5	2.5	0.5	13.25	F	S
11	4	2	0.5	2	0.5	2.5	0.75	12.25	M	P
12	4	2	0.5	2.25	0.75	2.5	0.5	12.5	M	P
Range	**4 – 4.5**	**2 – 2.5**	**0.2 – 0.75**	**2 – 2.25**	**0.5 – 0.75**	**2.5**	**0.5 – 0.75**	**12 – 13.75**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**4.25±0.07**	**2.29±0.07**	**0.56±0.03**	**2.14±0.04**	**0.56±0.03**	**2.5 ± 0**	**0.54±0.03**	**12.85 ± 0.14 S-13.1±0.12 P-12.3±0.12**		

TABLE XXI -Duration (in days) of development of *T. neocaledonicus* on *V. unguiculata* 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 develop-ment
1	4.5	2.25	1	2	1	2.5	1	14.25	M	P
2	4.5	2.75	1	2.25	1	2.5	1	15	F	S
3	4.75	2.5	1	2	1	2.5	1	14.75	M	S
4	4.5	2.5	1	2	1	2.5	1	14.5	M	P
5	4.75	2.75	1	2	1	2.5	1	15	F	S
6	4.75	2.25	1	2	1	2.75	1	14.75	F	S
7	4.5	2.25	1	2.25	1	2.5	1	14.5	M	S
8	4.5	2.5	1	2.25	1	2.5	1	14.75	F	S
9	4.5	2.75	1	2	1	2.75	1	15	F	S
10	4.5	2.25	1	2.5	1	2.5	1	14.75	F	S
11	4.5	2.25	1	2	1	2.75	1	14.5	M	P
12	4.75	2.5	1	2	1	2.75	1	15	F	S
Range	**4.5 – 4.75**	**2.25– 2.75**	**1**	**2 – 2.5**	**1**	**2.5 – 2.75**	**1**	**14.25 – 15**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**4.58±0.03**	**2.4±0.06**	**1 ± 0**	**2.1±0.05**	**1 ± 0**	**2.6±0.03**	**1 ± 0**	**14.73 ± 0.07 S-14.8±0.06 P-14.4±0.08**		

TABLE XXII - Duration (in days) of development of *T. neocaledonicus* on *V. unguiculata* 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 develop-ment
1	3	2	0.5	1.5	0.5	2	0.5	10	M	P
2	3	2.25	0.5	1.5	0.5	2	0.5	10.25	F	S
3	3	2	0.5	1.75	0.5	2	0.5	10.25	F	S
4	3.25	2	0.5	1.5	0.5	2	0.5	10.25	F	S
5	3	1.75	0.5	1.5	0.5	2	0.5	9.75	M	P
6	3.75	2	0.5	1.5	0.5	2	0.5	10.75	F	S
7	3.5	1.75	0.5	1.5	0.5	2	0.5	10.25	F	S
8	3	1.75	0.5	1.75	0.5	2	0.5	10	M	P
9	3	1.75	0.5	1.75	0.5	2.25	0.5	10.25	M	S
10	3.25	2.25	0.5	1.75	0.5	2	0.5	10.75	F	S
11	3.25	1.75	0.5	1.75	0.5	2	0.5	10.25	M	S
12	3	2	0.5	1.5	0.5	2.25	0.5	10.25	M	S
Range	**3 – 3.75**	**1.75 – 2.25**	**0.5**	**1.5 – 1.75**	**0.5**	**2 – 2.25**	**0.5**	**9.75 – 10.75**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.17±0.07**	**1.9±0.05**	**0.5 ± 0**	**1.6±0.04**	**0.5 ± 0**	**2.04±0.03**	**0.5 ± 0**	**10.25 ± 0.08 S-10.4±0.07 P-9.9±0.08**		

TABLE XXIII - Duration (in days) of development of *T. neocaledonicus* on *V. unguiculata* at 35± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	3.75	2.5	0.5	1.5	0.5	2.25	0.5	11.5	F	S
2	3.5	2.5	0.5	1.5	0.5	2.25	0.5	11.25	M	S
3	4	2.5	0.5	1.5	0.5	2	0.5	11.5	F	S
4	3.25	2.5	0.5	1.5	0.5	2	0.5	10.75	M	S
5	3.5	2.25	0.5	1.5	0.5	2	0.5	10.75	M	P
6	3.5	2.5	0.5	1.75	0.5	2	0.5	11.25	M	S
7	3.75	2.25	0.5	1.5	0.5	2	0.5	11	M	S
8	3.25	2.25	0.5	1.5	0.5	2	0.5	10.5	M	P
9	3.5	2.5	0.5	1.75	0.5	2.25	0.5	11.5	F	S
10	3.75	2.25	0.5	1.75	0.5	2	0.5	11.25	F	S
11	3.5	2.5	0.5	1.25	0.5	2	0.5	10.75	M	P
12	3.5	2.5	0.75	1.5	0.5	2	0.5	11.25	F	S
Range	**3.25 – 4**	**2.25 – 2.5**	**0.5**	**1.25 –1.75**	**0.5**	**2 –2.25**	**0.5**	**10.5 – 11.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.56±0.06**	**2.42±0.03**	**0.52±0.02**	**1.54±0.04**	**0.5 ± 0**	**2.06±0.03**	**0.5 ± 0**	**11.1 ± 0.09 S-11.2±0.08 P-10.7±0.08**		

TABLE XXV – Fecundity and longevity of *T. ludeni* on *M. deeringiana* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	No. of eggs laid on different days of oviposition							Total number of eggs laid	Female	Longevity (in days) (Pre-ovi + ovi + post-ovi periods)
	1	2	3	4	5	6	7			
1	2	3	6	8	4	2	0	25	V	9
2	3	4	7	9	3	0	Dead	26	V	8
3	3	6	8	7	4	0	Dead	27	M	7
4	2	5	9	12	7	2	0	37	M	8.5
5	3	7	9	13	6	3	1	42	M	9
6	1	4	5	8	3	1	0	22	V	8
7	1	2	6	10	5	3	0	28	M	8.5
8	2	6	7	3	2	Dead	-	20	V	6.5
9	1	3	6	9	3	1	0	23	V	8.5
10	3	6	11	8	4	1	0	33	M	9
Range	**1 - 3**	**2 - 7**	**5 - 11**	**3 - 13**	**2 - 7**	**0 - 3**	**0 - 1**	**M 27 - 42 V 20 - 26**		**M 6.5 - 9 V 6.5 - 9**
Mean ± SEM	**2.1±0.27**	**4.6±0.52**	**7.4±0.58**	**8.7±0.86**	**4.1±0.48**	**1.3±0.36**	**0.1±0.1**	**28.3 ± 2.2 M 33.4±2.8 V 23.2±1.1**	**M- Mated V- Virgin**	**8.0 ± 0.3 M 8.1 ± 0.48 V 8.0 ± 0.4**

TABLE XXVI – Fecundity and longevity of *T. ludeni* on *M. deeringiana* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	6	8	9	12	14	15	11	7	6	4	92	M	13
2	5	6	6	10	12	14	8	6	4	3	74	V	15
3	5	7	9	12	13	18	9	4	2	2	81	M	12
4	4	5	8	11	12	15	8	5	4	3	75	V	12
5	6	7	10	14	16	17	11	7	3	3	94	M	12.5
6	6	8	9	11	15	16	13	8	7	3	96	M	11.5
7	4	7	9	12	14	16	7	5	4	4	82	V	13
8	5	9	10	14	15	16	11	7	6	5	98	M	11
9	4	7	8	9	10	11	8	4	3	2	66	V	14
10	6	8	10	13	15	9	7	4	2	2	78	V	12
Range	**4 - 6**	**5 - 9**	**6 - 10**	**9 - 14**	**10 - 16**	**9 - 18**	**7 - 13**	**4 - 8**	**2 - 7**	**2 - 5**	**M 81 - 98 V 66 - 82**		**M 11 - 13 V 12 - 15**
Mean ± SEM	**5.1 ± 0.27**	**7.2 ± 0.36**	**8.8 ± 0.38**	**11.8 ± 0.51**	**13.6 ± 0.58**	**14.7 ± 0.87**	**9.3 ± 0.65**	**5.7 ± 0.47**	**4.1 ± 0.54**	**3.1 ± 0.31**	**83.6 ± 3.4 M 91.2±3.6 V 75±2.6**		**12.6 ± 0.37 M 12±0.35 V13.2±0.58**

TABLE XXVII – Fecundity and longevity of *T. ludeni* on *M. deeringiana* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	4	8	9	13	15	14	7	6	4	Dead	80	M	10
2	3	7	8	13	14	12	9	7	5	3	81	M	14.5
3	4	5	9	11	14	9	6	5	2	2	69	V	15
4	4	8	9	14	14	8	5	4	3	2	71	V	16
5	6	7	8	13	15	14	7	4	2	1	77	M	15.5
6	5	8	9	12	13	10	9	4	Dead	-	70	V	9
7	5	8	8	14	15	13	10	7	4	3	87	M	14.5
8	6	8	9	13	14	15	11	8	Dead	-	84	M	9
9	3	4	6	9	10	7	7	6	4	2	58	V	14.5
10	6	8	9	14	15	6	4	2	Dead	-	68	V	9
Range	**3 - 6**	**4 - 8**	**6 - 9**	**9 - 14**	**10 - 15**	**6 - 15**	**4 - 11**	**2 - 8**	**2 - 4**	**1 - 3**	**M 77 - 87 V 58 - 71**		**M 9 - 15.5 V 9 - 16**
Mean ± SEM	**4.6 ± 0.37**	**7.1 ± 0.45**	**8.4 ± 0.30**	**12.6 ± 0.49**	**13.9 ± 0.48**	**10.8 ± 1.01**	**7.5 ± 0.7**	**5.3 ± 0.57**	**2.4 ± 0.6**	**1.3 ± 0.39**	**74.5 ± 2.8 M 81.8±1.7 V 67.2±2.3**		**12.7 ± 0.95 M 12.7±1.3 V 12.7±1.5**

TABLE XXVIII - Duration (in days) of development of *T. ludeni* on *M. deeringiana* 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 develop-ment
1	4	1.5	1.5	1.5	1.	2.5	1	13	M	S
2	3.5	1.25	1.5	1.5	1.25	2.5	1	12.5	M	P
3	4	1.5	1.5	1.5	1.25	2.5	1	13.25	M	S
4	3.75	1.5	1.5	1.5	1.25	2.5	1	12	M	P
5	3.75	1.5	2	1.5	1.5	2.5	1.5	12.25	M	S
6	3.25	1	1.5	1.5	1.25	2.5	1	12	M	P
7	4	1.5	1.5	1.5	1.5	2.5	1	13.5	F	S
8	3.75	1.5	1.5	1.5	1	2.25	1	12.5	M	P
9	4	1	1.5	1.5	1.5	2.5	1.5	13.5	F	S
10	4	1.25	1.5	1.5	1	2.25	1	12.5	M	P
11	4	1.5	2	1.5	1.5	2.5	1	14	F	S
12	3.75	1.5	1.5	1.5	1.5	2.5	1	13.25	M	P
Range	**3.25 - 4**	**1 - 1.5**	**1.5 - 2**	**1.5**	**1 - 1.5**	**2.25 - 2.5**	**1 - 1.5**	**12 - 14**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.81±0.07**	**1.37±0.06**	**1.58±0.06**	**1.5±0**	**1.29±0.06**	**2.46±0.03**	**1.08±0.06**	**12.85 ± 0.19 S13.25±0.24 P12.46±0.19**		

TABLE XXIX - Duration (in days) of development of *T. ludeni* on *M. deeringiana* 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 develop-ment
1	2.75	1	1	1	1	2	1	9.75	M	S
2	2.5	1	0.5	1	1	1.75	1	8.75	M	P
3	3	1.25	1	1	1	2	1	10.25	F	S
4	2.5	1	1	1	1	2	1	9.5	M	P
5	2.75	1	1	1	1	2	1	9.75	M	S
6	2.5	1	1	1	1	1.75	1	9.25	M	P
7	2.75	1.25	1	1.5	1	2	1	10.5	F	S
8	2.5	1	0.5	1	1	1.75	1	8.75	M	P
9	3	1	1	1	1	1.75	1	9.75	M	S
10	2.5	1	1	1	1	1.75	1	9.25	M	P
11	2.5	1.25	1	1.5	1	2	1	10.25	F	S
12	2.5	1	0.5	1	1	1.75	1	8.75	M	P
Range	**2.5 - 3**	**1 - 1.25**	**0.5 - 1**	**1 - 1.5**	**1**	**1.75 - 2**	**1**	**8.75 - 10.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.64±0.06**	**1.06±0.03**	**0.87±0.06**	**1.08±0.06**	**1±0**	**1.87±0.04**	**1±0**	**9.54 ± 0.18 S10.04±0.13 P 9.04±0.13**		

TABLE XXX - Duration (in days) of development of *T. ludeni* on *M. deeringiana* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	3.22	1.25	1	1.5	1	2	1	10.75	F	S
2	2.5	1	1	1	1	2	1	9.5	M	P
3	3	1	1	1.5	1	2	1	10.5	M	S
4	2.75	1	1	1	1	2	1	9.75	M	P
5	2.75	1.25	1	1.5	1	2	1	10.5	M	S
6	2.75	1	1	1	1	2	1	9.75	M	P
7	3	1.25	1	1.5	1	2	1	10.75	F	S
8	2.5	1	1	1	1	1.75	1	9.25	M	P
9	3	1.25	1	1	1	2	1	10.25	M	S
10	2.75	1	0.75	1	1	1.75	1	9.25	M	P
11	2.75	1.25	1	1.5	1	2	1	10.5	F	S
12	2.75	1	0.75	1	1	1.75	1	9.25	M	P
Range	**2.5 - 3**	**1 - 1.25**	**0.75 - 1**	**1 - 1.5**	**1**	**1.75 - 2**	**1**	**9.25 - 10.75**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.89±0.06**	**1.1±0.04**	**0.96±0.03**	**1.2±0.07**	**1±0**	**1.94±0.03**	**1±0**	**10 ± 0.17 S10.54±0.08 P 9.46±0.1**		

TABLE XXXIII – Fecundity of *T. cinnabarinus* on *C. papaya* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	2	3	4	4	3	3	2	1	1	0	23	M	12.5
2	2	4	5	3	2	2	1	1	1	0	21	V	12.5
3	2	7	5	4	3	2	2	1	1	1	28	M	13.5
4	1	3	4	2	2	2	1	1	1	1	18	V	13.5
5	2	6	5	3	1	1	1	1	1	1	22	V	13
6	1	2	4	4	2	2	1	1	1	1	19	V	13.5
7	1	3	3	3	2	2	2	2	1	1	20	V	13.5
8	2	8	5	4	2	2	1	1	1	0	26	M	13.5
9	2	9	4	4	3	3	2	2	1	1	31	M	13
10	2	5	5	4	3	2	2	2	2	0	27	M	13
Range	**1 - 2**	**2 - 9**	**3 - 5**	**2 - 4**	**1 - 3**	**1 - 3**	**1 - 2**	**1 - 2**	**1 - 2**	**0 - 1**	**M 23 - 31 V 18 - 22**		**M12.5-13.5 V12.5-13.5**
Mean ± SEM	**1.7 ± 0.15**	**5.0 ± 0.76**	**4.4 ± 0.22**	**3.5 ± 0.22**	**2.3 ± 0.21**	**2.1 ± 0.18**	**1.5 ± 0.17**	**1.3 ± 0.15**	**1.1 ± 0.10**	**0.6 ± 0.16**	**23.5±1.4 M 27.0±1.3 V 20.0±0.7**		**13.1±0.13 M 13.1±0.2 V 13.2±0.2**

TABLE XXXIV – Fecundity of *T. cinnabarinus* on *C. papaya* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	4	6	10	8	6	4	2	2	1	43	M	9.5
2	6	8	13	7	5	3	2	2	2	48	M	10
3	5	8	12	10	6	3	3	2	1	50	M	10
4	2	9	11	7	6	2	2	1	1	41	M	10
5	2	4	10	8	6	3	2	2	1	38	V	10
6	2	5	9	9	4	2	2	1	1	35	V	10
7	3	7	14	8	4	3	3	2	0	44	M	9
8	5	6	9	7	2	1	1	1	0	32	V	9
9	4	5	11	7	3	2	2	2	0	36	V	9
10	5	7	10	6	4	3	2	2	2	40	V	10
Range	**2 - 6**	**4 - 9**	**9 - 14**	**6 - 10**	**2 - 6**	**1 - 4**	**1 - 3**	**1 - 2**	**0 - 1**	**M 41 - 50 V 32 - 40**		**M 9 - 10 V 9 - 10**
Mean ± SEM	**3.8 ± 0.47**	**6.5 ± 0.5**	**10.9 ± 0.53**	**7.7 ± 0.37**	**4.6 ± 0.45**	**2.6 ± 0.27**	**2.1 ± 0.18**	**1.7 ± 0.15**	**0.9 ± 0.23**	**40.7±1.8 M 45.2±1.6 V 36.2±1.3**		**9.6±0.15 M 9.7±0.2 V 9.6±0.25**

TABLE XXXV – Fecundity of *T. cinnabarinus* on *C. papaya* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	5	13	9	8	Dead	-	-	35	M	4.5
2	4	11	8	6	4	3	2	38	V	7.5
3	3	9	7	Dead	-	-	-	19	V	3.5
4	2	12	8	6	6	5	2	41	M	8
5	6	14	10	8	6	Dead	-	44	M	5.5
6	5	13	11	7	4	3	3	46	M	7
7	1	10	9	8	Dead	-	-	28	V	4.5
8	2	7	4	2	1	1	0	18	V	8
9	3	6	6	5	2	2	0	24	V	8
10	6	12	9	7	5	Dead	-	39	M	5.5
Range	**1 - 6**	**6 - 14**	**4 - 11**	**2 - 8**	**1 - 6**	**1 - 5**	**0 - 3**	**M 35 - 46 V 18 - 38**		**M 4.5 - 8 V 3.5 - 8**
Mean ± SEM	**3.7 ± 0.56**	**10.7 ± 0.84**	**8.1 ± 0.64**	**6.3 ± 0.64**	**4.0 ± 0.72**	**2.8 ± 0.66**	**1.4 ± 0.60**	**33.2±3.2 M 41.0±1.9 V 25.6±3.6**		**6.2±0.54 M6.1±0.62 V 6.3±0.96**

TABLE XXXVI – Fecundity of *T. cinnabarinus* on *D. lablab* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	1	3	6	4	3	2	2	1	1	1	24	V	13
2	2	3	9	6	4	2	1	1	1	1	30	M	12
3	1	2	4	4	3	2	2	1	1	1	21	V	13
4	1	3	5	6	4	3	2	2	1	1	28	M	13
5	4	5	3	3	2	2	1	1	1	1	23	V	12
6	1	5	6	4	3	2	2	1	1	1	26	M	11.5
7	2	3	9	5	4	3	2	2	1	1	32	M	13
8	2	5	6	5	4	3	2	2	1	1	31	M	12.5
9	1	3	3	4	3	2	1	1	1	1	20	V	11.5
10	1	1	5	3	2	1	1	1	1	1	17	V	12.5
Range	**1 - 4**	**1 - 5**	**3 - 9**	**3 - 6**	**2 - 4**	**1 - 3**	**1 - 2**	**1 - 2**	**1**	**1**	**M 26 - 32 V 17 - 32**		**M 11.5-13 V 11.5-13**
Mean ± SEM	**1.6 ± 0.30**	**3.3 ± 0.42**	**5.6 ± 0.67**	**4.4 ± 0.34**	**3.2 ± 0.25**	**2.2 ± 0.20**	**1.6 ± 0.16**	**1.3 ± 0.15**	**1 ± 0**	**1 ± 0**	**25.2±1.59 M 29.4±1.1 V 21.0±1.2**		**12.4±0.19 M 12.4±0.3 V 12.4±0.3**

TABLE XXXVII – Fecundity of *T. cinnabarinus* on *D. lablab* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	5	7	9	6	3	2	1	0	0	33	V	9
2	6	11	14	8	7	3	2	1	1	53	M	10
3	6	9	12	7	3	2	1	0	0	40	V	8.5
4	5	9	11	6	4	3	2	2	0	42	M	9
5	5	8	12	10	5	3	2	0	0	45	M	9
6	5	7	10	6	4	2	1	1	1	37	V	9.5
7	3	5	13	7	3	2	1	1	0	35	V	9
8	2	5	9	8	6	4	3	3	1	41	V	9.5
9	4	10	14	9	6	3	2	1	1	50	M	9.5
10	3	10	13	9	5	4	3	2	0	49	M	9
Range	**2 - 6**	**5 - 11**	**9 - 14**	**6 - 10**	**3 - 7**	**2 - 4**	**1 - 3**	**0 - 2**	**0 - 1**	**M 42 - 53 V 33 - 41**		**M 9-10 V 8.5-9.5**
Mean ± SEM	**4.4 ± 0.43**	**8.1 ± 0.66**	**11.7 ± 0.59**	**7.6 ± 0.45**	**4.6 ± 0.45**	**2.8 ± 0.25**	**1.8 ± 0.25**	**1.1 ± 0.31**	**0.4 ± 0.16**	**42.5±2.1 M 47.8±1.9 V 37.2±1.5**		**9.2±0.13 M 9.3±0.2 V 9.1±0.19**

TABLE XXXVIII – Fecundity of *T. cinnabarinus* on *D. lablab* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	6	15	14	9	5	3	2	54	M	7
2	7	14	8	6	4	Dead	-	39	M	6.5
3	2	9	4	3	2	1	0	21	V	7.5
4	1	4	4	3	2	1	1	16	V	7.5
5	5	13	11	6	Dead	-	-	35	M	5
6	2	9	6	5	3	2	0	27	V	7
7	3	8	7	6	4	2	Dead	30	V	6.5
8	4	11	9	8	6	6	Dead	44	M	6.5
9	5	10	6	5	4	3	3	36	M	7
10	4	10	8	6	4	3	2	37	V	7.5
Range	**1 -7**	**4 - 15**	**4 - 14**	**3 - 9**	**2 - 6**	**1 - 6**	**0 - 3**	**M 35 - 54 V 16 -37**		**M 5-7 V 6.5-7.5**
Mean ± SEM	**3.9 ± 0.60**	**10.3 ± 1.01**	**7.7 ± 0.98**	**5.7 ± 0.59**	**3.8 ± 0.43**	**2.6 ± 0.56**	**1.3 ± 0.49**	**33.9±3.5 M 41.6±3.5 V 26.2±3.2**		**6.8±0.24 M6.4±0.37 V 7.2±0.20**

TABLE XXXIX - Duration (in days) of development of *T. cinnabarinus* on *C. papaya* 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 develop-ment
1	3	2	1.5	1.5	1.5	1	1.5	12	M	S
2	4	1.5	1.5	1	1	1	1.5	11.5	M	P
3	3.5	2	1.5	1	1.5	1	1.5	12	F	S
4	3.5	2	1.5	1	1.5	1	2	11.5	M	P
5	4	1.5	1.5	1	1.5	1	2	12.5	F	S
6	3.5	1.5	1.5	1.5	1.5	1	2	12.5	F	S
7	3.5	1.5	1.5	1.5	1	1	2	12	M	S
8	3.5	2	1.5	1.5	1.5	1	2	13	F	S
9	4	2	1.5	1	1	1	2	12.5	F	S
10	3.5	1.5	1	1.5	1.5	1	1.5	11.5	M	P
11	3	1.5	1.5	1.5	1.5	1	2	12	M	S
12	4	1.5	1.5	1.5	1.5	1	2	13	F	S
Range	**3 - 4**	**1.5 – 2**	**1 – 1.5**	**1 – 1.5**	**1 – 1.5**	**1**	**1.5 - 2**	**11.5 – 13**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.58±0.10**	**1.7±0.07**	**1.45±0.04**	**1.29±0.07**	**1.37±0.06**	**1±0**	**1.8±0.07**	**12.16±0.15 S-12.4±0.14 P-11.5±0**		

TABLE XL - Duration (in days) of development of *T. cinnabarinus* on *C. papaya* 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 develop-ment
1	3	1.5	0.5	1	0.5	0.5	1	8	F	S
2	3	1	0.5	1	0.5	1	1	8	M	S
3	3	1.5	0.5	1	0.5	0.5	0.5	7.5	M	P
4	3	1	0.5	1	1	1	0.5	8	M	S
5	3	1	1	1	1	0.5	1	8.5	F	S
6	3	1	0.5	1	0.5	1	0.5	7.5	M	P
7	3	1	0.5	1	1	1	1	8.5	F	S
8	3	1	1	1	1	0.5	0.5	8	M	S
9	3	1	0.5	1	0.5	0.5	1	7.5	M	P
10	2.5	1	0.5	1	0.5	1	0.5	7	M	P
11	3	1	1	1	1	1	0.5	8.5	F	S
12	3	1.5	1	1	0.5	0.5	1	8.5	F	S
Range	**2.5 - 3**	**1 - 1.5**	**0.5 – 1**	**1**	**0.5 – 1**	**0.5 – 1**	**0.5 - 1**	**7 – 8.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.9±0.04**	**1.12±0.06**	**0.67±0.07**	**1±0**	**0.70±0.07**	**0.75±0.07**	**0.75±0.07**	**7.95±0.14 S-8.55±0.09 P-7.4±0.12**		

TABLE XLI - Duration (in days) of development of *T. cinnabarinus* on *C. papaya* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	2.5	1	0.5	0.5	0.5	0.5	0.5	6	M	P
2	2.5	1	0.5	0.5	0.5	1	0.5	6.5	M	S
3	3	1	0.5	0.5	0.5	1	0.5	6.5	M	S
4	2.5	1	0.5	1	0.5	1	0.5	7	F	S
5	2.5	0.5	0.5	1	0.5	1	0.5	6.5	F	S
6	2.5	0.5	0.5	0.5	0.5	1	0.5	6	M	P
7	2.5	1	0.5	Dead	-	-	-	-	-	-
8	3	1	0.5	0.5	0.5	Dead	-	-	-	-
9	3	1	0.5	1	0.5	0.5	0.5	7	F	S
10	2.5	Dead	-	-	-	-	-	-	-	-
11	3	1	0.5	1	0.5	1	0.5	7.5	F	S
12	3	1	0.5	1	0.5	1	Dead	-	-	-
Range	**2.5 - 3**	**0.5 - 1**	**0.5**	**0.5 - 1**	**0.5**	**0.5 – 1**	**0.5**	**6 – 7.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.7±0.07**	**0.91±0.06**	**0.5±0**	**0.75±0.08**	**0.5±0**	**0.9±0.07**	**0.5±0**	**6.62±1.8 S-6.83±0.16 P-6.0±0**		

TABLE XLII - Duration (in days) of development of *T. cinnabarinus* on *D. lablab* 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 develop-ment
1	3.5	1.5	1.5	1.5	1	1	1.5	11.5	F	S
2	3.5	1.5	1.5	1	1	1	1.5	11	M	P
3	3.5	1.5	1.5	1	1.5	1	1.5	11.5	M	S
4	3.5	1.5	1.5	1.5	1.5	1	1.5	12	F	S
5	3.5	1.5	1	1	1	1	1.5	10.5	M	P
6	3.5	2	1.5	1	1	1	1.5	11.5	F	S
7	3.5	1.5	1	1.5	1	1	1.5	11	M	P
8	3.5	1.5	1	1	1.5	1	1.5	11	M	P
9	4	2	1	1.5	1	1	1.5	12	F	S
10	3.5	1.5	1.5	1.5	1	1	1.5	11.5	F	S
11	3.5	2	1	1	1	1	1.5	10.5	M	P
12	3.5	2	1.5	1.5	1.5	1	1.5	12.5	F	S
Range	**3.5 - 4**	**1.5 - 2**	**1 – 1.5**	**1 – 1.5**	**1 – 1.5**	**1**	**1.5**	**10.5 – 12.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.5±0.04**	**1.7±0.07**	**1.3±0.07**	**1.25±0.08**	**1.2±0.07**	**1.0±0**	**1.5±0**	**11.37±0.17 S-11.8±0.15 P-10.8±0.12**		

TABLE XLIII - Duration (in days) of development of *T. cinnabarinus* on *D. lablab* 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 develop-ment
1	2.5	1	0.5	1	1	0.5	0.5	7	M	P
2	2.5	1	0.5	0.5	0.5	1	0.5	7	M	S
3	3	1	0.5	1	1	0.5	0.5	7.5	F	S
4	2.5	1	0.5	1	1	1	0.5	7.5	M	S
5	3	1	0.5	0.5	0.5	0.5	1	7	M	S
6	3	1	0.5	1	0.5	0.5	1	7.5	F	S
7	2.5	1	0.5	0.5	1	0.5	1	7	M	P
8	2.5	1	0.5	1	1	0.5	1	7.5	F	S
9	2.5	1	0.5	1	1	1	1	8	F	S
10	3	1	0.5	0.5	1	0.5	1	7.5	F	S
11	2.5	1	0.5	0.5	0.5	1	0.5	6.5	M	P
12	3	1	0.5	1	1	1	0.5	8	F	S
Range	**2.5 - 3**	**1**	**0.5**	**0.5 - 1**	**0.5 – 1**	**0.5 – 1**	**0.5 - 1**	**6.5 – 8**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.71±0.07**	**1±0**	**0.5±0**	**0.79±0.07**	**0.83±0.07**	**0.71±0.07**	**0.75±0.08**	**7.33±0.13 S-7.5±0.12 P-6.8±0.17**		

TABLE XLIV - Duration (in days) of development of *T. cinnabarinus* on *D. lablab* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	2.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5	M	P
2	2.5	0.5	0.5	0.5	0.5	Dead	-	-	-	-
3	2.5	0.5	0.5	0.5	0.5	1	0.5	6	M	P
4	2.5	0.5	0.5	1	0.5	0.5	0.5	6	M	S
5	3	0.5	0.5	1	0.5	0.5	0.5	6.5	F	S
6	3	1	0.5	1	0.5	0.5	0.5	7	F	S
7	2.5	1	0.5	1	0.5	0.5	0.5	6.5	F	S
8	2.5	0.5	Dead	-	-	-	-	-	-	-
9	2.5	0.5	0.5	0.5	0.5	1	Dead	-	-	-
10	3	0.5	0.5	0.5	0.5	0.5	0.5	6	M	S
11	2.5	0.5	0.5	1	0.5	1	0.5	6.5	F	S
12	3	0.5	0.5	0.5	0.5	1	0.5	6.5	F	S
Range	**2.5 - 3**	**0.5 - 1**	**0.5**	**0.5 - 1**	**0.5**	**0.5 – 1**	**0.5**	**5.5 – 7**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.67±0.07**	**0.58±0.06**	**0.5±0**	**0.73±0.08**	**0.5±0**	**0.7±0.08**	**0.5±0**	**6.27±0.15 S-6.4±0.13 P-5.7±0.25**		

TABLE XLVI – Fecundity of *E. orientalis on M. oleifera* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	1	3	4	6	7	4	2	1	0	Dead	28	M	10
2	2	3	5	6	7	2	1	0	Dead	-	26	M	9.5
3	1	1	2	3	2	2	1	1	1	0	15	V	11
4	2	3	5	6	7	5	2	1	0	0	30	V	11
5	2	3	4	8	6	4	1	0	Dead	-	28	V	10.5
6	1	3	4	5	6	2	1	1	1	0	25	V	12
7	1	1	2	3	4	2	2	1	1	0	18	V	13
8	3	4	6	7	8	3	2	1	1	0	35	M	13
9	3	4	5	7	9	2	1	1	Dead	-	32	M	10
10	2	4	4	8	10	3	2	1	0	Dead	34	M	10.5
Range	**1 - 3**	**1 - 4**	**2 - 16**	**3 - 8**	**2 - 10**	**2 - 5**	**1 - 2**	**0 - 1**	**0 - 1**	**0**	**M 26 - 35 V 15 - 30**		**M 9.5 - 13 V 10.5 - 13**
Mean ± SEM	**1.8 ± 0.25**	**2.9 ± 0.35**	**4.1 ± 0.40**	**5.9 ± 0.57**	**6.6 ± 0.73**	**2.9 ± 0.35**	**1.5 ± 0.17**	**0.8 ± 0.13**	**0.4 ± 0.16**	**0 ± 0**	**27.1 ± 2.0 M 31.0±1.7 V 23.2±2.9**		**11.1 ± 0.39 M 10.6±0.6 V11.5±0.45**

TABLE XLVII – Fecundity of *E. orientalis* on *M. oleifera* at 30 ± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	3	4	5	12	7	6	4	0	41	M	8
2	3	4	6	11	7	3	0	Dead	35	M	7
3	3	5	6	13	8	3	1	0	39	M	7
4	4	5	7	9	3	1	1	0	30	M	8
5	4	7	10	16	6	2	0	Dead	45	M	7
6	1	4	6	14	10	2	1	0	40	V	8
7	1	2	4	9	3	1	1	0	20	V	7
8	1	3	5	10	6	3	1	0	30	V	7.5
9	2	4	5	11	5	3	1	0	32	V	7.5
10	2	3	4	10	5	2	1	0	27	V	8
Range	**1 - 4**	**2 - 7**	**5 - 10**	**9 - 16**	**3 - 10**	**1 - 6**	**0 - 4**	**0**	**M 30 - 45 V 20 - 40**		**M 7 - 8 V 7.5 - 8**
Mean ± SEM	**2.4 ± 0.37**	**4.1 ± 0.43**	**5.8 ± 0.55**	**11.5 ± 0.72**	**6.0 ± 0.68**	**2.6 ± 0.45**	**1.1 ± 0.35**	**0 ± 0**	**33.9 ± 2.4 M 38.0±2.6 V 29.8±3.3**		**7.5 ± 0.14 M 7.4±0.24 V 7.6±0.19**

TABLE XLVIII – Fecundity of *E. orientalis* on *M. oleifera* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	1	3	6	9	4	3	2	2	Dead	30	V	9
2	2	4	4	4	2	2	1	1	Dead	20	V	9
3	1	2	5	8	6	3	2	Dead	-	27	V	8
4	2	3	4	6	5	2	1	Dead	-	23	V	8
5	2	4	5	6	3	3	1	1	Dead	25	V	9
6	3	4	4	6	5	4	4	3	Dead	33	M	8.5
7	3	6	7	9	6	5	4	Dead	-	40	M	8
8	3	4	5	7	4	3	2	2	Dead	30	M	9
9	3	7	8	11	4	3	2	1	Dead	39	M	9
10	3	3	4	7	5	5	4	3	Dead	34	M	8.5
Range	**1 - 3**	**2 - 7**	**4 - 8**	**4 - 11**	**2 - 6**	**3 - 5**	**1 - 4**	**0 - 3**	-	**M 30 - 40 V 20 - 30**		**M 8 - 9 V 8 - 9**
Mean ± SEM	**2.3 ± 0.26**	**4.0 ± 0.47**	**5.1 ± 0.48**	**7.3 ± 0.63**	**4.4 ± 0.40**	**3.3 ± 0.33**	**2.3 ± 0.39**	**1.3 ± 0.37**	-	**30 ± 2.1 M 35.2±1.9 V 25.0±1.7**		**8.6 ± 0.14 M 8.6±0.19 V 8.6±0.24**

TABLE XLIX - Duration (in days) of development of *E. orientalis* on *M. oleifera* 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 develop-ment
1	4.5	1.5	0.75	1	1	2	1.5	12.25	M	S
2	4	1.5	0.5	1	1.5	2	1	11.5	M	P
3	4.5	2	0.5	1	1.5	2	1.5	13	F	S
4	4	2	1	1	1	2	1	12	M	P
5	4.5	2	1	1	1	1.75	1.5	12.75	F	S
6	4	2	0.75	1	1	1.75	1	11.5	M	P
7	4.5	2.5	0.75	1	1.5	1.75	1	13.5	F	S
8	4	2.5	0.75	1	1	2	1	12.25	M	P
9	4.5	2	0.75	1	1	2	1.5	12.75	M	S
10	4	2	0.75	1	1	2	1	11.75	M	P
11	4.5	2	0.75	1	1.5	2	1.5	13.25	F	S
12	4	2	1	1	1	2	1	12	M	P
Range	**4 - 4.5**	**1.5 - 2.5**	**0.5 - 1**	**1**	**1 – 1.5**	**1.75 - 2**	**1 – 1.5**	**11.5 – 13.25**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**4.25±0.07**	**2±0.09**	**0.77±0.05**	**1±0**	**1.17±0.07**	**1.94±0.03**	**1.21±0.07**	**12.37 ± 0.19 S-12.9±0.18 P-11.8±0.19**		

TABLE L - Duration (in days) of development of *E. orientalis* on *M. oleifera* 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 develop-ment
1	3	1	0.5	1	0.75	1.5	0.75	8.5	M	S
2	3	1	0.5	0.75	0.5	1.5	0.75	8	M	P
3	3	1.5	0.5	0.75	0.5	1.5	0.75	8.5	F	S
4	3	1	0.5	0.75	0.75	1.5	0.75	8.25	M	P
5	3.5	1	0.5	1	0.75	1.5	0.75	9	F	S
6	3	1	0.5	0.75	0.75	1	0.75	7.75	M	P
7	3	1	0.5	1	0.75	1.5	0.75	8.5	M	S
8	3	1.5	0.5	0.75	0.75	1	0.75	8.25	M	P
9	3	1	0.5	1	0.75	1.5	0.75	8.5	F	S
10	3	1	0.5	0.75	0.5	1	0.75	7.5	M	P
11	3	1.5	0.5	1	0.75	1.5	0.75	9	F	S
12	3	1	0.5	0.75	0.5	1	0.75	7.5	M	P
Range	**3 - 3.5**	**1 - 1.5**	**0.5**	**0.75 - 1**	**0.5 – 0.75**	**1 – 1.5**	**0.75**	**7.75 – 9**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.04±0.04**	**1.1±0.06**	**0.5± 0**	**0.85±0.04**	**0.67±0.03**	**1.33±0.07**	**0.75± 0**	**8.27 ± 0.14 S-8.67±0.10 P-7.87±0.14**		

TABLE LI - Duration (in days) of development of *E. orientalis* on *M. oleifera* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	3	1.5	0.75	0.75	1	1.75	1	9.75	F	S
2	3	1	0.75	1	0.75	1.75	1	9.25	M	P
3	3.5	1	0.75	1	1	1.75	1	10	F	S
4	3	1	0.75	1	1	1.5	1	9.25	M	P
5	3.5	1	0.75	1	1	1.5	1	9.75	M	S
6	3	1.5	0.5	0.75	1	1.5	1	9.25	M	P
7	3.5	1.5	0.5	0.75	0.75	1.75	1	9.75	F	S
8	3	1.5	0.5	1	0.75	1.5	1	9.25	M	P
9	3	1.5	0.5	1	1	1.5	1	9.5	M	S
10	3	1.5	0.5	0.75	0.75	1.5	1	9	M	P
11	3	1.5	0.5	1	1	1.75	1	9.75	F	S
12	3	1.5	0.5	1	0.75	1.5	1	9.25	M	P
Range	**3 - 3.5**	**1 - 1.5**	**0.5 – 0.75**	**0.75 - 1**	**0.75 – 1**	**1.5 – 1.75**	**1**	**9 – 10**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.12±0.06**	**1.33±0.07**	**0.6±0.04**	**0.92±0.03**	**0.89±0.04**	**1.6±0.04**	**1±0**	**9.48 ± 0.09 S-9.75±0.06 P-9.2±0.04**		

TABLE LIII – Fecundity of *O. biharensis* on *M. esculenta* at 25 ± 2ºC & 80 ± 5% RH

Sl. No.	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			
1	1	3	5	6	7	2	1	1	0	Dead	26	V	12
2	1	2	3	5	7	2	2	1	1	0	24	V	13
3	1	2	4	4	8	2	1	1	1	1	25	V	14
4	5	6	6	7	10	4	1	1	0	Dead	40	M	11.5
5	4	6	9	12	6	3	2	2	Dead	-	44	M	11
6	3	5	5	13	6	5	3	1	1	1	43	M	13
7	1	2	4	5	7	2	1	1	0	0	23	V	12
8	3	4	6	8	4	2	1	1	1	1	31	V	13
9	4	7	8	9	11	4	2	2	1	Dead	48	M	11
10	1	5	7	9	5	4	3	3	1	Dead	38	M	11.5
Range	**1 - 5**	**2 - 7**	**3 - 9**	**4 - 13**	**4 - 10**	**2 - 5**	**1 - 3**	**1 - 3**	**1**	**0 - 1**	**M 38 - 48 V 23 - 31**		**M 11 - 13 V 12 - 14**
Mean ± SEM	**2.4 ± 0.5**	**4.2 ± 0.6**	**5.7 ± 0.6**	**7.8 ± 0.9**	**7.1 ± 0.67**	**3.0 ± 0.36**	**1.7 ± 0.26**	**1.4 ± 0.22**	**0.6 ± 0.16**	**0.7 ± 0.15**	**34.2 ± 2.9 M 42.6±1.7 V 25.8±1.4**		**12.2 ± 0.32 M 11.6±0.4 V 12.8±0.4**

TABLE LIV – Fecundity of *O. biharensis* on *M. esculenta* at 30± 2ºC & 70 ± 5% RH

Sl. No.	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			
1	2	4	7	9	8	6	3	2	1	42	M	10
2	5	6	8	11	9	5	3	2	1	50	M	10.5
3	4	8	8	12	10	6	6	3	1	58	M	10.5
4	2	4	5	9	7	4	3	1	1	36	V	10.5
5	5	6	8	10	4	2	2	1	0	38	M	9
6	2	5	7	10	4	4	2	1	0	35	M	9.5
7	1	3	4	7	6	4	3	1	1	30	V	10.5
8	1	4	7	10	5	2	1	1	1	32	V	9.5
9	2	3	5	6	3	3	2	2	1	27	V	10.5
10	2	2	5	8	6	2	1	1	1	28	V	10.5
Range	**1 - 5**	**2 - 8**	**4 - 8**	**6 - 12**	**3 - 10**	**2 - 6**	**1 - 6**	**1 - 3**	**0 - 1**	**M 35 - 58 V 27 - 36**		**M 9 – 10.5 V 9.5–10.5**
Mean ± SEM	**2.6 ± 0.47**	**4.5 ± 0.56**	**6.4 ± 0.48**	**9.2 ± 0.57**	**6.2 ± 0.72**	**3.8 ± 0.48**	**2.6 ± 0.45**	**1.5 ± 0.22**	**0.8 ± 0.13**	**37.6 ± 3.1 M 44.6±4.2 V 30.6±1.6**		**10.1 ± 0.18 M 9.9±0.3 V 10.3±0.2**

TABLE LV – Fecundity of *O. biharensis* on *M. esculenta* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	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			
1	2	9	11	13	8	5	3	2	53	M	8.5
2	2	4	7	10	8	6	4	3	44	V	9
3	1	2	3	9	6	5	4	2	32	V	9
4	1	3	5	9	8	6	2	1	35	V	9
5	2	3	3	10	8	6	4	3	39	V	9
6	2	5	6	11	9	5	5	2	45	M	8.5
7	4	7	9	13	11	7	3	2	56	M	8.5
8	2	3	8	15	6	4	6	2	46	V	8.5
9	4	6	10	14	7	6	4	3	54	M	8.5
10	5	8	11	16	14	6	4	2	66	M	9
Range	**1 - 5**	**2 - 9**	**3 - 11**	**5 - 13**	**6 - 15**	**4 - 7**	**2 - 6**	**1 - 3**	**M 45 - 66 V 32 - 46**		**M 8.5 - 9 V 8.5 - 9**
Mean ± SEM	**2.5 ± 0.43**	**5.0 ± 0.76**	**7.3 ± 0.95**	**12.0 ± 0.80**	**8.5 ± 0.76**	**5.6 ± 0.26**	**3.9 ± 0.35**	**2.2 ± 0.20**	**47.0 ± 3.29 M 54.8± 3.4 V 39.2±2.6**		**8.75 ± 0.08 M 8.6±0.1 V 8.9±0.1**

TABLE LVI - Duration (in days) of development of *O. biharensis* on *M. esculenta* 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 develop-ment
1	3.5	1	0.5	2	0.5	1.5	0.5	9.5	F	S
2	3.5	1	0.5	1.5	0.5	1	0.5	8.5	M	P
3	3.5	1	0.5	2	0.5	1.5	0.5	9.5	F	S
4	3.5	1	0.5	1.5	0.5	1.5	0.5	9	M	P
5	4	1	0.5	1.5	0.5	1.5	0.5	9.5	F	S
6	3.75	0.5	0.5	2	0.5	1	0.5	8.75	M	P
7	3.75	1	0.5	1.5	0.5	1.5	0.5	9.25	M	S
8	4	1	0.5	1.5	0.5	1	0.5	9	M	P
9	4	1	0.5	2	0.5	1	0.5	9.5	F	S
10	4	0.5	0.5	1.5	0.5	1.5	0.5	9	M	P
11	4	1	0.5	1.5	0.5	1	0.5	9	M	S
12	4	0.5	0.5	1.5	0.5	1.5	0.5	9	M	P
Range	**3.5 - 4**	**0.5 - 1**	**0.5**	**1.5 - 2**	**0.5**	**1 – 1.5**	**0.5**	**8.5 – 9.5**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**3.79±0.07**	**0.87±0.06**	**0.5± 0**	**1.67±0.07**	**0.5± 0**	**1.29±0.07**	**0.5± 0**	**9.12 ± 0.09 S-9.37±0.08 P-8.87±0.08**		

TABLE LVII - Duration (in days) of development of *O. biharensis* on *M. esculenta* 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 develop-ment
1	2.75	0.75	0.5	1.5	0.5	1.25	0.5	7.75	F	S
2	2.75	0.5	0.5	1	0.5	1.25	0.5	7	M	P
3	2.75	0.75	0.5	1.5	0.5	1.25	0.5	7.75	F	S
4	3	0.75	0.5	1	0.5	1	0.5	7.25	M	P
5	3	0.75	0.5	1.5	0.5	1.25	0.5	8	F	S
6	2.75	0.5	0.5	1	0.5	1.25	0.5	7	M	P
7	2.75	0.75	0.5	1.5	0.5	1.5	0.5	8	F	S
8	2.75	0.5	0.5	1	0.5	1.25	0.5	7	M	P
9	3	0.75	0.5	1.25	0.5	1	0.5	7.5	M	S
10	2.75	0.5	0.5	1	0.5	1	0.5	6.75	M	P
11	3	0.75	0.5	1	0.5	1.25	0.5	7.5	M	S
12	2.75	0.75	0.5	1	0.5	1	0.5	7	M	P
Range	**2.75 - 3**	**0.5 - 0.75**	**0.5**	**1 – 1.5**	**0.5**	**1 – 1.25**	**0.5**	**6.75 – 8**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.83±0.03**	**0.67±0.03**	**0.5± 0**	**1.19±0.07**	**0.5± 0**	**1.19±0.04**	**0.5± 0**	**7.37 ± 0.12 S-7.75±0.09 P-7.0±0.06**		

TABLE LVIII - Duration (in days) of development of *O. biharensis* on *M. esculenta* at 35 ± 2ºC & 60 ± 5% RH

Sl. No.	Egg	Larva	1st Q	Proto-nymph	2nd Q	Deuto-nymph	3rd Q	Total duration	Male/ Female	Nature of develop-ment
1	2.75	0.5	0.5	1	0.5	1.25	0.5	7	M	S
2	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
3	3	0.5	0.5	1	0.5	1.25	0.5	7.25	F	S
4	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
5	3	0.5	0.5	1	0.5	1.25	0.5	7.25	F	S
6	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
7	3	0.75	0.5	1	0.5	1	0.5	7.25	F	S
8	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
9	3	0.5	0.5	1	0.5	1.25	0.5	7.25	F	S
10	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
11	2.75	0.75	0.5	1	0.5	1	0.5	7	M	S
12	2.5	0.5	0.5	1	0.5	1	0.5	6.5	M	P
Range	**2.5 - 3**	**0.5 - 0.75**	**0.5**	**1**	**0.5**	**1 – 1.25**	**0.5**	**6.5 – 7.25**	**M-Male F-Female S-Sexual P-Parthenogenetic**	
Mean ± SEM	**2.71±0.07**	**0.54±0.03**	**0.5±0**	**1±0**	**0.5±0**	**1.08±0.03**	**0.5±0**	**6.83 ± 0.10 S-7.17±0.05 P-6.5±0**		

TABLE III - Host Range and Seasonal distribution of Spider mites studied

Sl. No.	Spider Mite	Host Range	Seasonal Distribution
1.	*Tetranychus neocaledonicus* Andre	*Moringa oleifera, Vigna unguiculata, Solanum melongena, Abelmoschus esculentus, Dolichos lablab, Amaranthus tricolor, Cucumis sativus, Cucurbita pepo, Phaseolus vulgaris, Manihot esculenta, Carica papaya, Brassica oleraceae, S. tuberosum, Coriandrum sativus, Citrus lemon, Mangifera indica, Pisum sativum, Daucus carota, Glycine max, Lycopersicon esculentum*	Occurs throughout the year Peak : February – May Moderate: January Scanty: June - December
2.	*T. ludeni* Zacher	*V. unguiculata, S. melongena, A. esculentus, D. lablab, A. tricolor, Mucuna deeringiana, G. max, P. vulgaris, C. lemon, B. oleraceae, C. maxima, C. sativus, L. esculentum, Luffa acutangula, V. radiata, D. biflorus, A. viridis, M. charantia, C. pepo, M. oleifera, Musa sp.*	Occurs throughout the year Peak : May – July Moderate: April Scanty: August - March
3.	*T. cinnabarinus* (Boisduval)	*D. lablab, A. tricolor, C. papaya, C. pepo, V. unguiculata, A. esculentus, M. charantia, C. sativus, M. esculenta, S. melongena, B. oleraceae, Coccinia cordifolia, Trichosanthes anguina, Lagenaria siceraria, L. acutangula, S. nigrum, L. esculentum, A. viridis, Mentha sp., Musa sp.*	Occurs throughout the year Peak : February - May Moderate: October - January Scanty: June - September
4.	*Eutetranychus orientalis* (Klein)	*M. oleifera, M. esculenta, P. vulgaris, M. charantia, C. lemon, Cassia occidentalis, C. papaya, Musa sp., L. acutangula.*	Occurs throughout the year Peak : February - April Moderate: May Scanty: June - January

5.	*Oligonychus biharensis* (Hirst)	*M. esculenta, Areca catechu, Rosa indica, M. indica, S. melongena*	Occurs throughout the year Peak : February - May Moderate: June Scanty: July - January

TABLE X - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. neocaledonicus* on *A. tricolor* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2ºC & 80 ± 5% RH	1	2.5	9	1
	2	2.5	10	2.5
	3	2.5	10	3
	4	2.75	9	1
	5	2.5	9	3
	6	2.75	9	2.5
	7	2.5	10	3
	8	2.75	9	1
	9	2.5	8	3
	10	2.5	8	3
	Mean ± SEM	**2.57 ± 0.04**	**9.1 ± 0.23**	**2.3 ± 0.29**
30 ± 2ºC & 70 ± 5% RH	1	1	8	3
	2	1.5	7	3
	3	1.5	7	2
	4	1.5	7	2
	5	2	8	3
	6	1.5	8	2
	7	2	8	2
	8	2	8	2
	9	1.5	7	2
	10	1.5	7	3
	Mean ± SEM	**1.6 ± 0.01**	**7.5 ± 0.17**	**2.4 ± 0.16**
35 ± 2ºC & 60 ± 5% RH	1	1.5	8	2
	2	1.5	7	2
	3	1	8	2
	4	1	7	2
	5	1.5	8	2
	6	1	8	2.5
	7	1	7	2.5
	8	1	7	2.5
	9	1.5	7	2
	10	1.5	7.5	2.5
	Mean ± SEM	**1.25 ± 0.08**	**7.45 ± 0.16**	**2.2 ± 0.08**

TABLE XI - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. neocaledonicus* on *V. unguiculata* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2°C & 80 ± 5% RH	1	2.5	10	3
	2	2.75	10	3
	3	2.5	10	3
	4	2.75	9	3
	5	2.75	9	3
	6	2.5	10	3
	7	2.5	9	3
	8	2.5	10	3
	9	2.75	10	3
	10	2.75	10	3
	Mean ± SEM	**2.62 ± 0.04**	**9.7 ± 0.15**	**3.0 ± 0**
30 ± 2°C & 70 ± 5% RH	1	2	7	2.5
	2	1.5	8	2.5
	3	1.5	6	3
	4	2	7	3
	5	2	7	3
	6	1.5	7	2
	7	1.5	7.5	2
	8	2	8	3
	9	2	6	2
	10	2	7	3
	Mean ± SEM	**1.8 ± 0.08**	**7.05 ± 0.22**	**2.6 ± 0.14**
35 ± 2°C & 60 ± 5% RH	1	1	8	2
	2	1.5	8	3
	3	1.5	8	2
	4	1	8	2
	5	1.5	8	2
	6	1.75	8	2
	7	1.5	8.5	2.5
	8	1.5	8	2
	9	1.5	8.5	2.5
	10	1.5	8	2
	Mean ± SEM	**1.42 ± 0.07**	**8.1 ± 0.07**	**2.2 ± 0.11**

TABLE XXIV - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. ludeni* on *M. deeringiana* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2ºC & 80 ± 5% RH	1	2	6	1
	2	2	5	1
	3	2	4	1
	4	2	6	0.5
	5	2	7	0
	6	1.5	6	0.5
	7	2	6	0.5
	8	1.5	5	0
	9	2	6	0.5
	10	2	6	1
	Mean ± SEM	**1.9 ± 0.07**	**5.7 ± 0.26**	**0.6 ± 0.12**
30 ± 2ºC & 70 ± 5% RH	1	0.5	11	0.5
	2	0.5	14	0.5
	3	0.5	11	0.5
	4	0.5	11	0.5
	5	0.5	11.5	0.5
	6	0.5	10.5	0.5
	7	0.5	12	0.5
	8	0.5	10	0.5
	9	0.5	13	0.5
	10	0.5	11	0.5
	Mean ± SEM	**0.5 ± 0**	**11.5 ± 0.38**	**0.5 ± 0**
35 ± 2ºC & 60 ± 5% RH	1	1	9	0
	2	1	12	1.5
	3	1	13	1
	4	1	14	1
	5	1	13	1.5
	6	1	8	0
	7	1	12	1.5
	8	1	8	0
	9	1	12	1.5
	10	1	8	0
	Mean ± SEM	**1 ± 0**	**10.9 ± 0.75**	**0.8 ± 0.22**

TABLE XXXI - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. cinnabarinus* on *C. papaya* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2ºC & 80 ± 5% RH	1	1	9.5	2
	2	1	9.5	2
	3	1	10	2.5
	4	1	10	2.5
	5	1	10	2
	6	1	10	2.5
	7	1	10.5	2
	8	1	10.5	2
	9	1	10	2
	10	1	10	2
	Mean ± SEM	**1 ± 0**	**10 ± 0.1**	**2.15 ± 0.07**
30 ± 2ºC & 70 ± 5% RH	1	0.5	8.5	0.5
	2	0.5	9	0.5
	3	0.5	9	0.5
	4	0.5	9	0.5
	5	0.5	9	0.5
	6	0.5	9	0.5
	7	0.5	8	0.5
	8	0.5	8	0.5
	9	0.5	8	0.5
	10	0.5	9	0.5
	Mean ± SEM	**0.5 ± 0**	**8.65 ± 0.15**	**0.5 ± 0**
35 ± 2ºC & 60 ± 5% RH	1	0.5	6.5	0.5
	2	0.5	6.5	0.5
	3	0.5	6	0.5
	4	0.5	6	0.5
	5	0.5	6.5	0.5
	6	0.5	7	0.5
	7	0.5	7	0.5
	8	0.5	6.5	0.5
	9	0.5	6	0.5
	10	0.5	6.5	0.5
	Mean ± SEM	**0.5 ± 0**	**6.45 ± 0.12**	**0.5 ± 0**

TABLE XXXII - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *T. cinnabarinus* on *D. lablab* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2ºC & 80 ± 5% RH	1	1.5	9	2.5
	2	1	8.5	2.5
	3	1	10	2
	4	1	10	2
	5	1.5	10	0.5
	6	1.5	9.5	0.5
	7	1	9.5	2.5
	8	1.5	9	2
	9	1	10	1.5
	10	1.5	9	2
	Mean ± SEM	**1.25 ± 0.08**	**9.45 ± 0.17**	**1.8 ± 0.24**
30 ± 2ºC & 70 ± 5% RH	1	0.5	7.5	1
	2	0.5	8.5	1
	3	0.5	7.5	0.5
	4	0.5	8	0.5
	5	0.5	7.5	1
	6	0.5	8.5	0.5
	7	0.5	8	0.5
	8	0.5	8.5	0.5
	9	0.5	8.5	0.5
	10	0.5	8	0.5
	Mean ± SEM	**0.5 ± 0**	**8.05 ± 0.14**	**0.65 ± 0.07**
35 ± 2ºC & 60 ± 5% RH	1	0.5	6	0.5
	2	0.5	6	0.5
	3	0.5	6.5	0.5
	4	0.5	6	0.5
	5	0.5	6.5	0.5
	6	0.5	6	0.5
	7	0.5	6	0.5
	8	0.5	6	0.5
	9	0.5	6	0.5
	10	0.5	6	0.5
	Mean ± SEM	**0.5 ± 0**	**6.1 ± 0.07**	**0.5 ± 0**

TABLE XLV - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *E. orientalis* on *M. oleifera* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2ºC & 80 ± 5% RH	1	1	8	1
	2	1.5	7	1
	3	1	9	1
	4	1	8	2
	5	1.5	7	2
	6	1	9	2
	7	1	9	3
	8	1	9	3
	9	1	8	1
	10	1	8	1.5
	Mean ± SEM	**1.1 ± 0.067**	**8.2 ± 0.24**	**1.75 ± 0.25**
30 ± 2ºC & 70 ± 5% RH	1	0.5	7	0.5
	2	0.5	6	0.5
	3	0.5	6	0.5
	4	0.5	7	0.5
	5	0.5	6	0.5
	6	0.5	6	1
	7	0.5	6	1
	8	0.5	7	0.5
	9	0.5	7	0.5
	10	0.5	6	0.5
	Mean ± SEM	**0.5 ± 0**	**6.4 ± 0.16**	**0.6 ± 0.067**
35 ± 2ºC & 60 ± 5% RH	1	0.5	8	0.5
	2	0.5	8	0.5
	3	0.5	7	0.5
	4	0.5	7	0.5
	5	0.5	8	0
	6	0.5	7	0.5
	7	0.5	8	0.5
	8	0.5	8	0.5
	9	0.5	8	0.5
	10	0.5	8	0
	Mean ± SEM	**0.5 ± 0**	**7.7 ± 0.15**	**0.4 ± 0.07**

TABLE LII - Duration (in days) of pre-oviposition, oviposition and post-oviposition periods of *O. biharensis* on *M. esculenta* at different temperature-humidity conditions

Temp.-Humidity	Sl. No.	Pre-oviposition	Oviposition	Post-oviposition
25 ± 2°C & 80 ± 5% RH	1	2	8	2
	2	2	9	2
	3	2	10	2
	4	2	8	1.5
	5	2	8	1
	6	1.5	10	1.5
	7	2	8	2
	8	1.5	10	1.5
	9	1.5	8.5	1
	10	2	8.5	1
	Mean ± SEM	**1.8 ± 0.07**	**8.8 ± 0.28**	**1.5 ± 0.14**
30 ± 2°C & 70 ± 5% RH	1	1	8.5	0.5
	2	1	8.5	1
	3	1	8.5	1
	4	1	9	0.5
	5	1	8	0
	6	1	8	0.5
	7	1	9	0.5
	8	1	8.5	0
	9	1	9	0.5
	10	1	8.5	1
	Mean ± SEM	**1 ± 0**	**8.5 ± 0.11**	**0.5 ± 0.12**
35 ± 2°C & 60 ± 5% RH	1	0.5	7.5	0.5
	2	0.5	8	0.5
	3	0.5	8	0.5
	4	0.5	8	0.5
	5	0.5	8	0.5
	6	0.5	7.5	0.5
	7	0.5	7.5	0.5
	8	0.5	7.5	0.5
	9	0.5	7.5	0.5
	10	0.5	8	0.5
	Mean ± SEM	**0.5 ± 0**	**7.7 ± 0.08**	**0.5 ± 0**

Table II Sampling Localities

Site No.	Locality	District	Type of Habitat	Species of host plants
I	C. U. campus	Malappuram	Shrub jungle	15
II	Thalappara	Malappuram	Cassava field	14
III	Chettiarmad	Malappuram	Vegetable field	10
IV	Villunniyaal	Malappuram	Vegetable field	13
V	Azhinjilam	Kozhikode	Vegetable field	12
VI	Panambra	Kozhikode	Vegetable field	7
VII	Kottupadam	Kozhikode	Kitchen garden	5
VIII	Edavannapara	Kozhikode	Vegetable field	10
IX	Pantheerankavu	Kozhikode	Home yard	3
X	Velluvambram	Malappuram	Vegetable field	8
XI	Balussery	Kozhikode	Kitchen garden	5
XII	Payyannur	Kannur	Vegetable field	8
XIII	Chowwa	Kannur	Home yard	4
XIV	Kelakam	Kannur	Vegetable field	11
XV	Dwaraka	Wayanad	Kitchen garden	13
XVI	Meenangadi	Wayanad	Vegetable field	9
XVII	Makkaraparambu	Malappuram	Vegetable field	10
XVIII	Chalakkudy	Thrissur	Kitchen garden	8
XIX	Punkunnam	Thrissur	Home yard	6
XX	Mannuthy	Thrissur	Vegetable field	15
XXI	Kechery	Thrissur	Vegetable field	8
XXII	Veliyannur	Thrissur	Kitchen garden	5
XXIII	Kollengode	Palakkad	Vegetable field	9
XXIV	Olavokkode	Palakkad	Kitchen garden	6
XXV	Thenkurissi	Palakkad	Kitchen garden	7

TABLE IV Relative abundance of the spider mites under study

Sl No.	Site	Spider mite species				
		T. neocaledonicus	***T. ludeni***	***T. cinnabarinus***	***E. orientalis***	***O. biharensis***
1.	I	++	+++	+++	++	++
2.	II	+	++	++	++	+++
3.	III	+++	+++	++	++	+++
4.	IV	++	+++	+++	++	+++
5.	V	++	+++	+++	++	++
6.	VI	-	++	-	-	++
7.	VII	+++	-	+++	-	+
8.	VIII	-	++	++	-	+
9.	IX	+++	+++	-	-	+
10.	X	++	+++	+++	-	++
11.	XI	++	+++	+++	++	-
12.	XII	-	++	-	-	-
13.	XIII	-	+++	-	-	-
14.	XIV	+++	-	++	-	+
15.	XV	+	++	+	-	++
16.	XVI	-	+++	++	-	++
17.	XVII	+++	-	++	-	-
18.	XVIII	++	+++	-	+	-
19.	XIX	+	++	+++	++	-
20.	XX	-	++	++	-	-
21.	XXI	++	+++	+++	-	-
22.	XXII	++	+++	-	-	-
23.	XXIII	-	+	+++	+	-
24.	XXIV	-	++	++	+	-
25.	XXV	+++	+	++	-	++
No. of sites showing presence		**17**	**22**	**19**	**10**	**14**

+++ = High incidence, ++ = Low incidence, + = Scarce & - = Absence of mites

PLATE II

Fig. 1. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *T. neocaledonicus* on *A. tricolor*

Fig. 2. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *T. neocaledonicus* on *V. unguiculata*

PLATE III

Fig. 1. Influence of varying temperature-humidity conditions on fecundity of *T. neocaledonicus* on *A. tricolor*

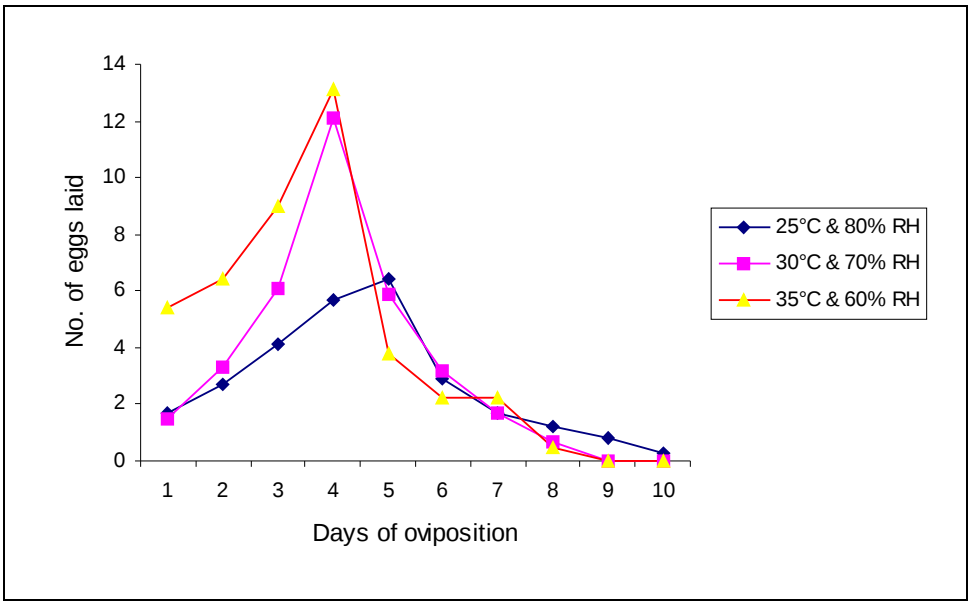


Fig. 2. Influence of varying temperature-humidity conditions on fecundity of *T. neocaledonicus* on *V. unguiculata*

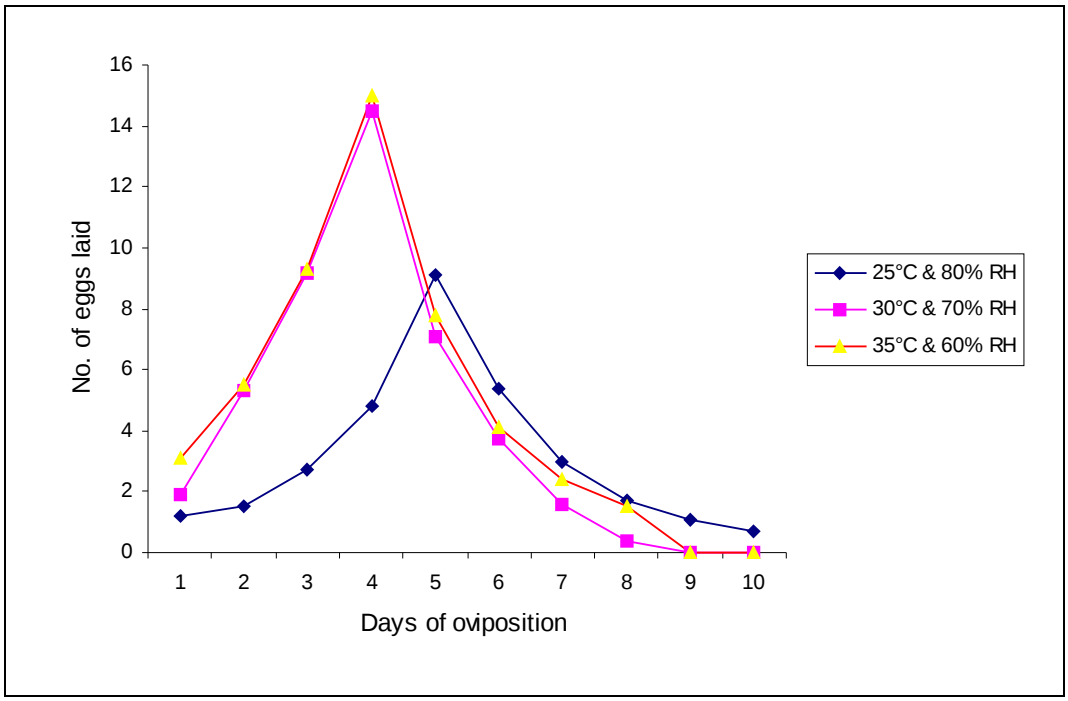


PLATE IV

Fig. 1. Duration of development of life stages of *T. neocaledonicus* at 25 ± 2ºC & 80 ± 5% RH on *A. tricolor*

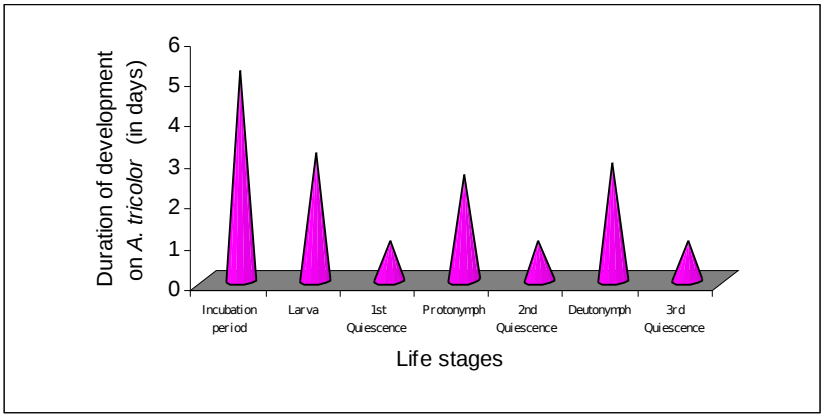


Fig. 2. Duration of development of life stages of *T. neocaledonicus* at 30 ± 2ºC & 70 ± 5% RH on *A. tricolor*

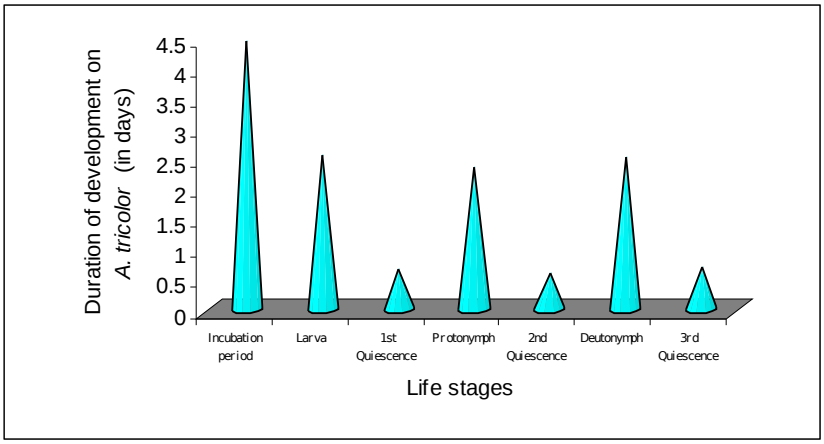


Fig. 3. Duration of development of life stages of *T. neocaledonicus* at 35 ± 2ºC & 60 ± 5% RH on *A. tricolor*

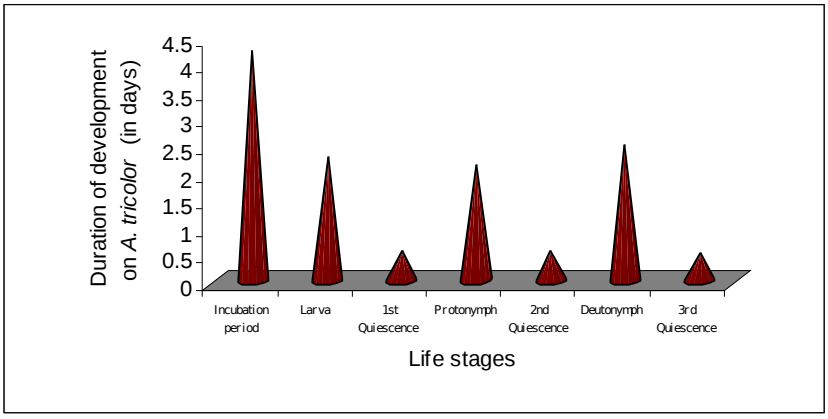


PLATE V

Fig. 1. Duration of development of life stages of *T. neocaledonicus* at 25 ± 2ºC & 80 ± 5% RH on *V. unguiculata*

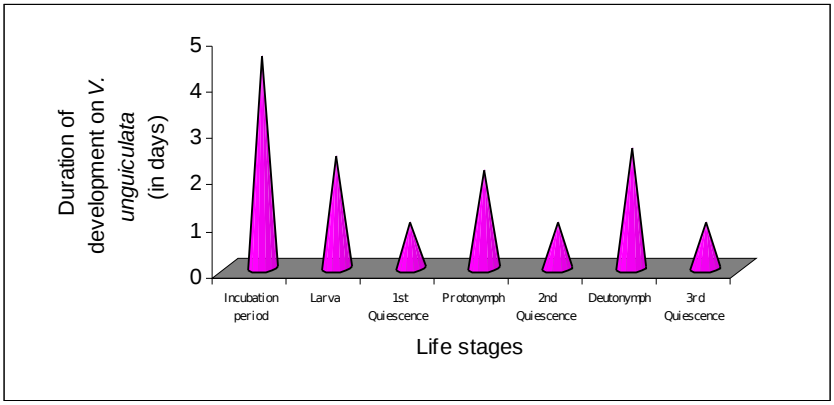


Fig. 2. Duration of development of life stages of *T. neocaledonicus* at 30 ± 2ºC & 70 ± 5% RH on *V. unguiculata*

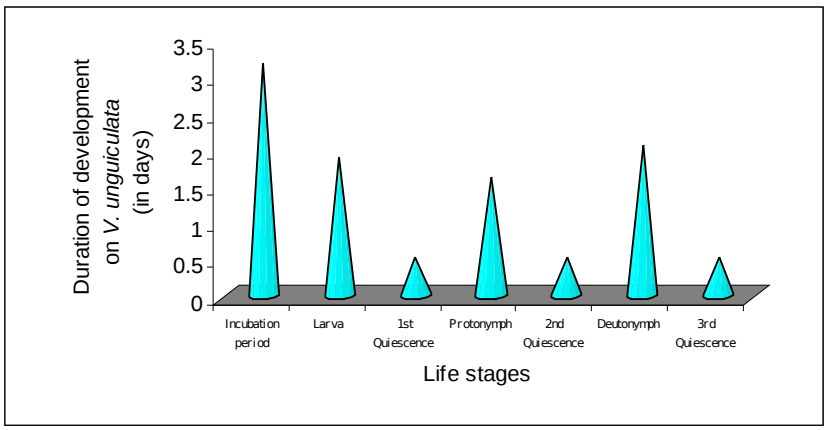


Fig. 3. Duration of development of life stages of *T. neocaledonicus* at 35 ± 2ºC & 60 ± 5% RH on *V. unguiculata*

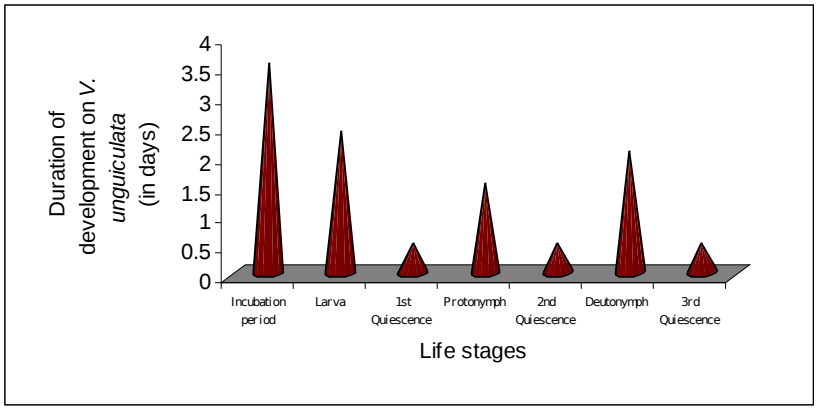


PLATE VI

Fig. 1. Comparative histogram showing duration of life stages of *T. neocaledonicus* under different temperature-humidity conditions on *A. tricolor*

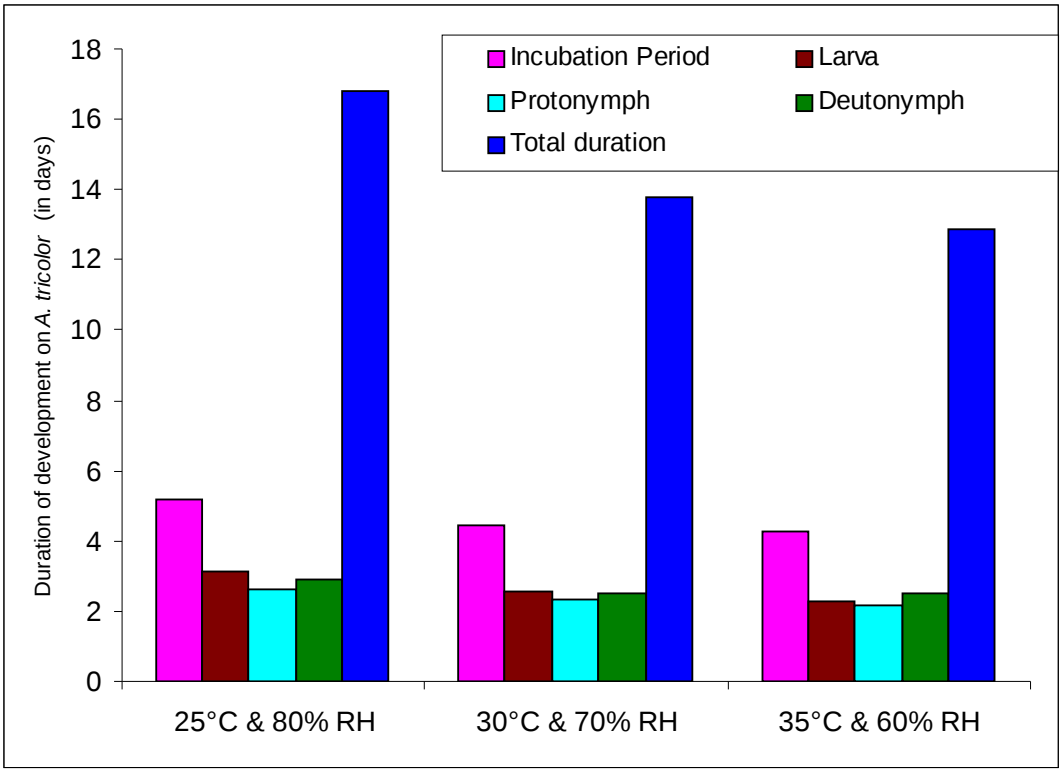


Fig. 2

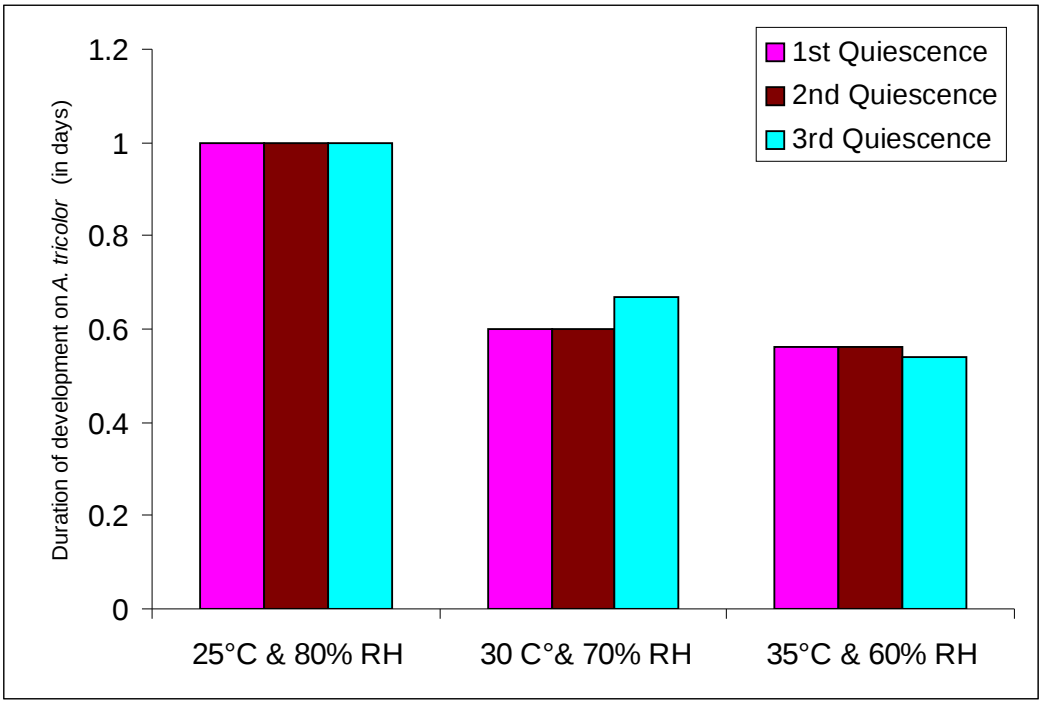


PLATE VII

Fig. 1. Comparative histogram showing duration of life stages of *T. neocaledonicus* under different temperature-humidity conditions on *V. unguiculata*

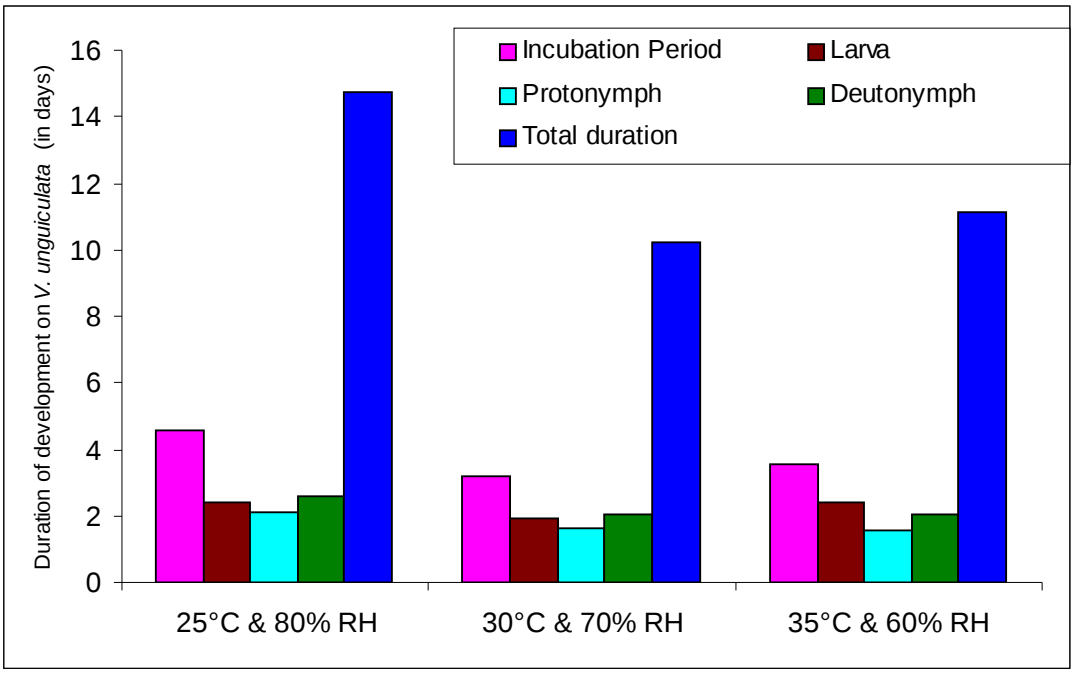


Fig. 2

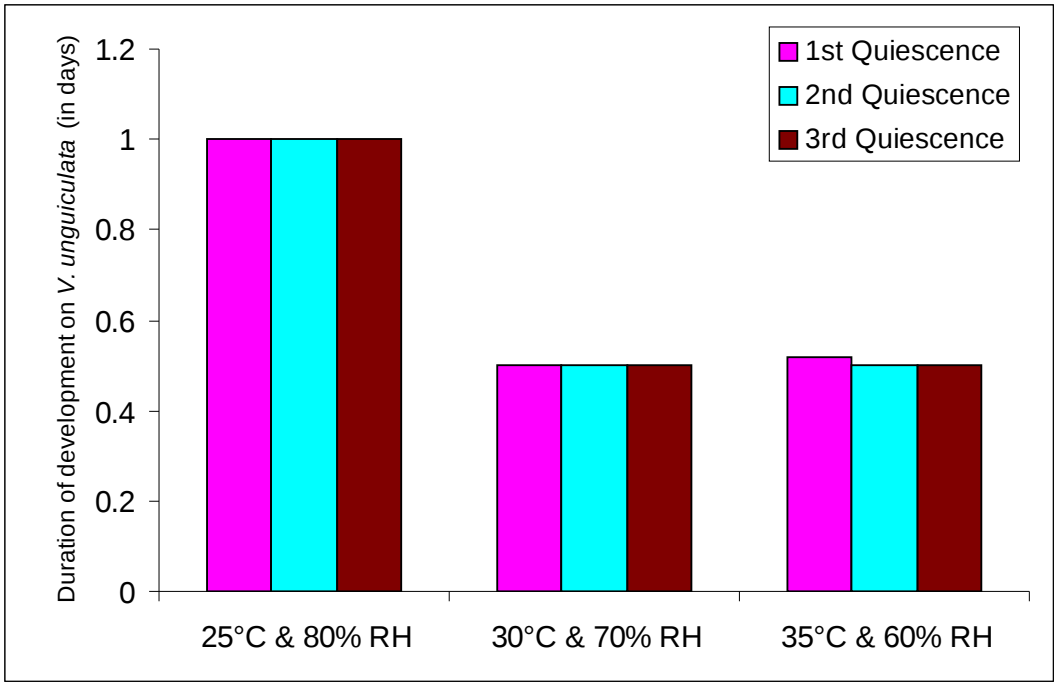


PLATE VIII

Fig. 1. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *T. neocaledonicus* on *A. tricolor*

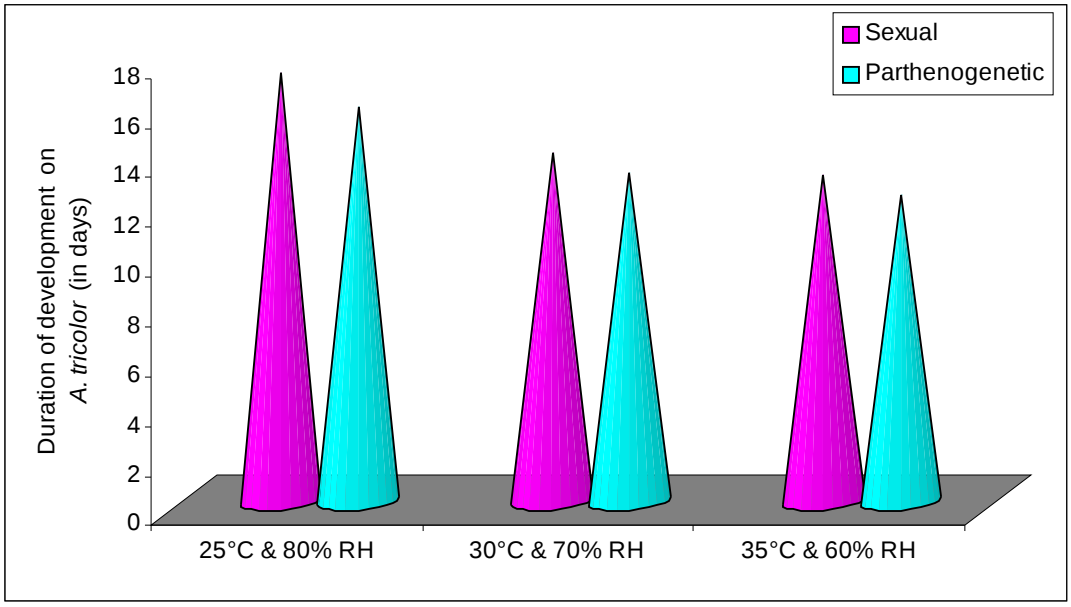


Fig. 2. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *T. neocaledonicus* on *V. unguiculata*

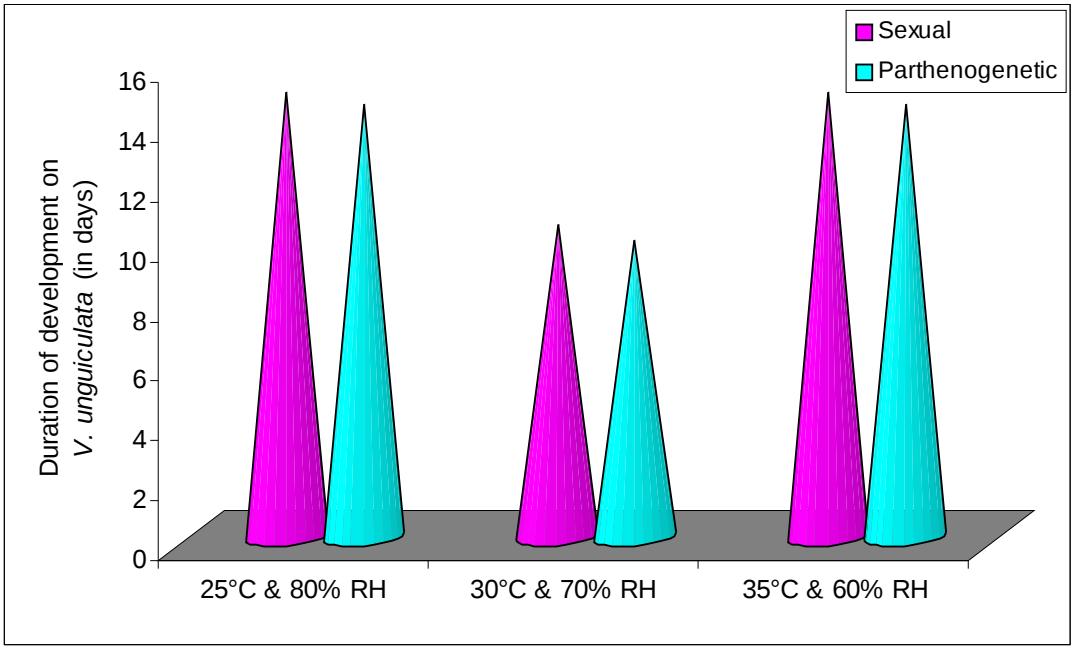


PLATE XIII

Fig. 1. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *T. ludeni*

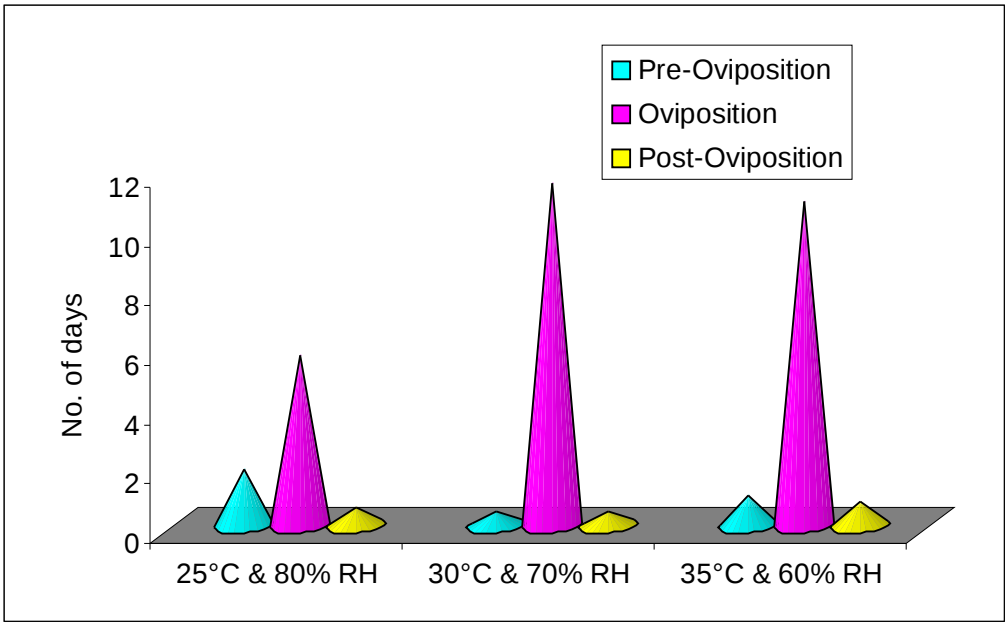


Fig. 2. Influence of varying temperature-humidity conditions on fecundity of *T. ludeni*

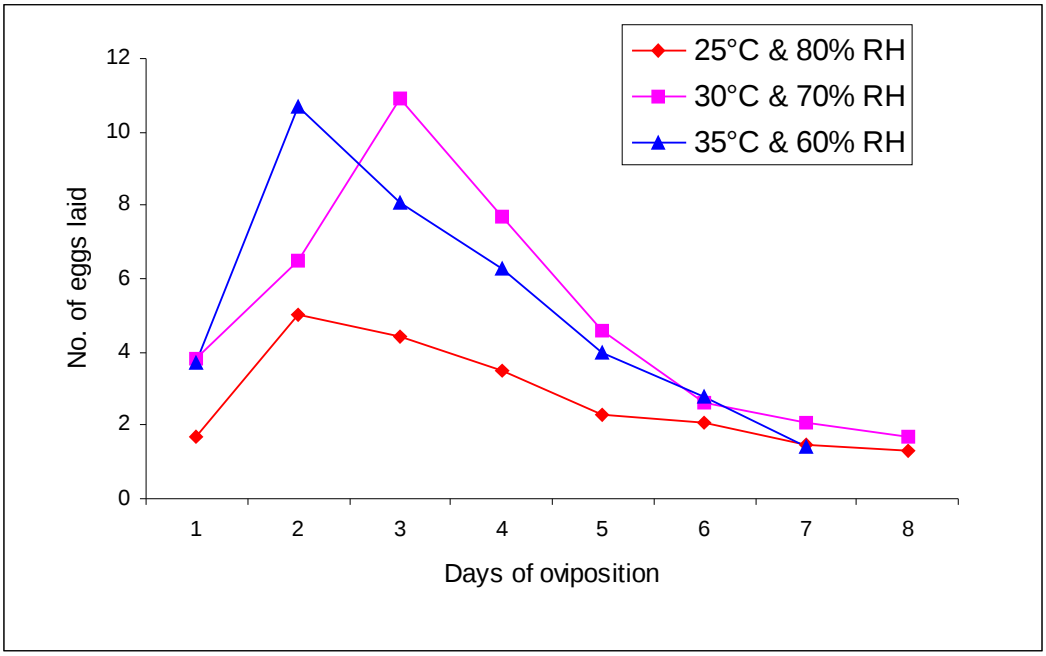


PLATE XIV

Fig. 1. Duration of development of life stages of *T. ludeni* at 25 ± 2ºC & 80 ± 5% RH on *M. deeringiana*

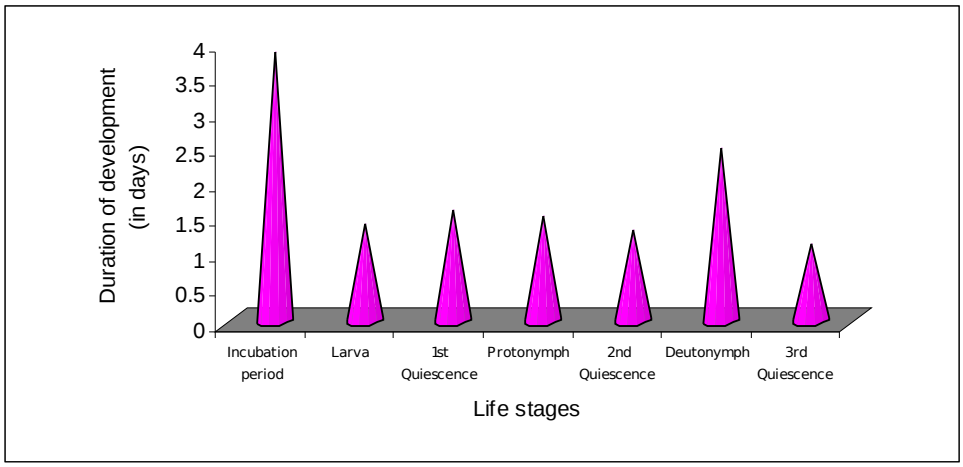


Fig. 2. Duration of development of life stages of *T. ludeni* at 30 ± 2ºC & 70 ± 5% RH on *M. deeringiana*

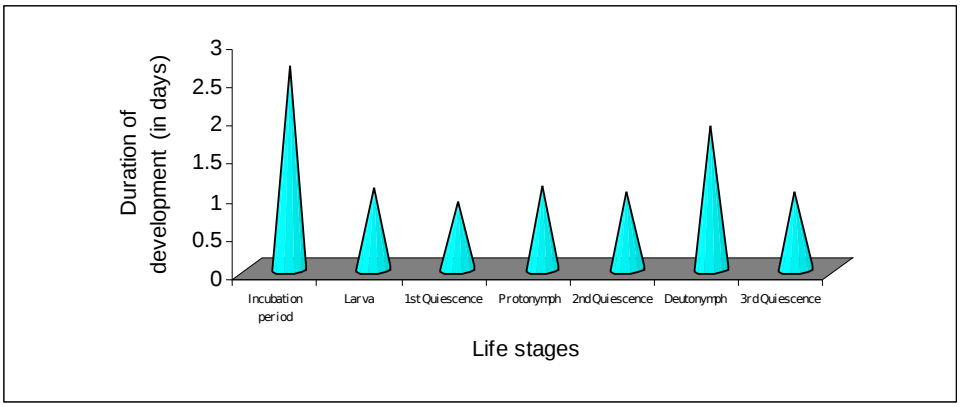


Fig. 3. Duration of development of life stages of *T. ludeni* at 35 ± 2ºC & 60 ± 5% RH on *M. deeringiana*

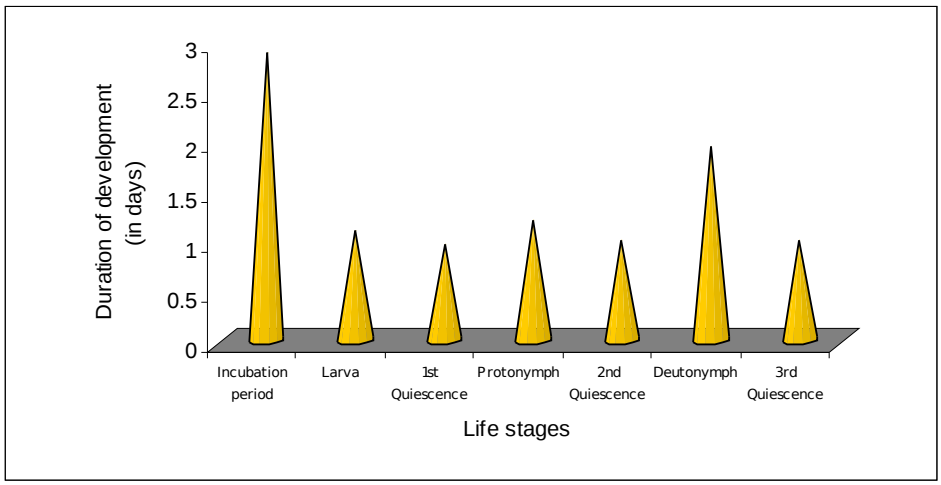


PLATE XV

Fig. 1. Comparative histogram showing duration of life stages of *T. ludeni* on *M. deeringiana* under different temperature-humidity conditions

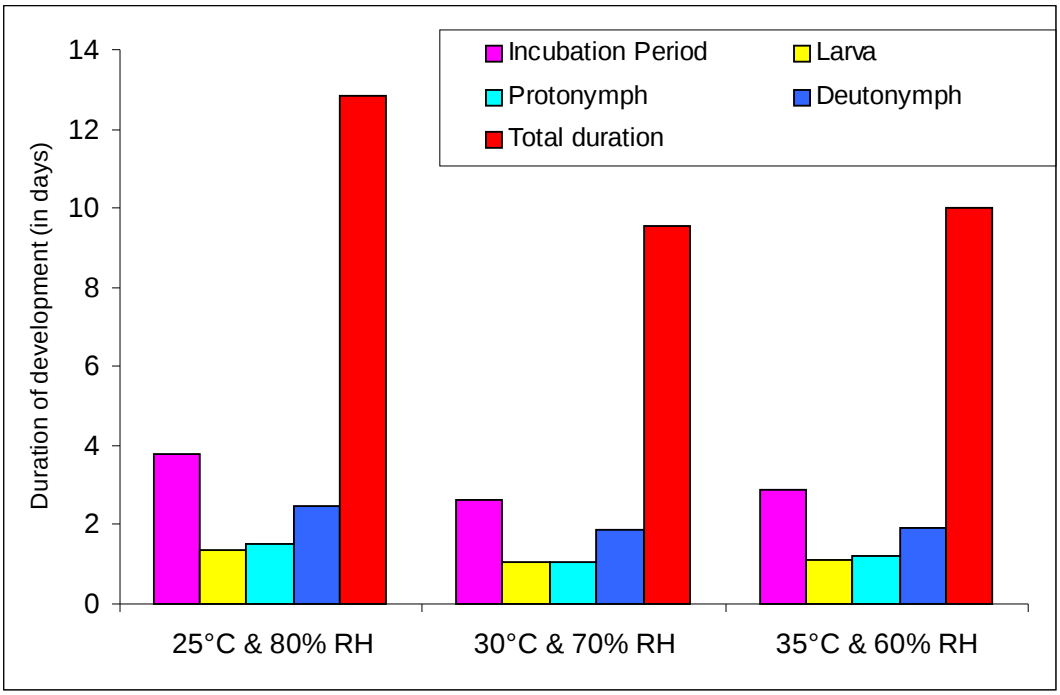


Fig. 2

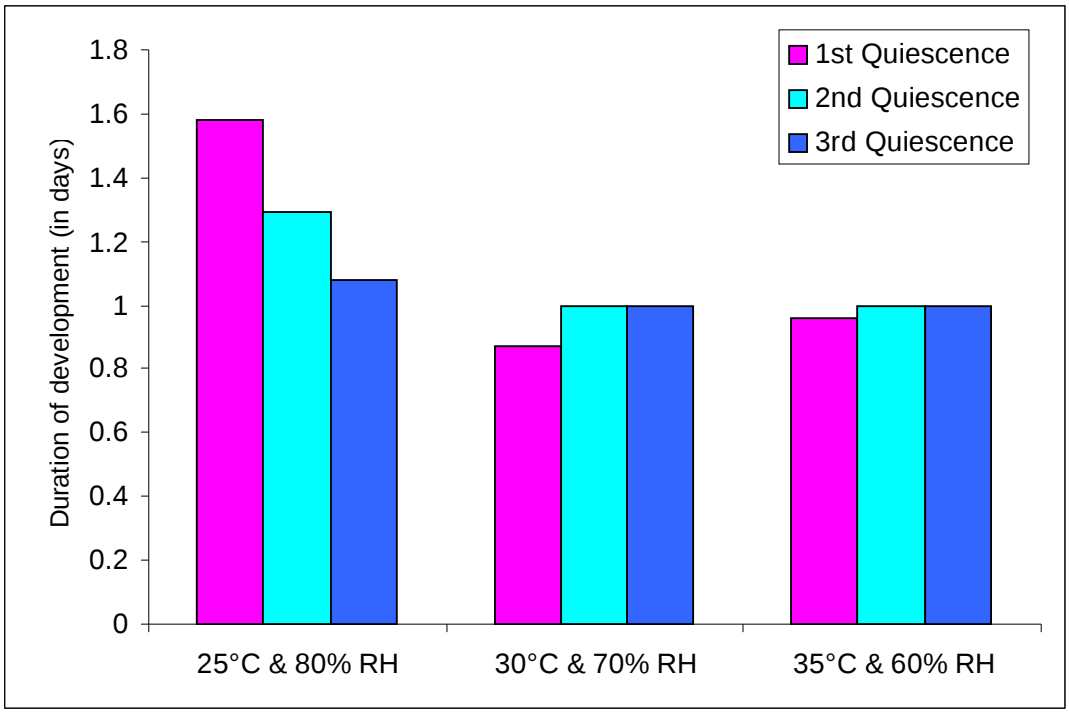


PLATE XVI

Fig. 1. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *T. ludeni* on *M. deeringiana*

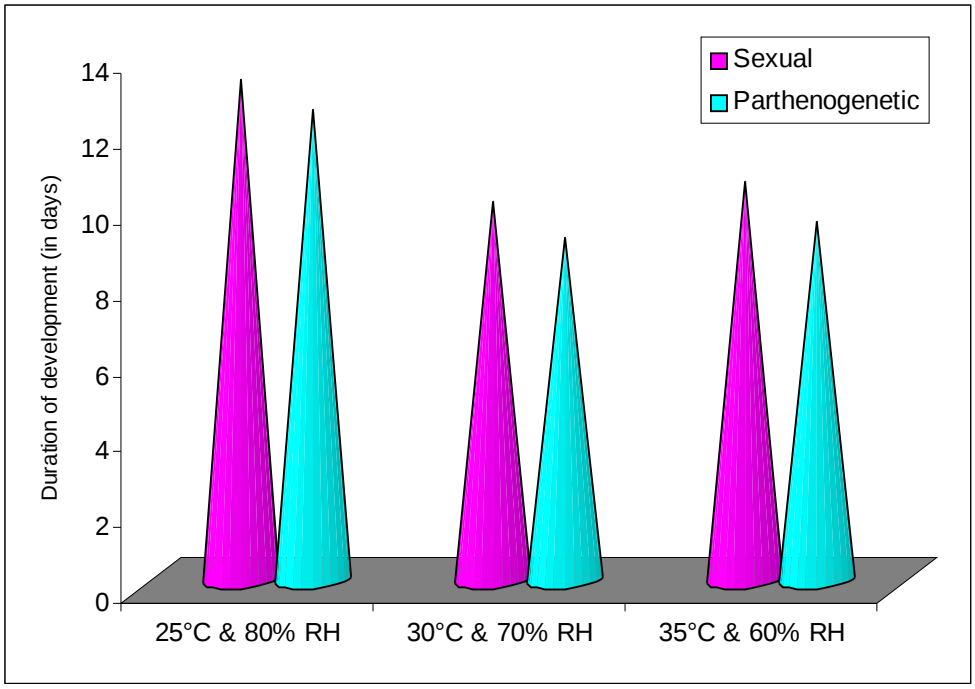


PLATE XX

Fig. 1. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *T. cinnabarinus* on *C. papaya*

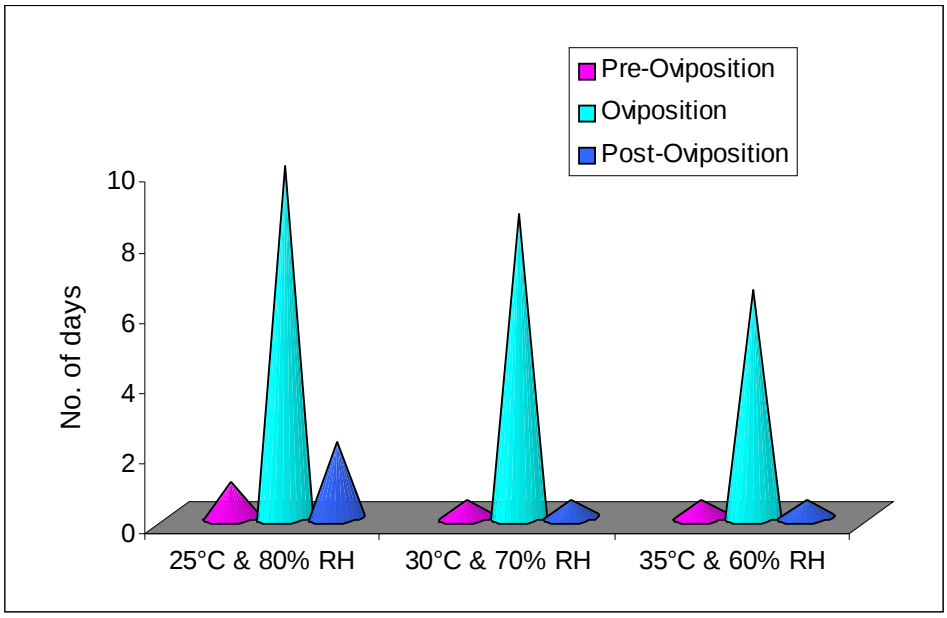


Fig. 2. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *T. cinnabarinus* on *D. lablab*

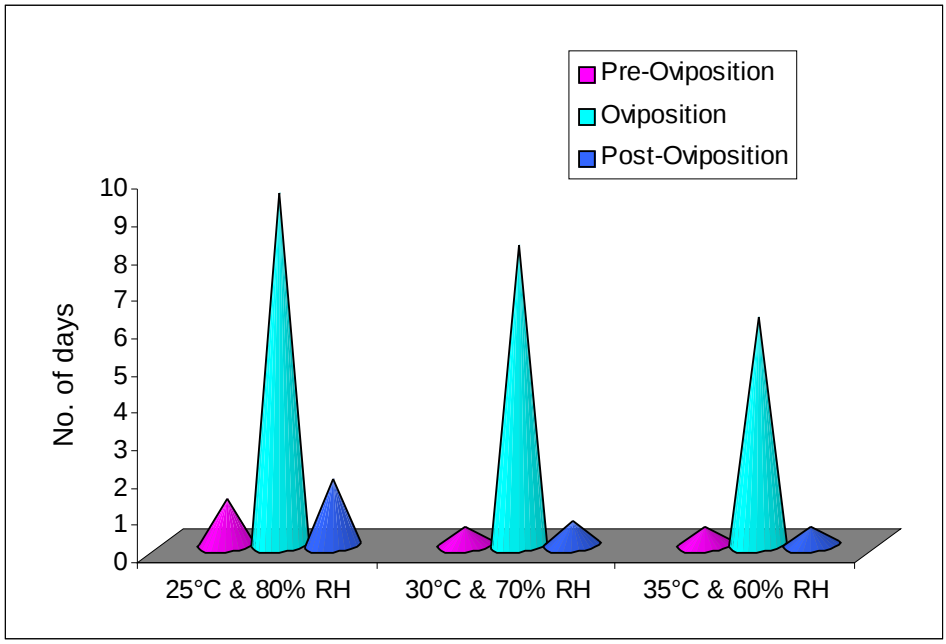


PLATE XXI

Fig. 1. Influence of varying temperature-humidity conditions on fecundity of *T. cinnabarinus* on *C. papaya*

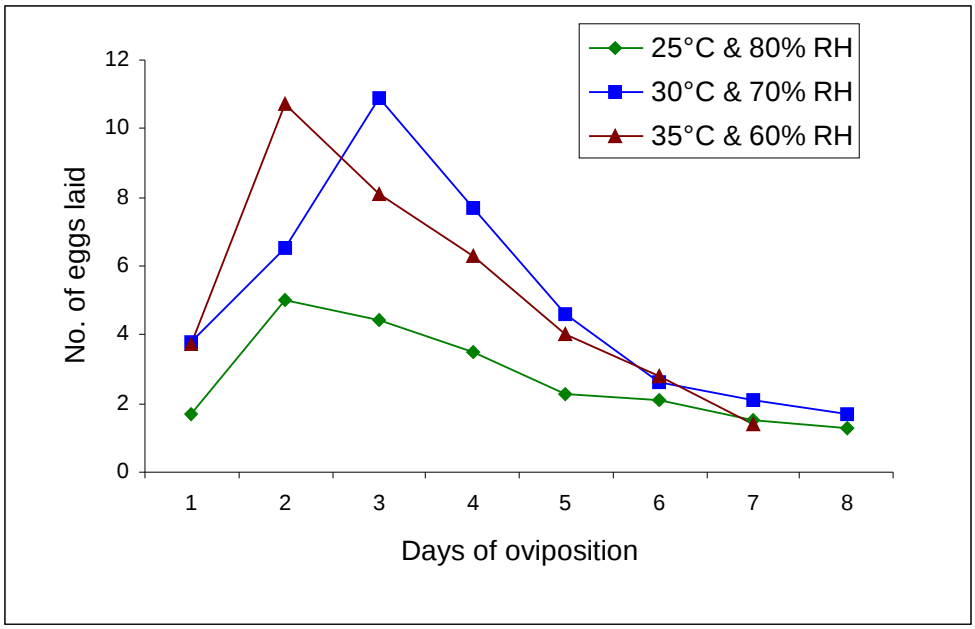


Fig. 2. Influence of varying temperature-humidity conditions on fecundity of *T. cinnabarinus* on *D. lablab*

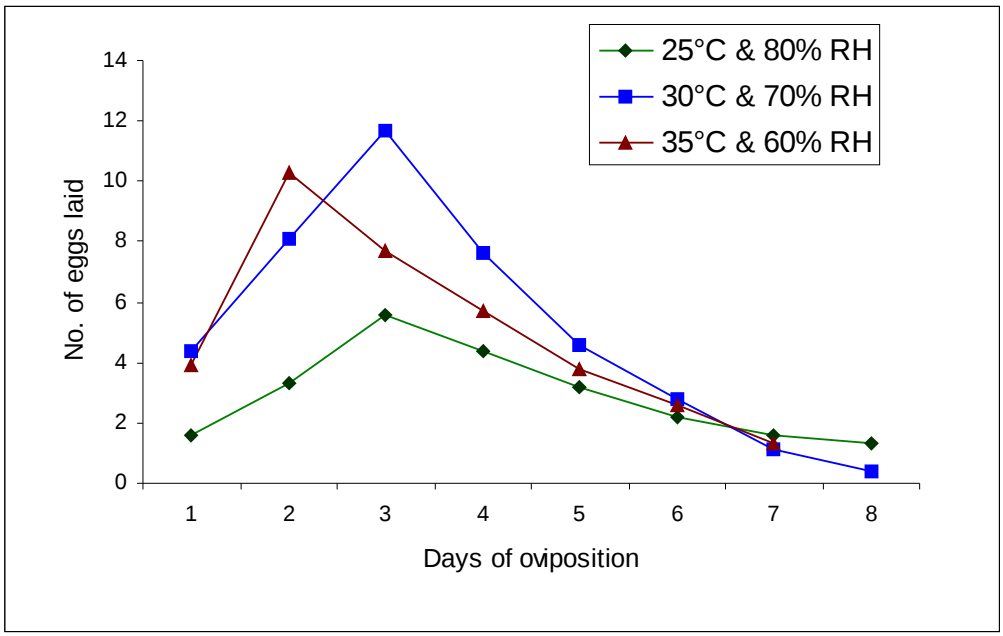


PLATE XXII

Fig. 1. Duration of development of life stages of *T. cinnabarinus* at 25 ± 2ºC & 80 ± 5% RH on *C. papaya*

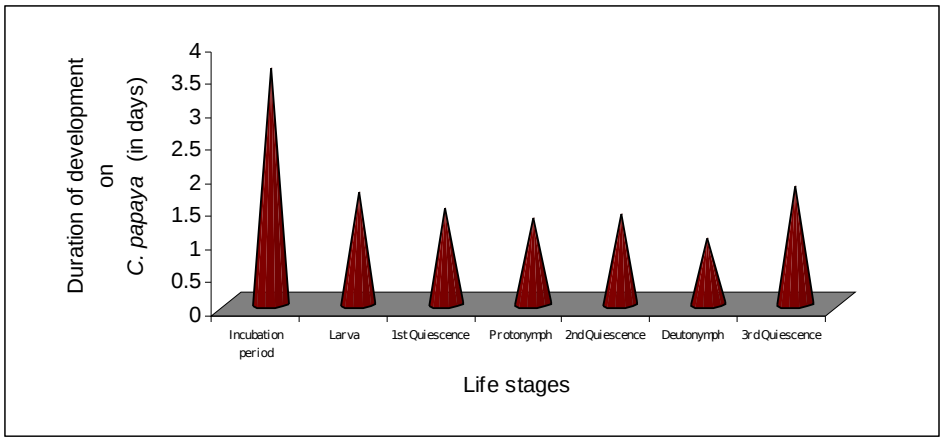


Fig. 2. Duration of development of life stages of *T. cinnabarinus* at 30 ± 2ºC & 70 ± 5% RH on *C. papaya*

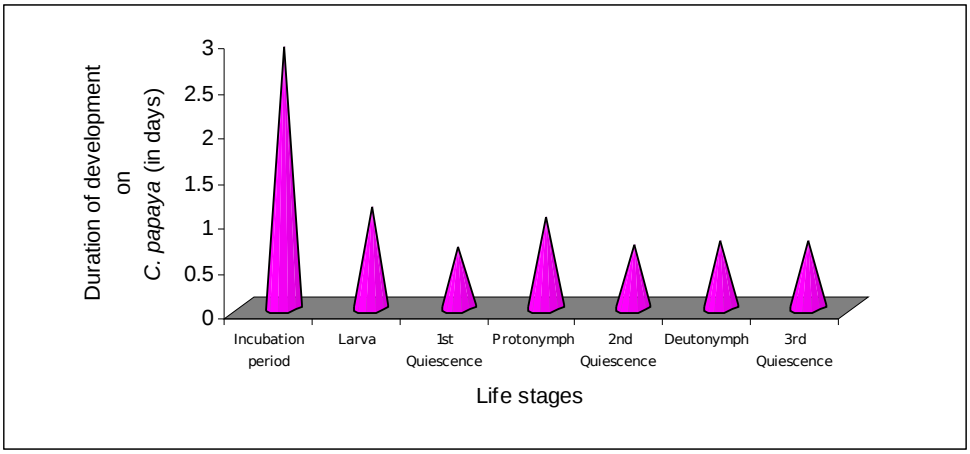


Fig. 3. Duration of development of life stages of *T. cinnabarinus* at 35 ± 2ºC & 60 ± 5% RH on *C. papaya*

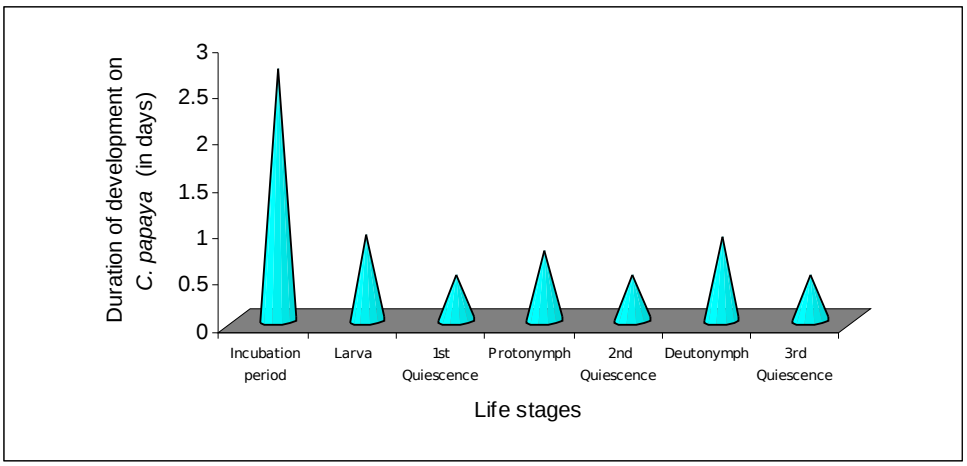


PLATE XXIII

Fig. 1. Duration of development of life stages of *T. cinnabarinus* at 25 ± 2ºC & 80 ± 5% RH on *D. lablab*

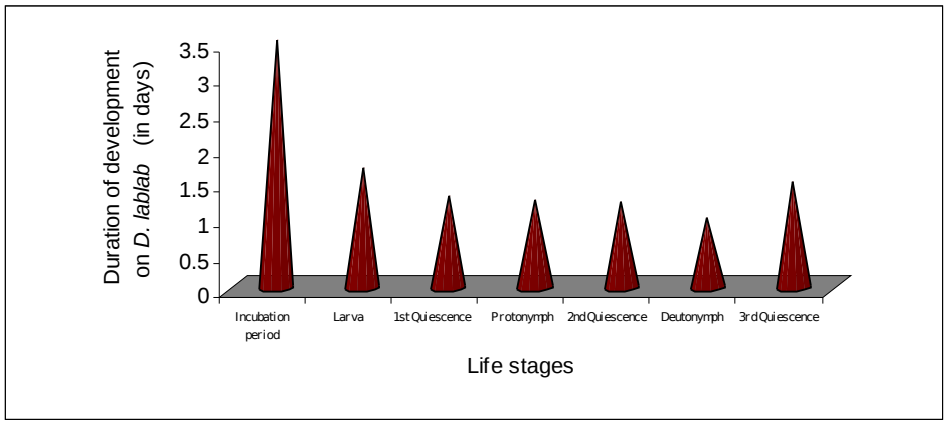


Fig. 2. Duration of development of life stages of *T. cinnabarinus* at 30 ± 2ºC & 70 ± 5% RH on *D. lablab*

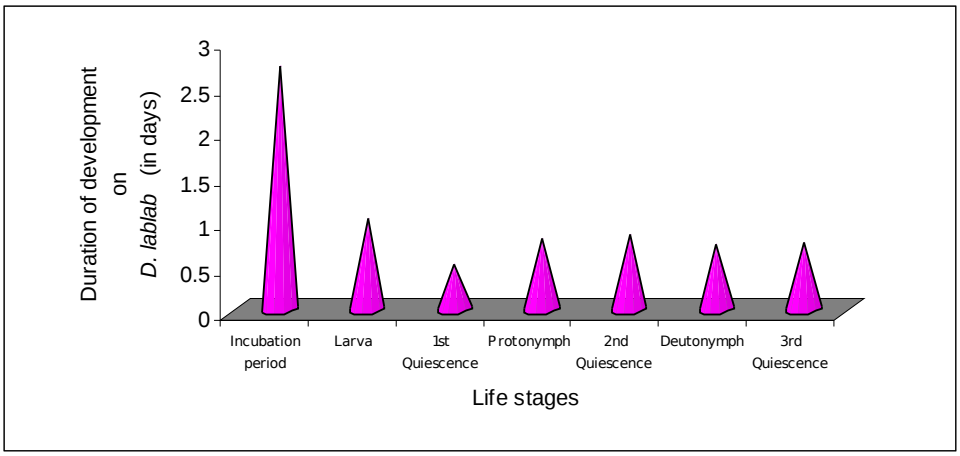


Fig. 3. Duration of development of life stages of *T. cinnabarinus* at 35 ± 2ºC & 60 ± 5% RH on *D. lablab*

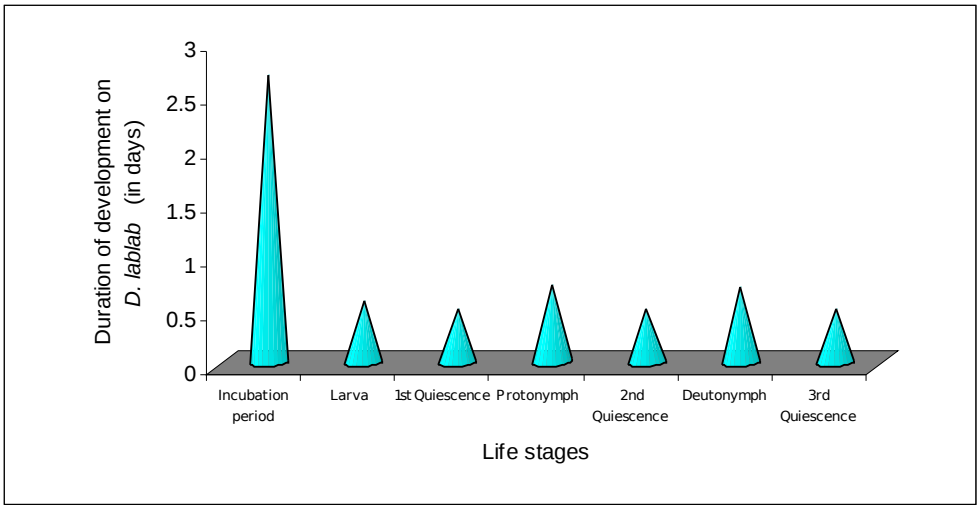


PLATE XXIV

Fig. 1. Comparative histogram showing duration of life stages of *T. cinnabarinus* on *C. papaya* under different temperature-humidity conditions

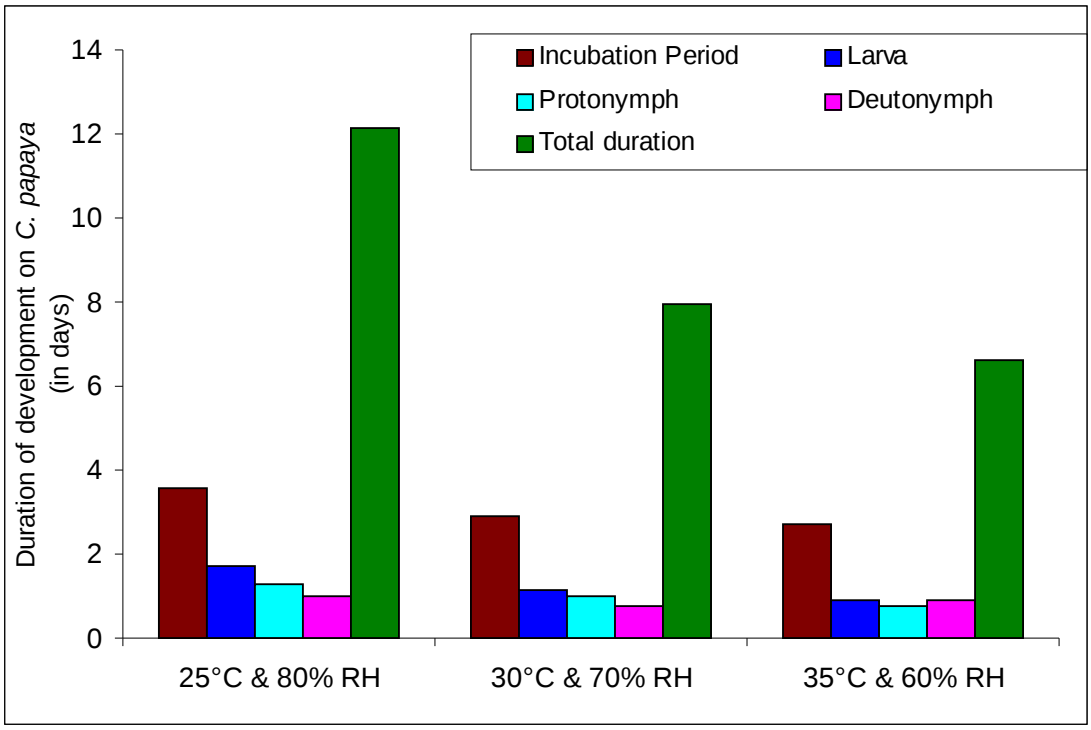


Fig. 2

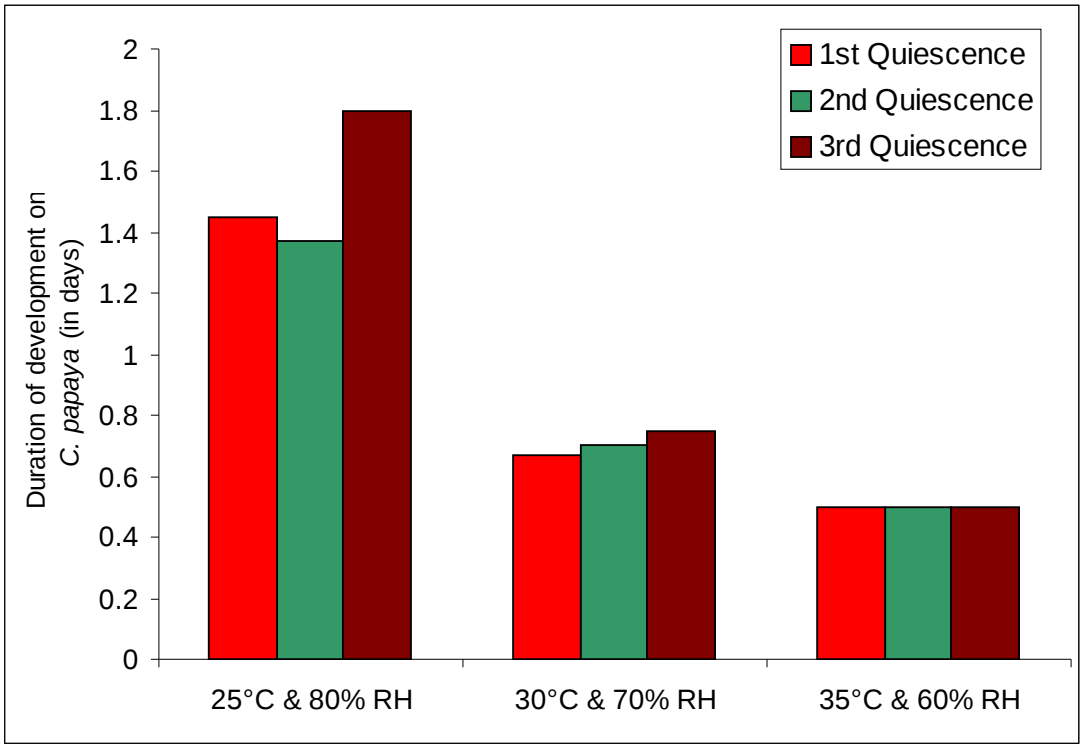


PLATE XXV

Fig. 1. Comparative histogram showing total duration of life stages of *T. cinnabarinus* on *D. lablab* under different temperature-humidity conditions

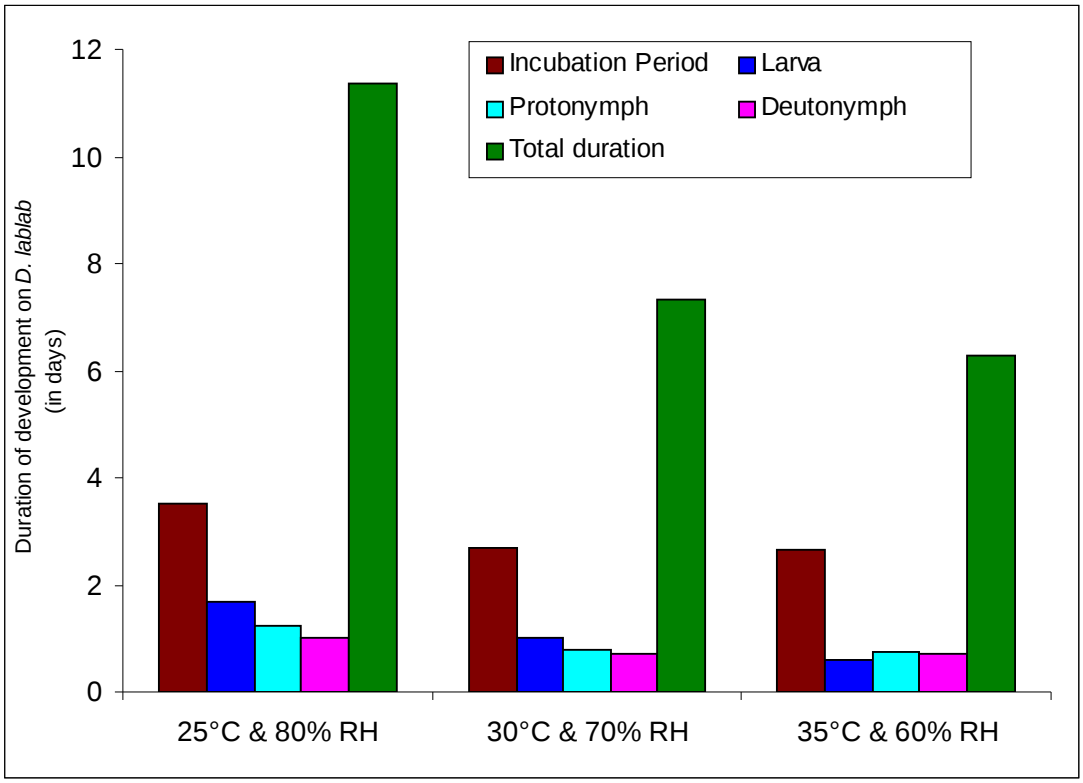


Fig. 2

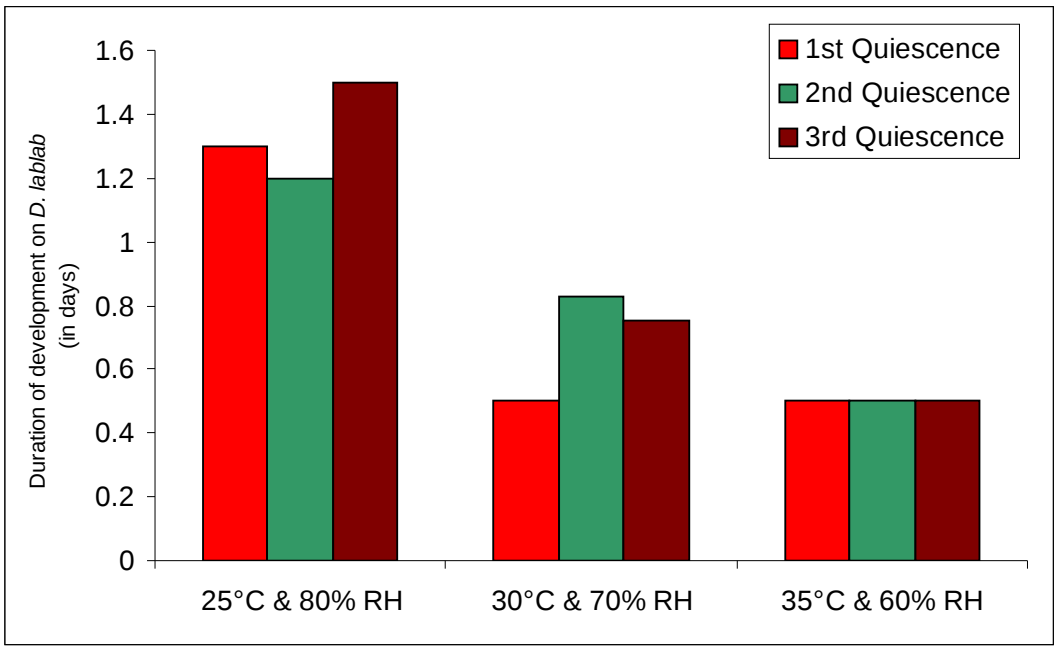


PLATE XXVI

Fig. 1. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *T. cinnabarinus* on *C. papaya*

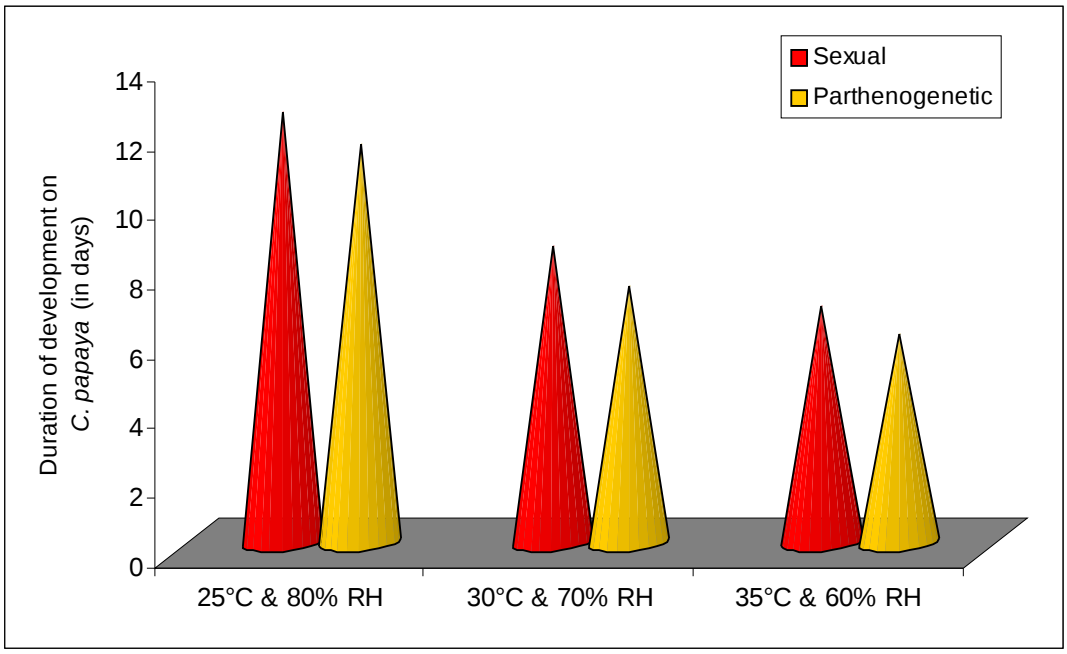


Fig. 2. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *T. cinnabarinus* on *D. lablab*

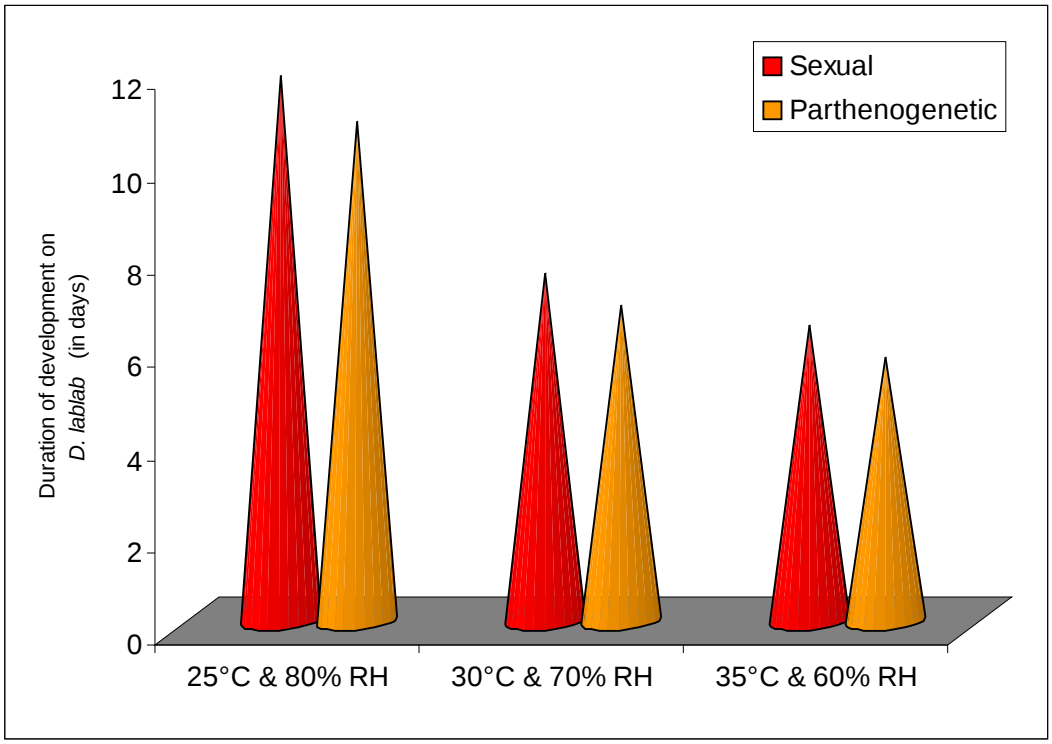


PLATE XXX

Fig. 1. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *E. orientalis*

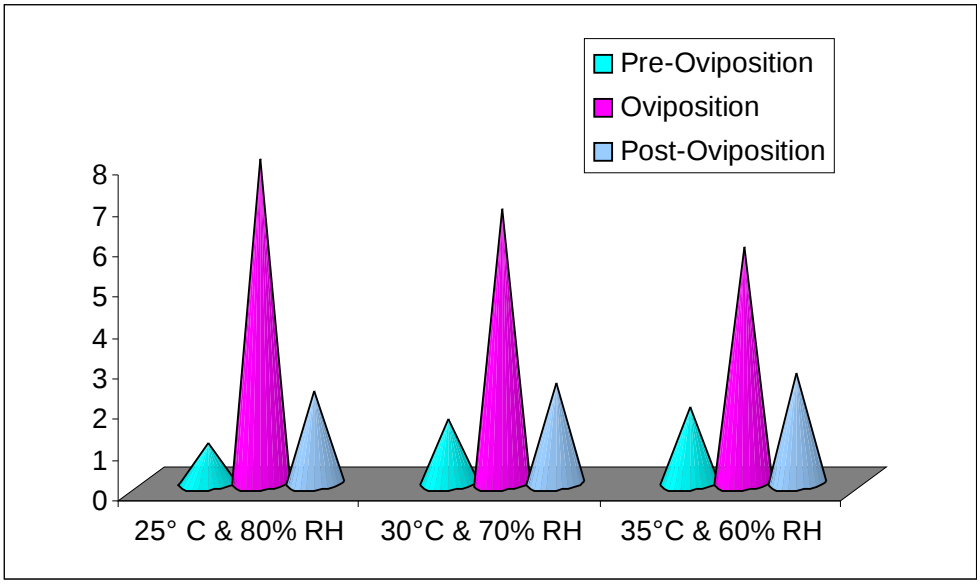


Fig. 2. Influence of varying temperature-humidity conditions on fecundity of *E. orientalis*

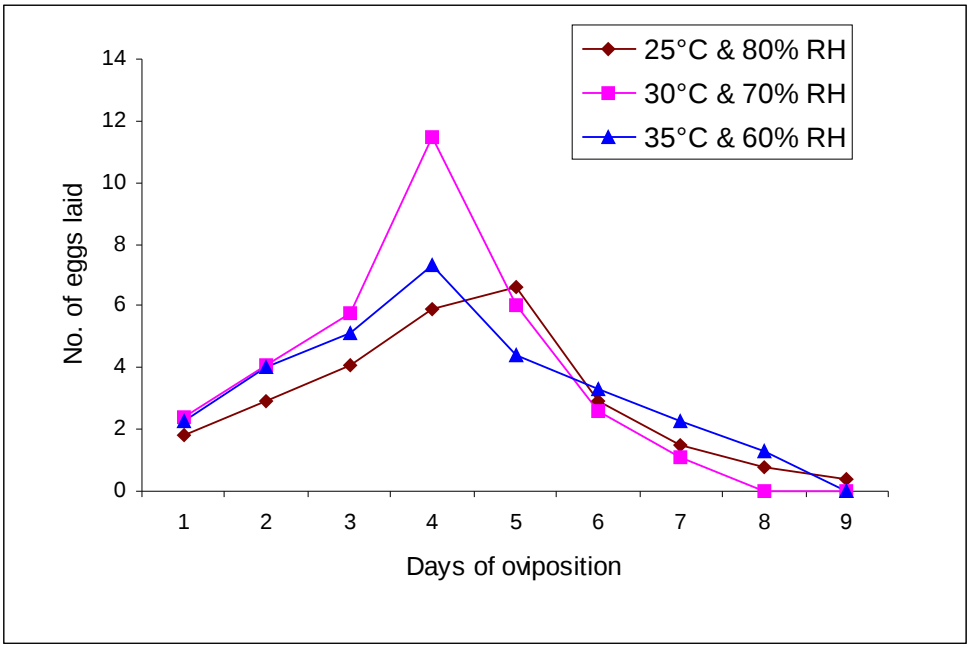


PLATE XXXI

Fig. 1. Duration of development of life stages of *E. orientalis* at 25 ± 2ºC & 80 ± 5% RH on *M. oleifera*

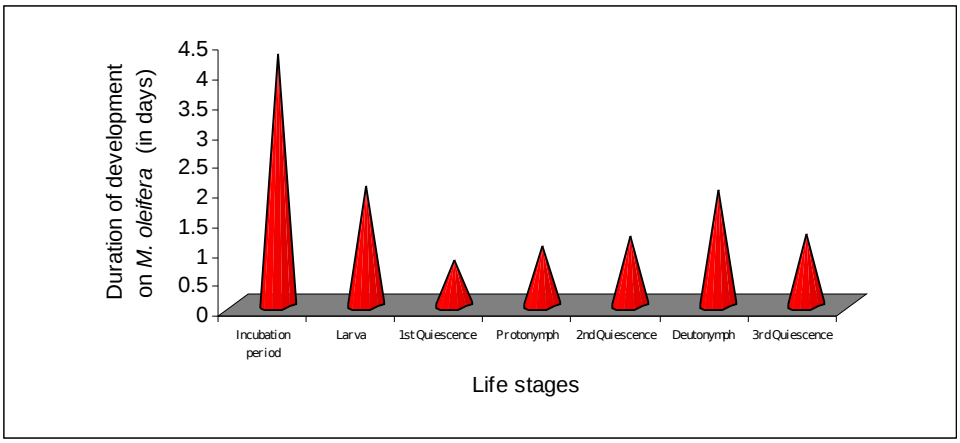


Fig. 2. Duration of development of life stages of *E. orientalis* at 30 ± 2ºC & 70 ± 5% RH on *M. oleifera*

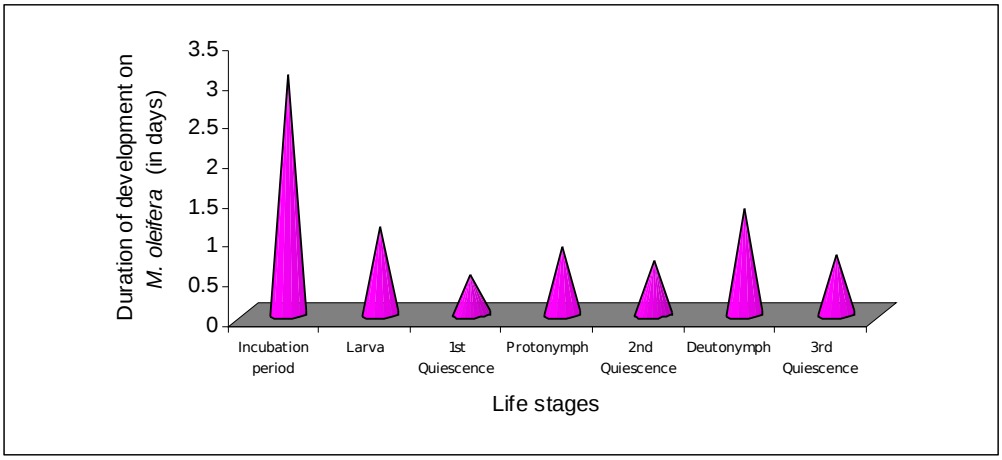


Fig. 3. Duration of development of life stages of *E. orientalis* at 35 ± 2ºC & 60 ± 5% RH on *M. oleifera*

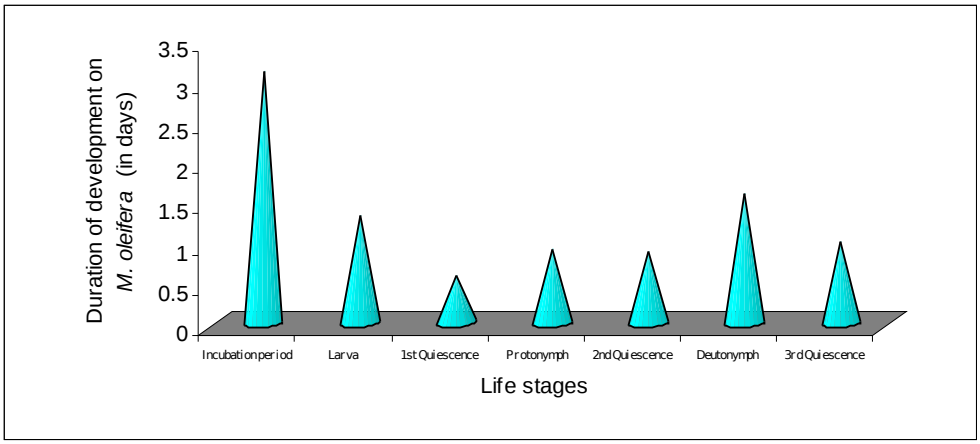


PLATE XXXII

Fig. 1. Comparative histogram showing duration of life stages under different temperature-humidity conditions

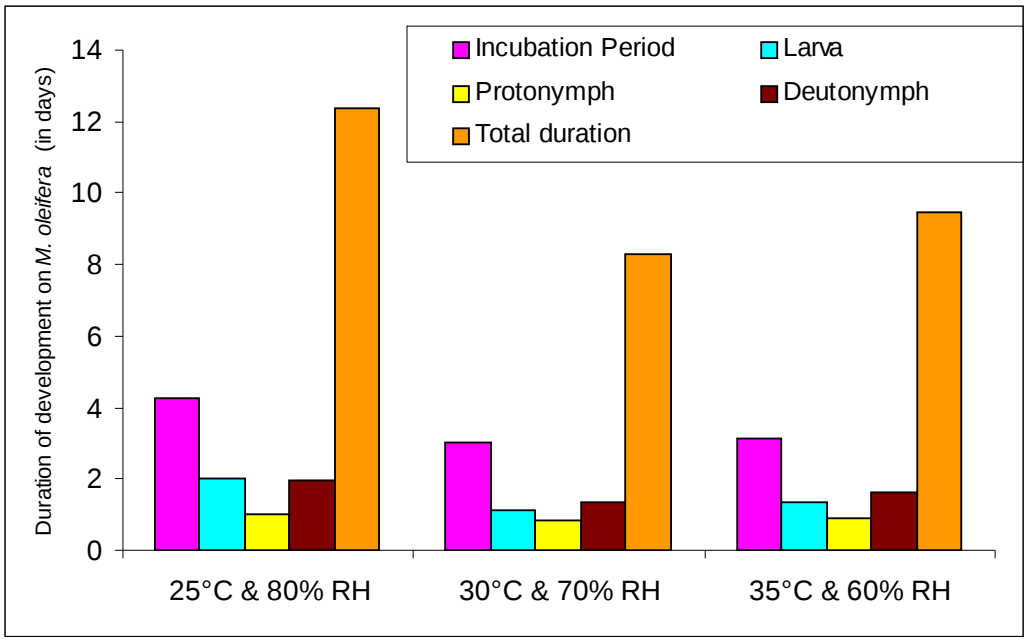


Fig. 2

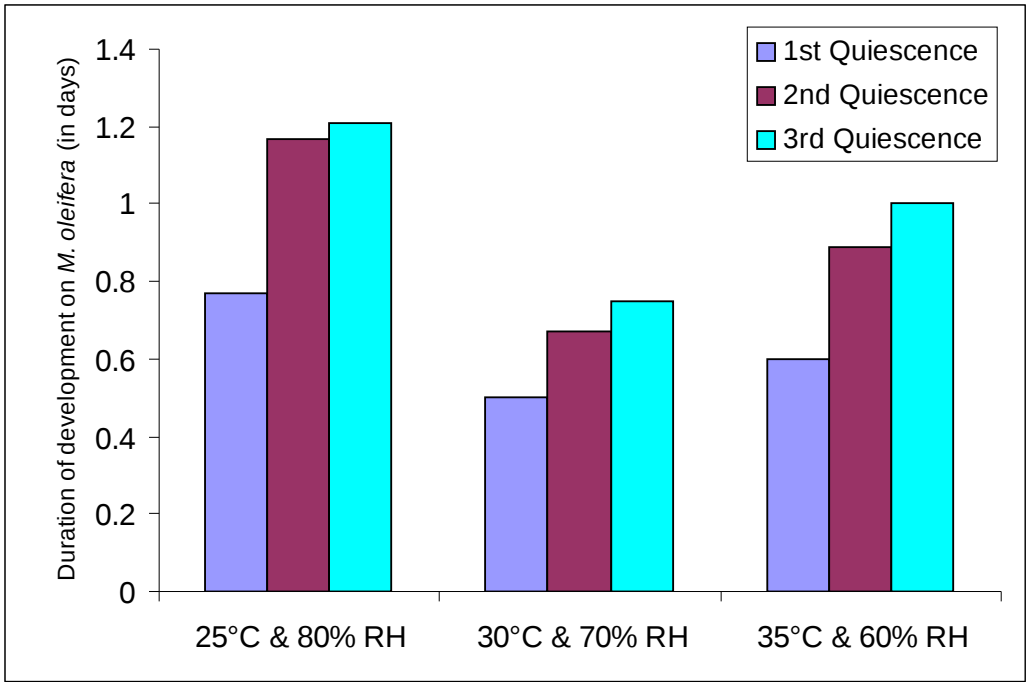


PLATE XXXIII

Fig. 1. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *E. orientalis* on *M. oleifera*

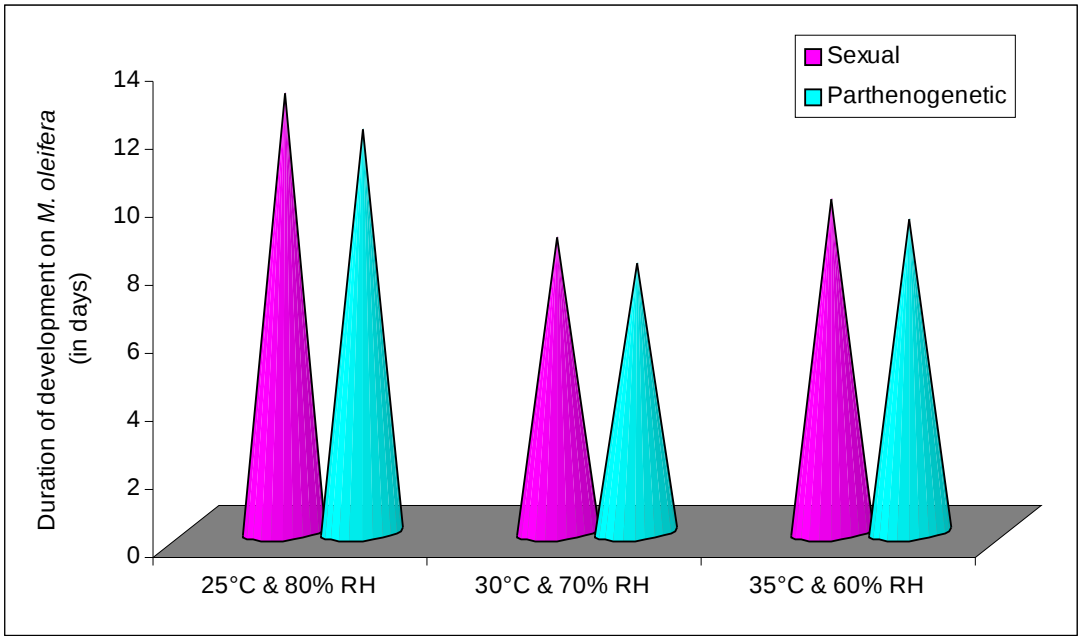


PLATE XXXVII

Fig. 1. Impact of varying temperature-humidity conditions on Pre-oviposition, Oviposition and Post-oviposition periods of *O. biharensis*

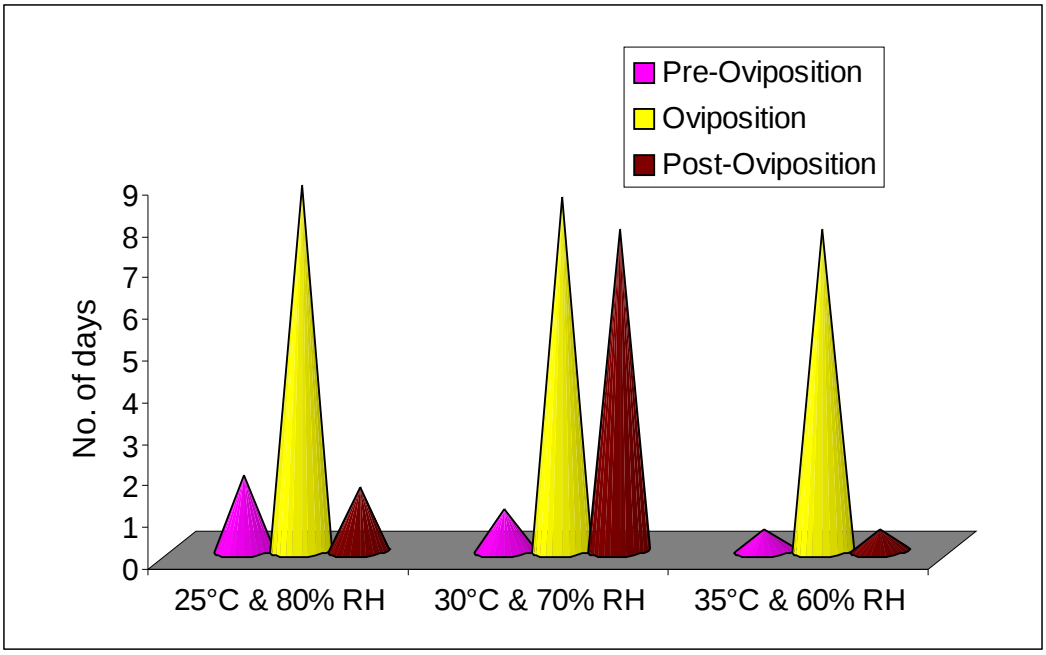


Fig. 2. Influence of varying temperature-humidity conditions on fecundity of *O. biharensis*

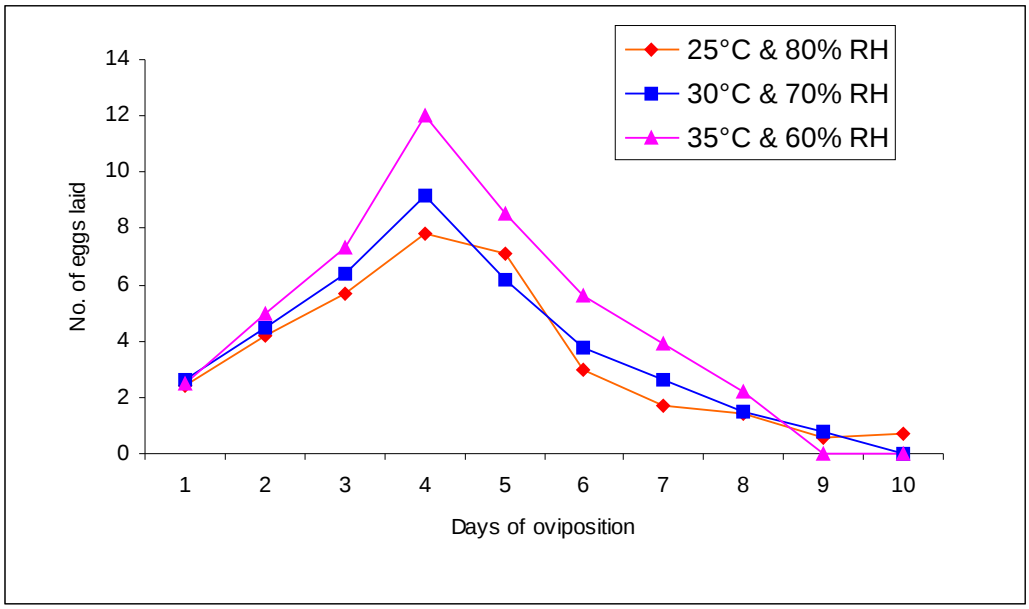


PLATE XXXVIII

Fig. 1. Duration of development of life stages of *O. biharensis* at 25 ± 2ºC & 80 ± 5% RH on *M. esculenta*

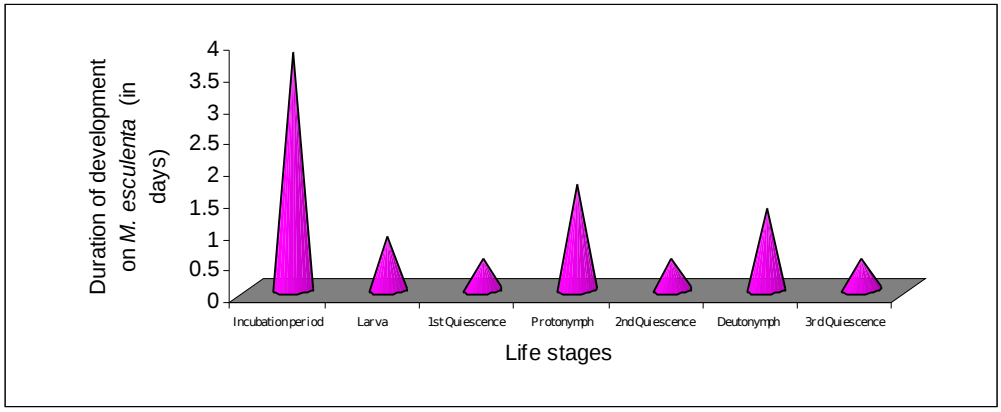


Fig. 2. Duration of development of life stages of *O. biharensis* at 30 ± 2ºC & 70 ± 5% RH on *M. esculenta*

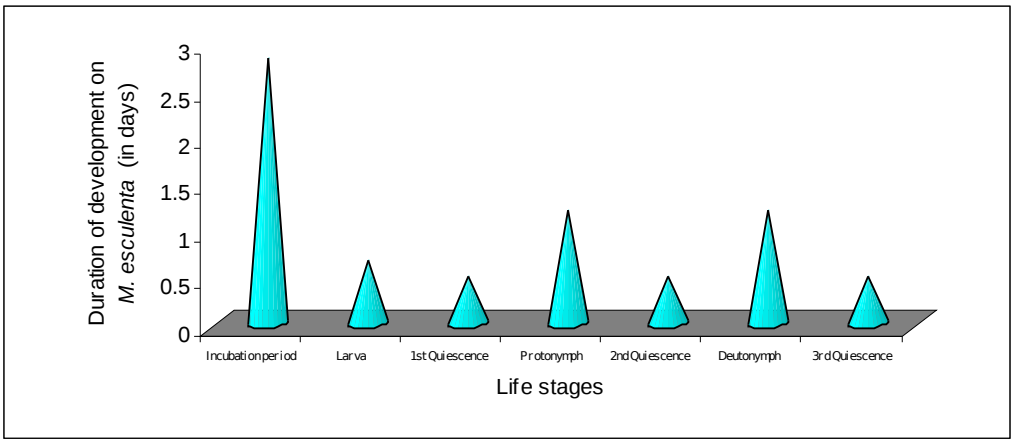


Fig. 3. Duration of development of life stages of *O. biharensis* at 35 ± 2ºC & 60 ± 5% RH on *M. esculenta*

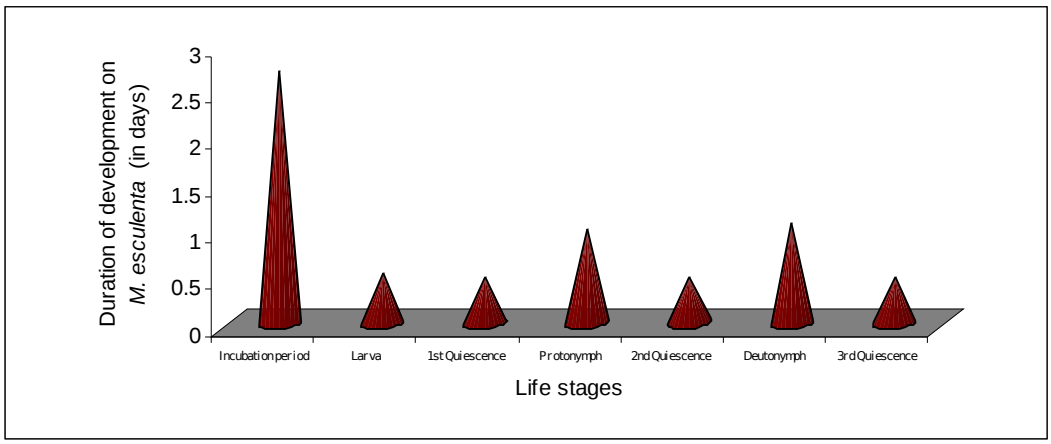


PLATE XXXIX

Fig. 1. Comparative histogram showing duration of life stages under different temperature-humidity conditions

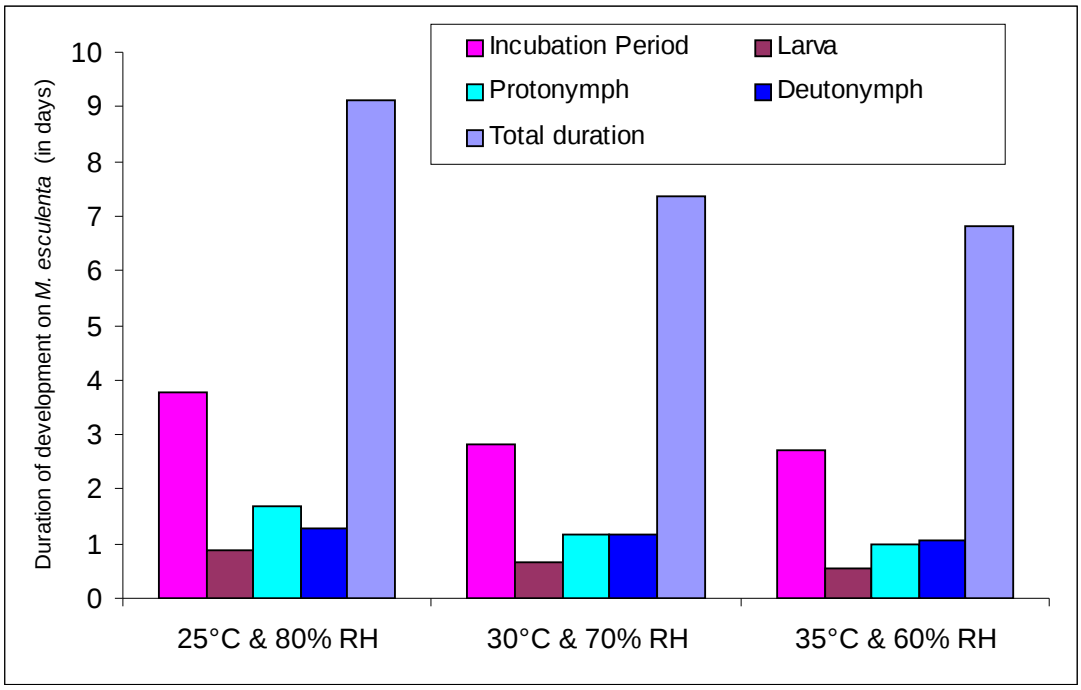


Fig. 2. Influence of varying temperature-humidity conditions on duration of sexual and parthenogenetic generations of *O. biharensis* on *M. esculenta*

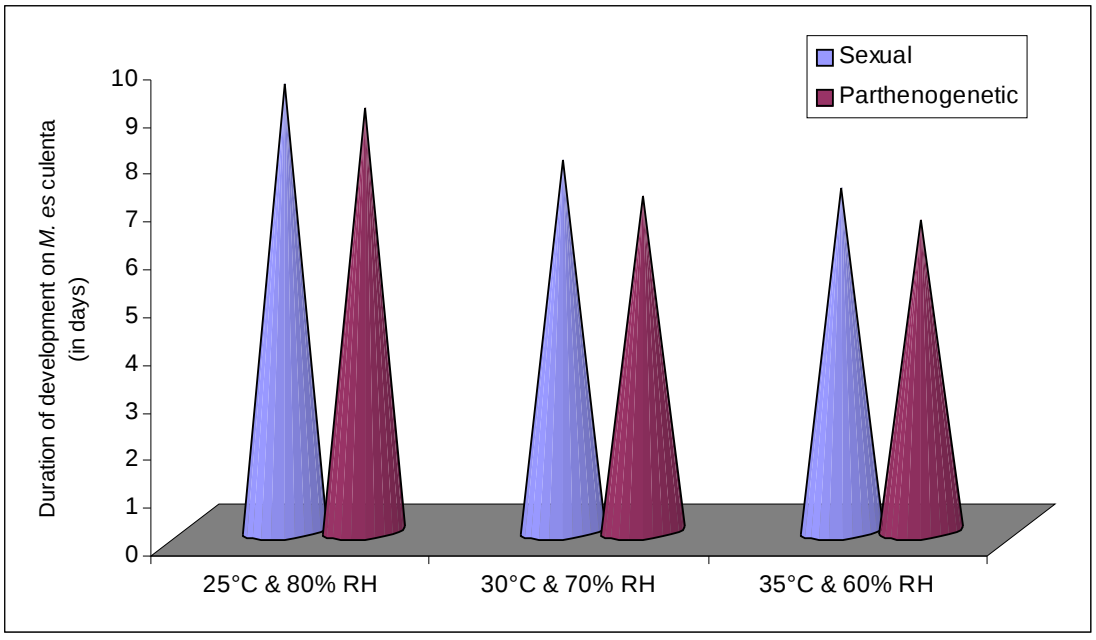


PLATE I

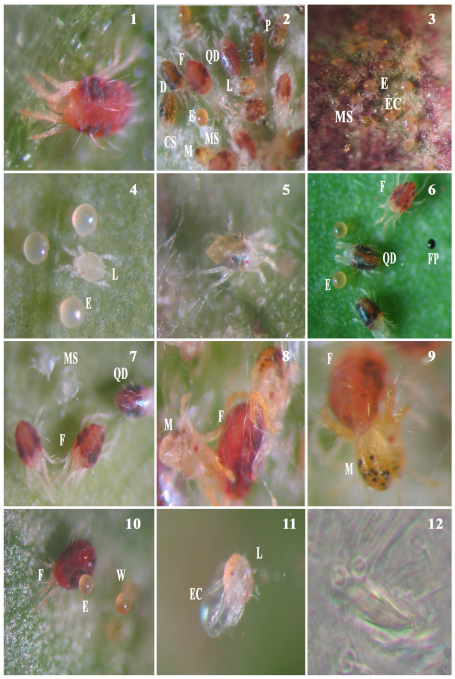


PLATE XII

PLATE XI

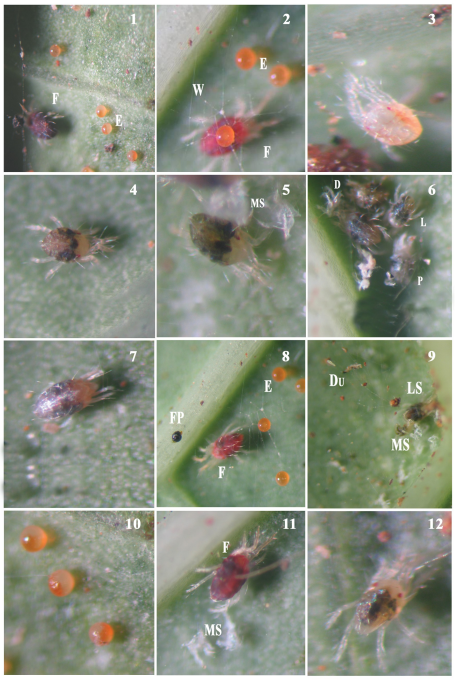
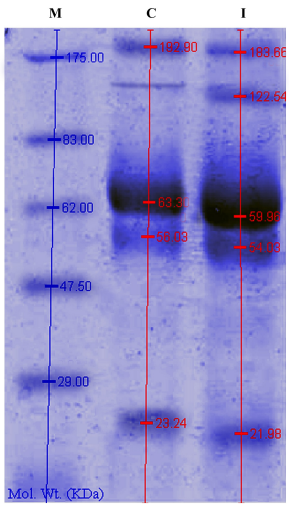


PLATE XLII

SDS PAGE Gel of *M. esculenta* leaves infested by *O.biharensis*



M- Marker C - Control I - Infested

PLATE XXIX

PLATE XLIII

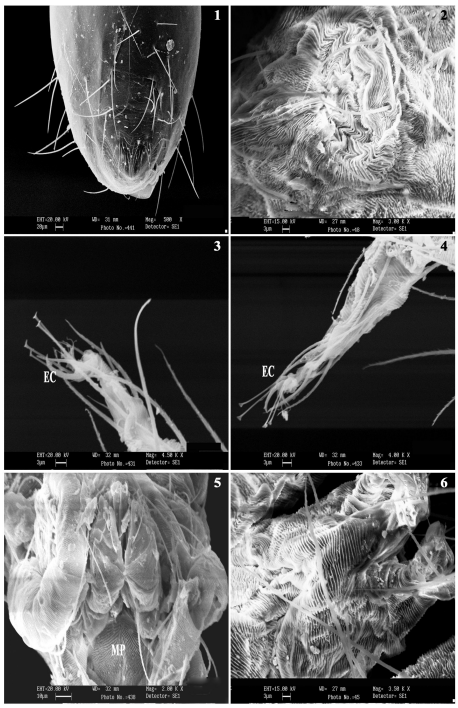


PLATE XLI

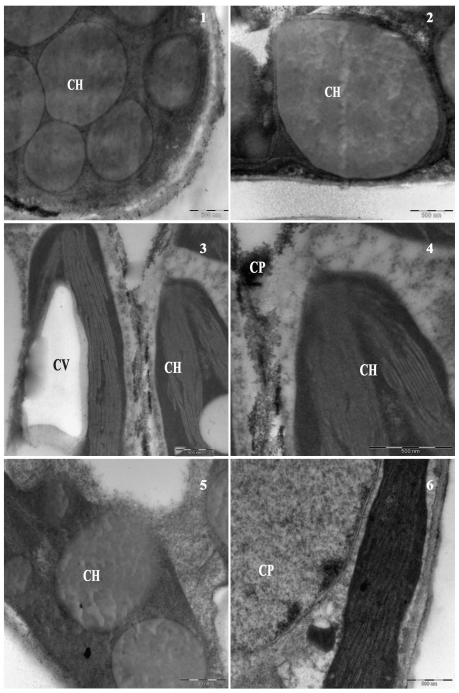


PLATE XL

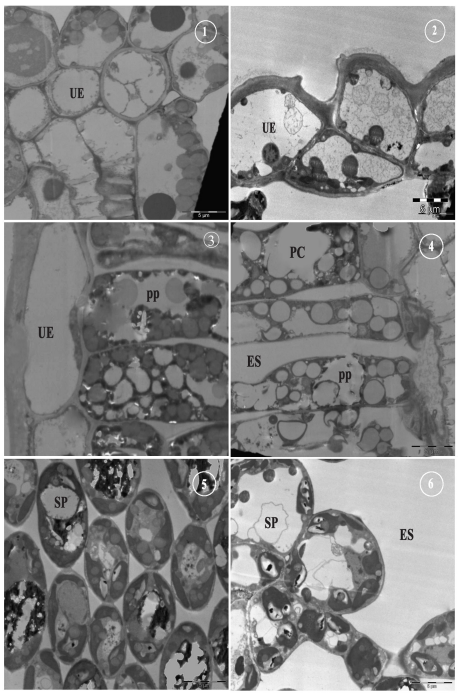


PLATE XVIII

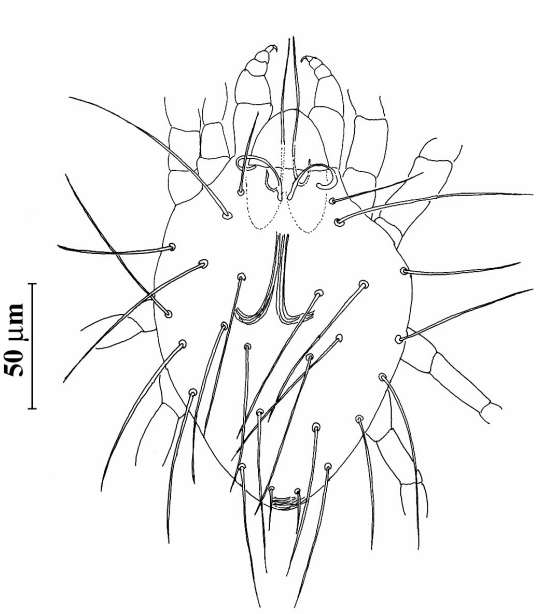


Fig. 1

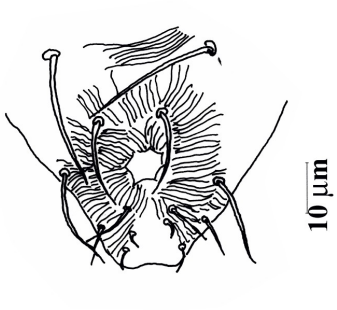


Fig. 2

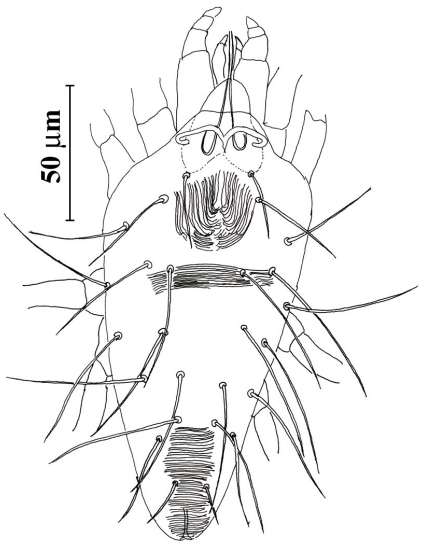


Fig. 3

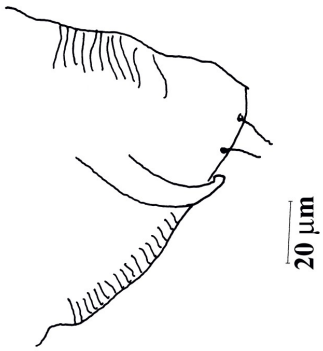


Fig. 4

PLATE IX

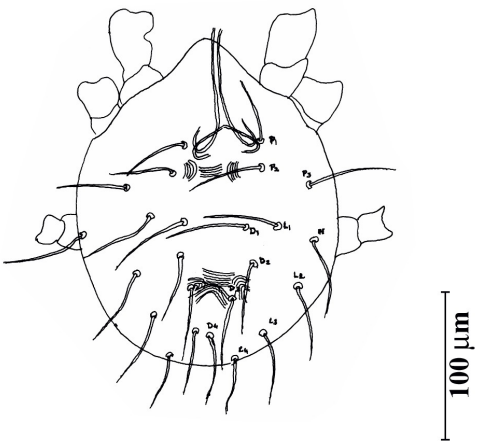


Fig. 1

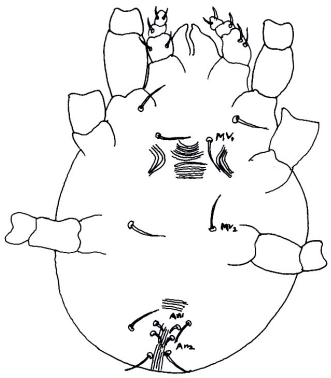


Fig. 2

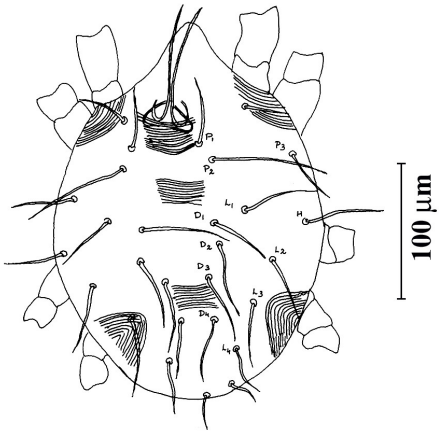


Fig. 3

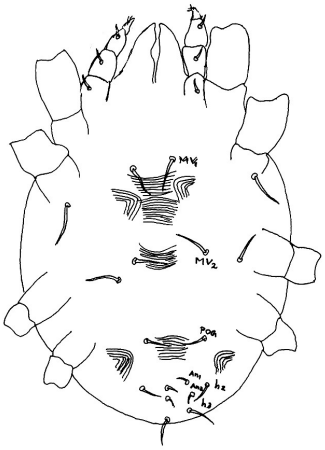


Fig. 4

PLATE X

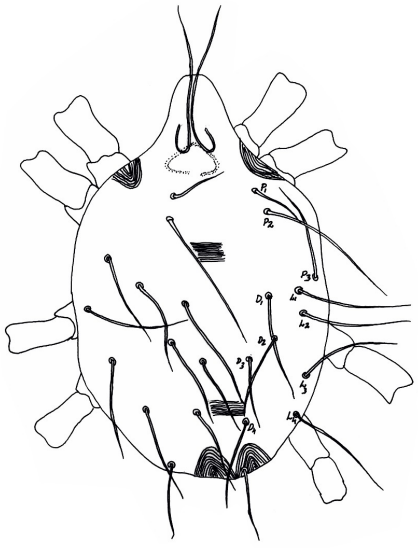


Fig. 1

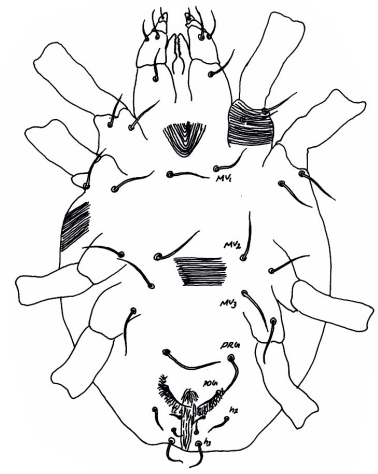


Fig. 2

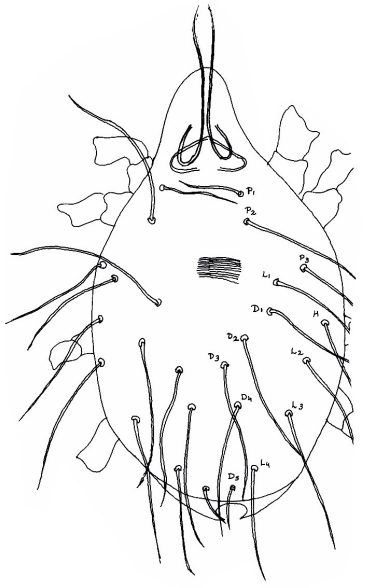


Fig. 3

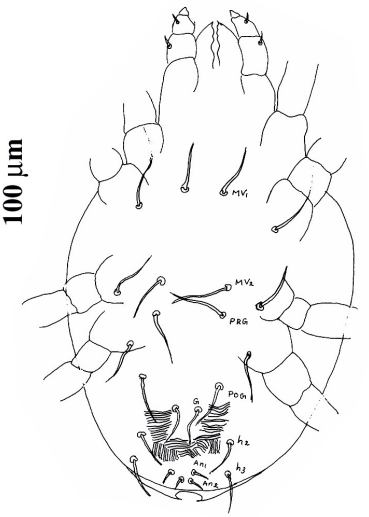


Fig. 4

PLATE XI

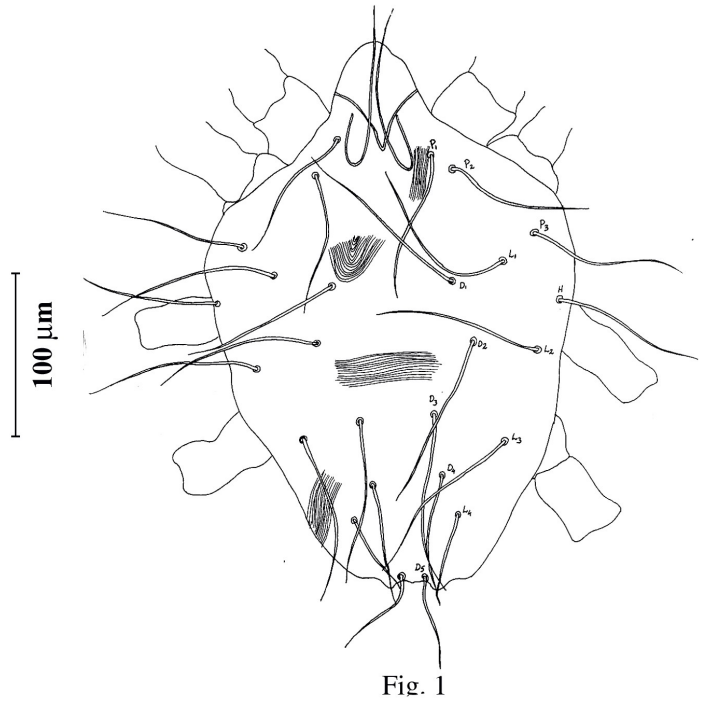


Fig. 1

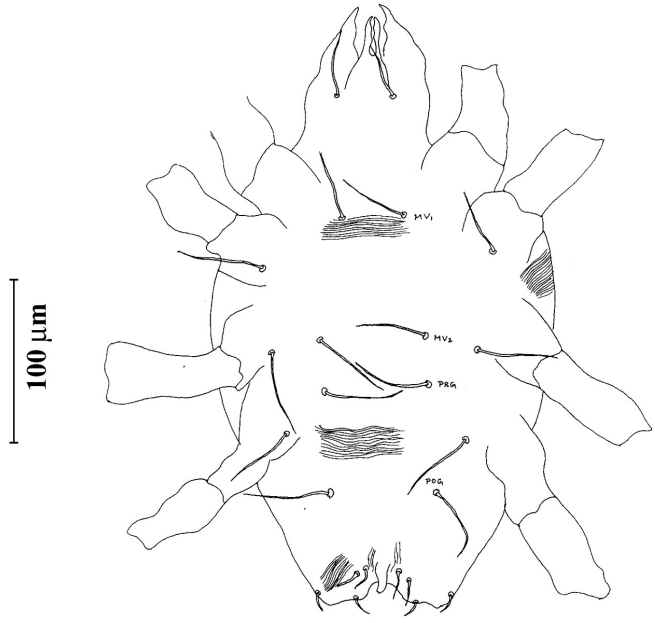
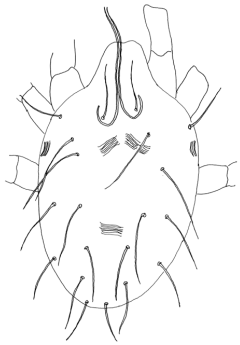


Fig. 2

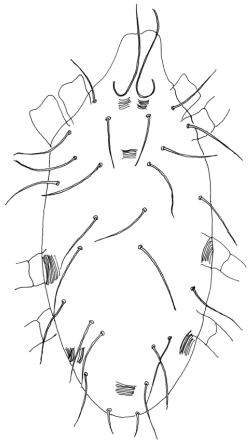
PLATE XLIV



50 µm

Fig. 1

Fig.2



50 µm

Fig. 3

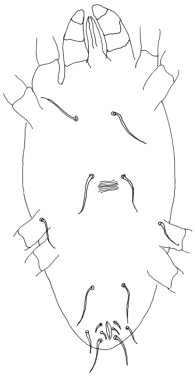
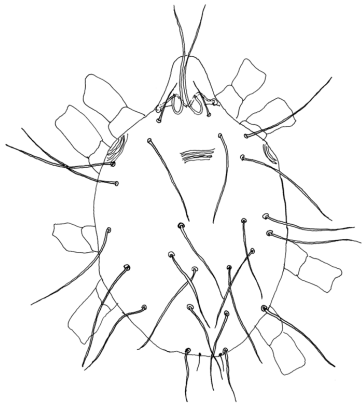


Fig. 4



100 µm

Fig. 5

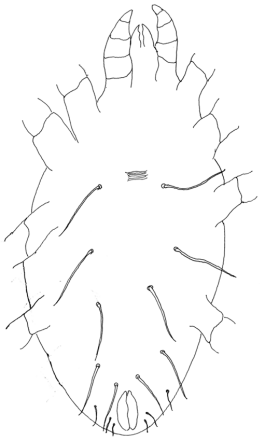


Fig. 6

PLATE XLV

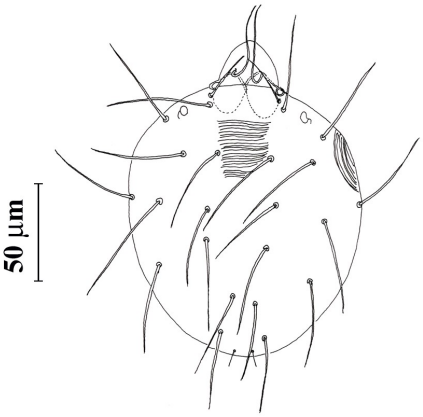


Fig. 1

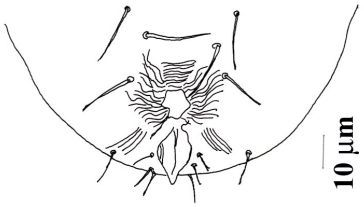


Fig. 2

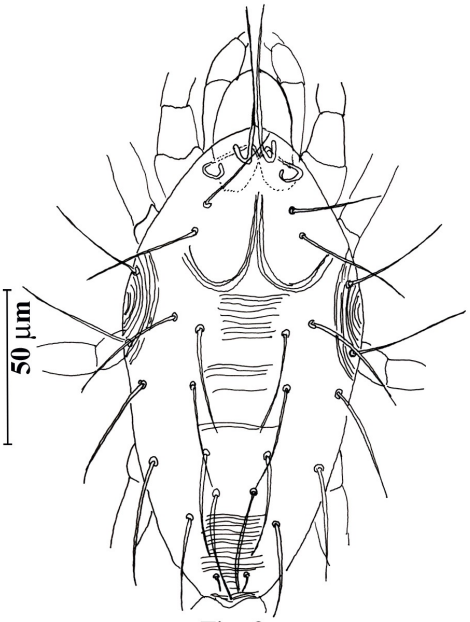


Fig. 3

Fig. 4

PLATE XVII

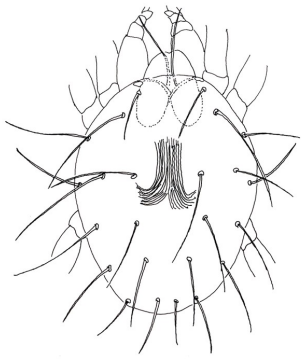


Fig. 1

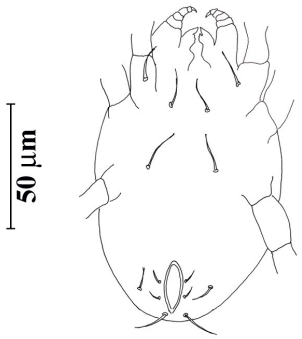


Fig. 2

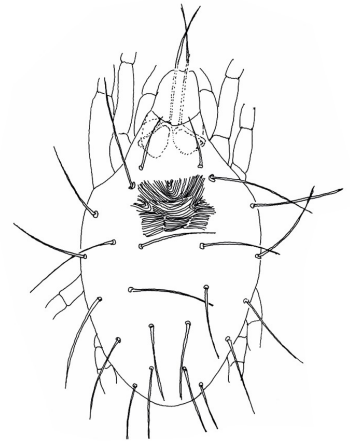


Fig. 3

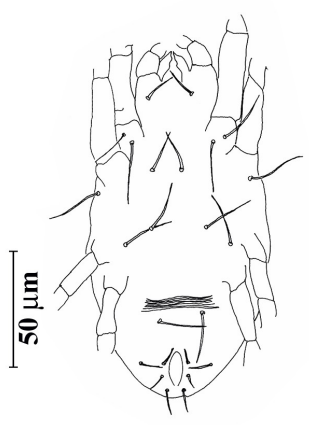


Fig. 4

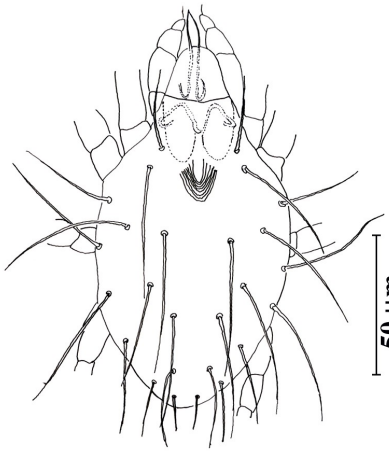


Fig. 5

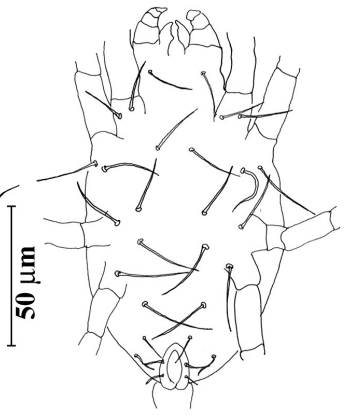
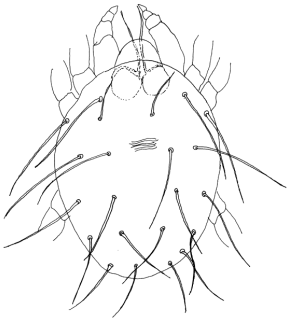


Fig. 6

PLATE XXVII



25 µm

Fig. 1

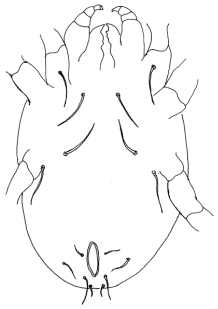
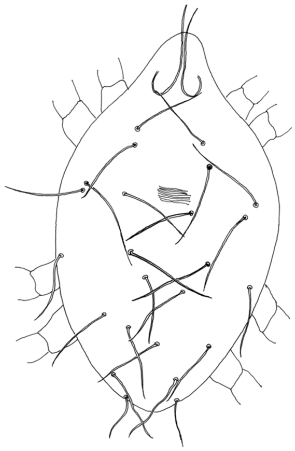


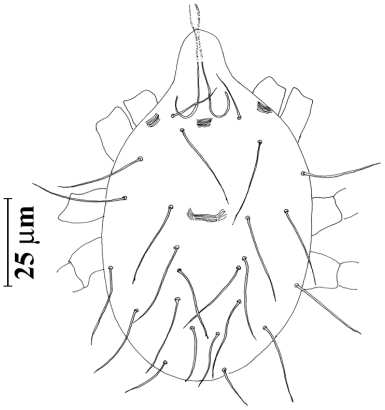
Fig.2



25 µm

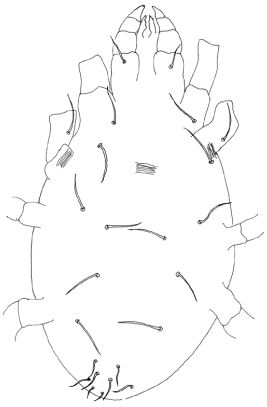
Fig.3

Fig. 3



25 µm

Fig. 5



25 µm

Fig. 6

PLATE XXXIV

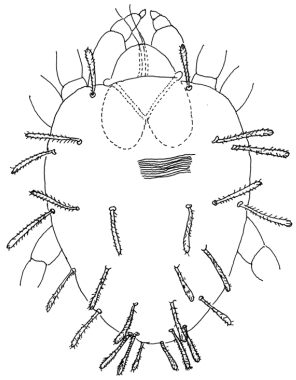


Fig. 1

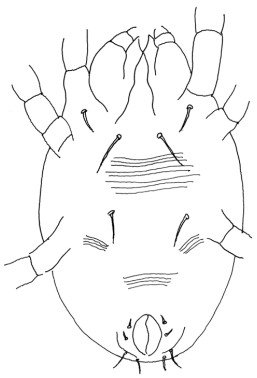


Fig.2

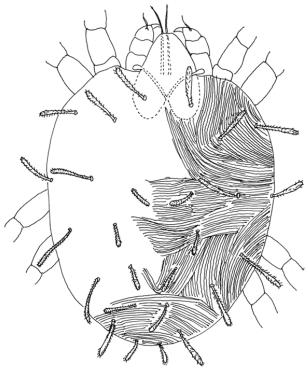


Fig. 3

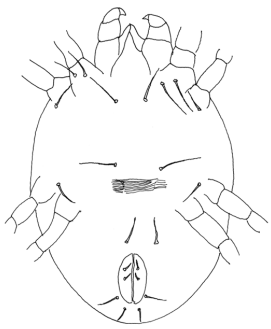


Fig. 4

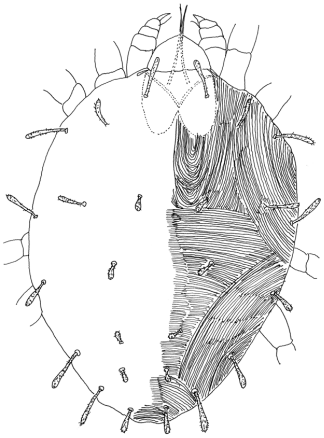


Fig. 5

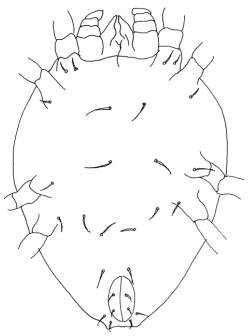


Fig. 6

PLATE XXXV

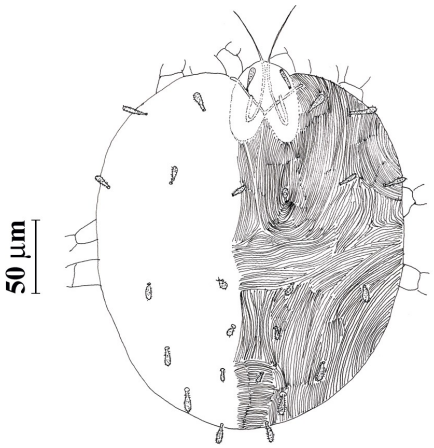


Fig. 1

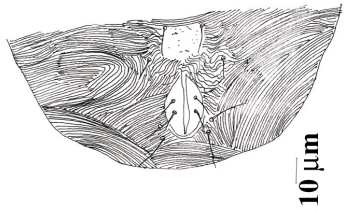


Fig. 2

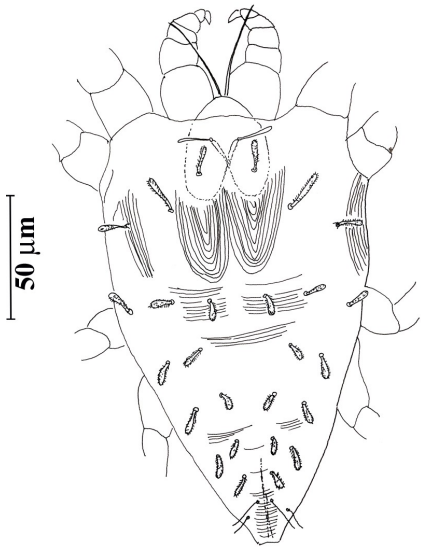


Fig. 3

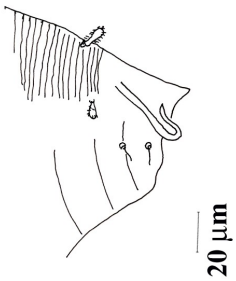
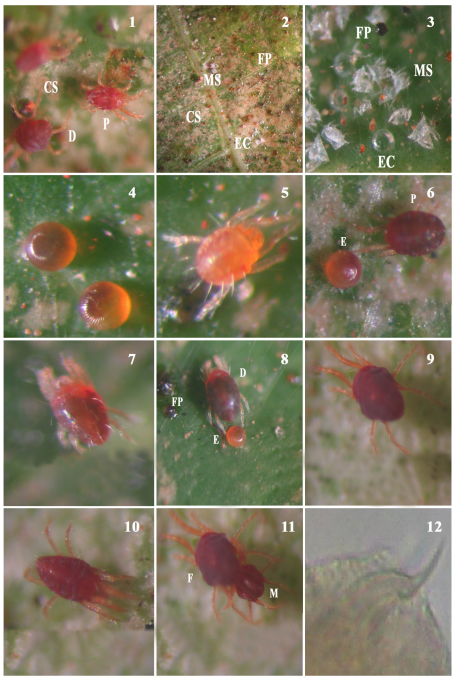


Fig. 4

PLATE XXXVI



BIOLOGICAL STUDIES OF SPIDER MITES (ACARI: TETRANYCHIDAE) INFESTING VEGETABLE CROPS

TThesis submitted in partial fulfilment
of the requirements for the award of Degree of

DOCTOR OF PHILOSOPHY IN ZOOLOGY

By

SANGEETHA G KAIMAL

DIVISION OF ACAROLOGY
DEPARTMENT OF ZOOLOGY
UNIVERSITY OF CALICUT
KERALA - INDIA

2009

PLATE XXVIII

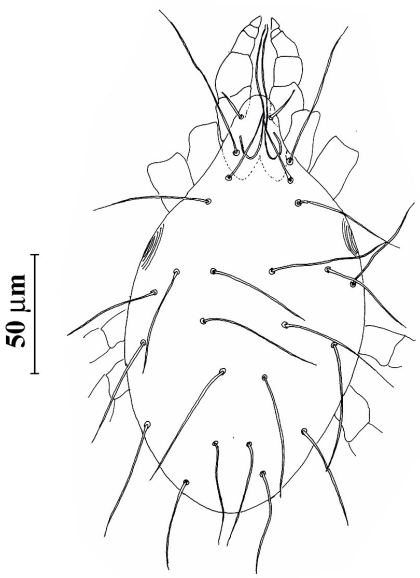


Fig. 1

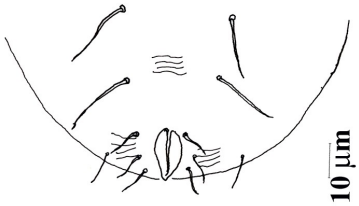


Fig. 2

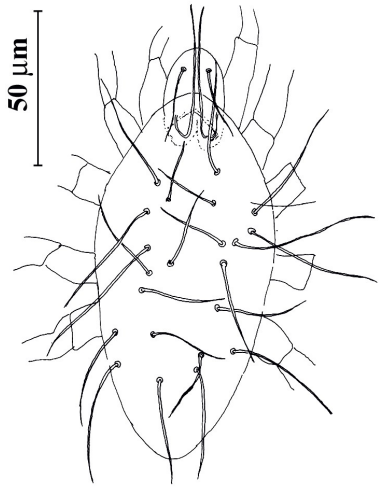


Fig. 3

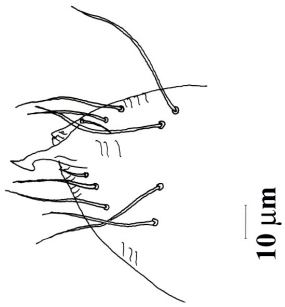


Fig. 4