

**BIO-ECOLOGY OF SOUTH AMERICAN TOMATO
LEAF MINER, *TUTA ABSOLUTA* (MEYRICK)
(LEPIDOPTERA: GELECHIIDAE)**

**DEVARAJ, A. N.
UHS14PGM503**

**DEPARTMENT OF ENTOMOLOGY
COLLEGE OF HORTICULTURE
UHS CAMPUS, GKVK, BENGALURU-560065
UNIVERSITY OF HORTICULTURAL SCIENCES
BAGALKOT-587 103
AUGUST, 2016**

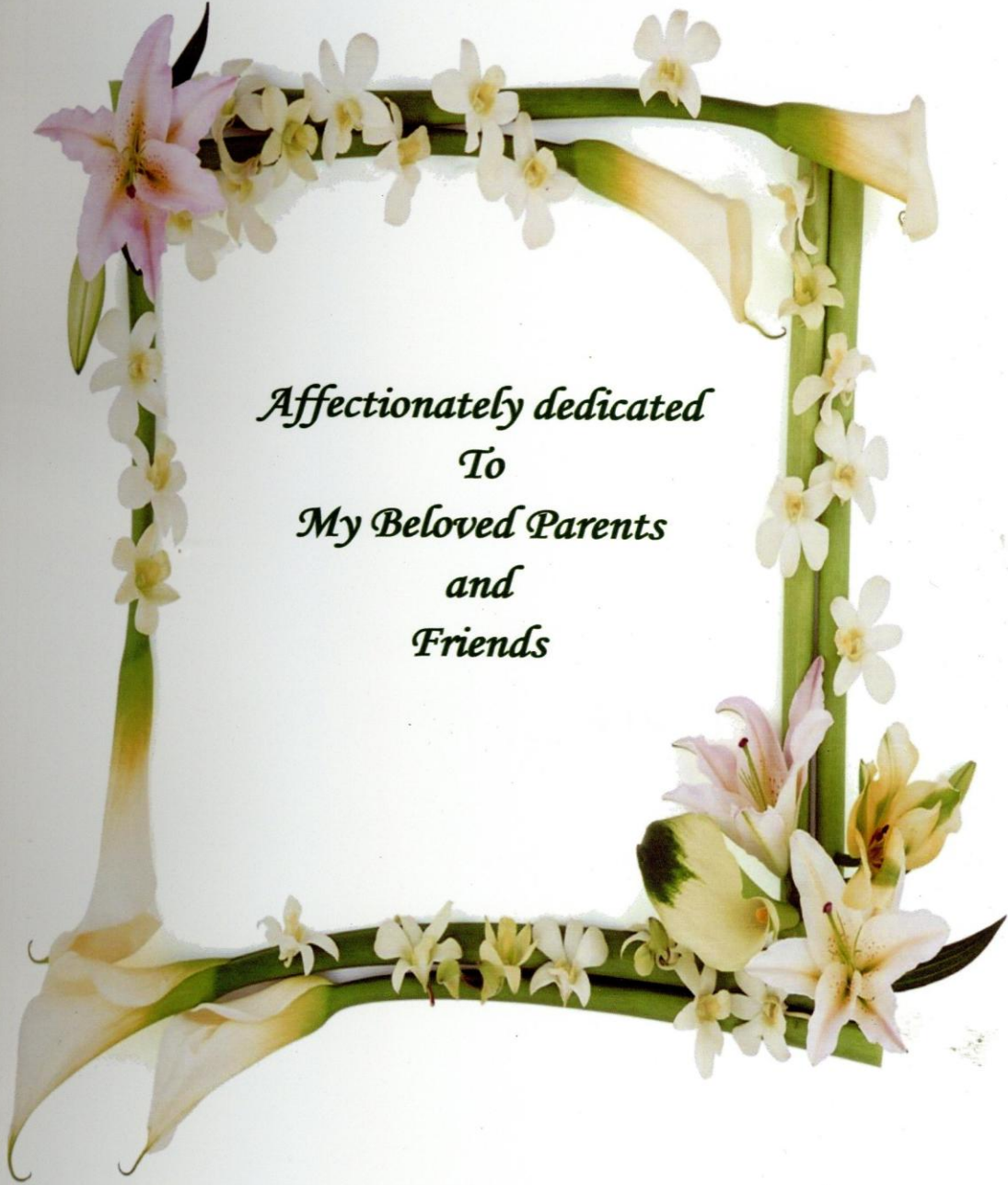
**BIO-ECOLOGY OF SOUTH AMERICAN TOMATO
LEAF MINER, *TUTA ABSOLUTA* (MEYRICK)
(LEPIDOPTERA: GELECHIIDAE)**

*Thesis submitted to the
University of Horticultural Sciences, Bagalkot
In partial fulfillment of the requirements for the award of
the Degree of*

MASTER OF SCIENCE (Horticulture)
In
ENTOMOLOGY

By
DEVARAJ, A. N.

**DEPARTMENT OF ENTOMOLOGY
COLLEGE OF HORTICULTURE
UHS CAMPUS, GKVK, BENGALURU-560065
UNIVERSITY OF HORTICULTURAL SCIENCES,
BAGALKOT-587 104
AUGUST, 2016**



*Affectionately dedicated
To
My Beloved Parents
and
Friends*

DEPARTMENT OF ENTOMOLOGY
UNIVERSITY OF HORTICULTURAL SCIENCES, BAGALKOT-587
103

CERTIFICATE

This is to certify that the thesis entitled “**Bio-ecology of South American tomato leaf miner, *Tuta absoluta* (Meyrick), (Lepidoptera: Gelechiidae)**” submitted by **Mr. DEVARAJ, A. N., ID No. UHS14PGM503** in partial fulfillment of the requirements for the award of degree **MASTER OF SCIENCE (Horticulture)** in **ENTOMOLOGY** to the University of Horticultural Sciences, Bagalkot, is a record of *bonafide* research work done by him during the period of his study in this university under my guidance and supervision and no part of the thesis has been previously submitted for the award of any other degree, diploma, associateship, fellowship or any other similar titles.

Bengaluru

16.09.2016

(PRASAD KUMAR)

Major Advisor

APPROVED BY:

CHAIRMAN: _____

(PRASAD KUMAR)

MEMBERS:1. _____

(G. K. RAMEGOWDA)

2. _____

(M. ANJANAPPA)

3. _____

(N. ASHWATHANARAYANA REDDY)

4. _____

(C. G. SANGEETHA)

ACKNOWLEDGEMENT

The completion of this thesis was made possible by the valuable assistance I received from many people. It is with pleasure that I acknowledge the efforts of the many people who have contributed to the development of this thesis.

*Indeed the words at my command are not adequate to convey the depth of my feeling and gratitude to my Major Advisor and Chairman of Advisory Committee, **Dr. Prasad Kumar**, Professor and Head, Department of Entomology, College of Horticulture, Mysuru for his most valuable and inspiring guidance with his friendly nature, love and affection and magnanimous attitude right from the day, constant encouragement, enormous help and constructive criticism throughout the course of this investigation and preparation of this manuscript. His unflinching courage and conviction will always inspire me and I hope to continue to work with his noble thoughts.*

*I am extremely thankful and my sincere gratitude to the members of my Advisory committee **Dr. G. K. Ramegowda**, Assistant professor of Entomology RHREC, Bengaluru, **Dr. M. Anjanappa**, Professor, Department of Vegetable Science, **Dr. Sangeetha, C. G.**, Assistant Professor, Department of Plant Pathology, College of Horticulture, Bengaluru and **Dr. N. Ashwathanarayana Reddy**, Assistant Professor of Entomology, HREC, Hogalagere for their valuable help, suggestions, genuine cooperation and constant encouragement provided at every stage of the thesis preparation.*

*I am humbly offer my sincere thanks my department head **Dr. J. Jayappa**, Assistant professor and Head, Department of Entomology, College of Horticulture, Bengaluru, for his help and co-operation extended to me during the course of my study. I'm very thankful to **Dr. V. Devappa**, Professor and Head, Department of Plant Pathology, College of Horticulture, Bengaluru for his kind co-operation in helping for my research. I'm very grateful to **Dr. Ankitha Gupta**, Principal Scientist, NBAIR, Bengaluru for her quick and immediate response in identifying the natural enemies.*

*I thank **Dr. G. K. Ramegowda**, **Dr. N. Ashwathanarayana Reddy** and **Dr. J. Jayappa**, for their good guidance since from beginning of my course work and research work and for their valuable suggestions and constant encouragement, help and extravagant*

support to reach this valuable goal. And I thank **Mr. K. Tulsiram**, PC, KVK, Kolar for his help in completing the course.

I thank **Dr. K. Umesha**, Dean, College of horticulture, UHS Campus, GKVK, Bengaluru, for his kind help during my course of study.

I am thankful to the all non-teaching staff members of the College of Horticulture, UHS Campus, GKVK, Bengaluru for their valuable guidance and moral support during my stay in this dept.

I am gratefully indebted to my parents **Mr. Nagaraju, B. M., & Mrs. Nagarathna, H. R.** for their affection, words of encouragement, boundless love, unflagging inspiration, interest and selfless sacrifice. I owe all my success to them. I express my heartfelt love and affection from the inner core of heart to my friendly brother **Mr. Vinay Kumar, A. N.** and lovely sister **Mrs. Prema, A. N.** belovved brother in law **Mr. Shashi Kumar, H. C.** and to my cute nephew **Mr. Shashank, H. S.** for their constant encouragement moral support whose love and affection have no equivalent and as an everlasting source of inspiration to me.

It is my pleasure to extend my sincere thanks to my dear friends **Rajesh, D., Naveena, N. E., Nithin Kumar, V. C., Hari Kishor, Karan, Kumar, Puly Sir, Chimpu, Paani, Anila, Bhatta, Athigere, Sampath, Chethu, Shobith, Pyari, Kothma, Sangamesh, Praful, Bangi, Mahaveer, Pavan, PC Sir, Roopini and others** who's timely support, help, suggestions and co-operation during my research helped me a lot in bringing out this manuscript.

My sincere thanks are also to those who helped me directly or indirectly during my work that I couldn't include individually.

In case of any omission or deletion does not mean lack of gratitude.

Bengaluru

September, 2016

(**Devaraj, A. N.**)

**BIO-ECOLOGY OF SOUTH AMERICAN TOMATO LEAF MINER, *TUTA ABSOLUTA*
(MEYRICK) (LEPIDOPTERA: GELECHIIDAE)**

DEVARAJ, A. N.

ABSTRACT

Investigations on Bio-ecology of South American tomato leaf miner, *Tuta absoluta* (Meyrick) was undertaken at Department of Entomology, College of Horticulture, Bengaluru by focussing on field surveys, seasonal incidence, natural enemies, collateral hosts and laboratory biology.

Surveys carried in four districts of Southern Karnataka viz., Bengaluru Rural, Chikkaballapura, Kolar and Mysuru from July 2015 to April 2016 revealed that *T. absoluta* infestation ranged from 10.41 per cent (Yelawala) to 17.45 per cent on leaf (Chikkaballapura), and 4.74 per cent (Yelawala) to 8.76 per cent fruit damage (Shidlaghatta). With respect to seasonal pattern, infestation was low during November 2015 and maximum during February 2016. Incidence was positively influenced by maximum temperature and negatively influenced by relative humidity, wind speed and rainfall. Lowest infestation was recorded on crops with less than 30 days old. Polythene mulch (black with silver colour) has reduced the damage by *T. absoluta*. Brinjal, capsicum and *Solanum viarum* were recorded as new collateral host records in India. Two natural enemies, parasitoid, *Bracon* sp. (Hymenoptera: Braconidae) and predator, *Nesidiocoris tenuis* Reuter (Hemiptera: Miridae) were recorded as potential natural enemies.

Adult moths were active during dawn and dusk and mated four to six times in their life time. Female preferred apical portion of plant for oviposition with a mean fecundity of 153-163 eggs. Total larval period was 9.49 days and pupal period was 6.15 days during November 2015 to March 2016. Total life cycle of *T. absoluta* recorded was 32.4 days on tomato under ambient laboratory conditions.

(Devaraj, A. N.)
Date: 16.09.2016

(Prasad Kumar)
(Chairperson)

ದಕ್ಷಿಣ ಅಮೆರಿಕದ ಎಲೆ ಸುರಂಗ ಕೀಟ, ಟ್ಯೂಟ ಅಬ್ಸಲೂಟ (ಮೆರಿಕ್)
(ಲೆಪಿಡಾಪ್ಟೆರ: ಗೆಲಿಚಿಡೆ) ಜೀವಾವರಣದ ಅಧ್ಯಯನ
ದೇವರಾಜ್, ಎ. ಎನ್.

ಸಾರಾಂಶ

ದಕ್ಷಿಣ ಅಮೆರಿಕದ ಎಲೆ ಸುರಂಗ ಕೀಟ ಟ್ಯೂಟ ಅಬ್ಸಲೂಟ, ಜೀವಾವರಣದ ಸಂಶೋಧನೆಯನ್ನು ಕೀಟಶಾಸ್ತ್ರ, ವಿಭಾಗ, ತೋಟಗಾರಿಕೆ ಕಾಲೇಜು, ಬೆಂಗಳೂರಿನಲ್ಲಿ ಹಾಗೂ ದಕ್ಷಿಣ ಕರ್ನಾಟಕದ ನಾಲ್ಕು ಪ್ರಮುಖ ಟೋಮ್ಯೆಟೊ ಬೆಳೆಯುವ ಜಿಲ್ಲೆಗಳಲ್ಲಿ ಸಮೀಕ್ಷೆಯನ್ನು ಜುಲೈ 2015 ರಿಂದ ಏಪ್ರಿಲ್ 2016 ರ ತನಕ ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು. ಕೀಟದ ಮೇಲೆ ವಾತಾವರಣ ಪರಿಣಾಮ, ನೈಸರ್ಗಿಕ ಶತ್ರುಗಳು, ಆಸರೆ ಸಸ್ಯ ಹಾಗೂ ಪ್ರಯೋಗಾಲಯದಲ್ಲಿ ಜೀವನ ಚರಿತ್ರೆಯನ್ನು ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು.

ಬೆಂಗಳೂರು ಗ್ರಾಮಾಂತರ, ಚಿಕ್ಕಬಳ್ಳಾಪುರ, ಕೋಲಾರ ಮತ್ತು ಮೈಸೂರು ಜಿಲ್ಲೆಗಳಲ್ಲಿ ನಡೆಸಿದ ಸಮೀಕ್ಷೆಯ ಪ್ರಕಾರ ಎಲೆ ಸುರಂಗದ ಕೀಟವು ಎಲೆಗಳ ಮೇಲೆ ಕನಿಷ್ಠ ಶೇ. 10.41 (ಇಲವಾಲ) ಗರಿಷ್ಠ ಶೇ. 17.45 (ಚಿಕ್ಕಬಳ್ಳಾಪುರ), ಹಾಗೂ ಹಣ್ಣಿನ ಮೇಲೆ ಕನಿಷ್ಠ ಶೇ. 4.74 (ಇಲವಾಲ) ಗರಿಷ್ಠ ಶೇ. 8.76 (ಶಿಡ್ಲಘಟ್ಟ) ಹಾನಿಯನ್ನುಂಟು ಮಾಡಿರುತ್ತದೆ. ವಾತಾವರಣದ ಪರಿಣಾಮದಿಂದ ಎಲೆ ಸುರಂಗದ ಕೀಟದ ಭಾದೆಯು ನವೆಂಬರ್ 2015 ತಿಂಗಳಲ್ಲಿ ಕಡಿಮೆಯಿದ್ದು ಗರಿಷ್ಠ ಮಟ್ಟವನ್ನು ಫೆಬ್ರವರಿ ತಿಂಗಳಲ್ಲಿ ತಲುಪಿತು. ಇದರ ಹಾನಿಯ ಮೇಲೆ ತಾಪಮಾನವು ಹೆಚ್ಚಿನ ಪ್ರಭಾವವನ್ನು ಬೀರಿದ್ದು ಉಳಿದ ವಾತಾವರಣದ ಅಂಶಗಳಾದ ಸಾಪೇಕ್ಷ ಆದ್ರ್ರತೆ, ಗಾಳಿಯ ವೇಗ ಹಾಗೂ ಮಳೆಯ ಪ್ರಭಾವವು ಋಣಾತ್ಮಕವಾಗಿರುತ್ತದೆ. ಸಮೀಕ್ಷೆಯ ಪ್ರಕಾರ ಕೀಟದ ಭಾದೆಯು 30 ದಿನಗಳಿಗಿಂತ ಕೆಳಗಿನ ಬೆಳೆಗಳಲ್ಲಿ ಕಡಿಮೆ ಪ್ರಮಾಣದಲ್ಲಿ ಕಂಡು ಬಂದಿರುತ್ತದೆ ಹಾಗೂ ಕಪ್ಪು ಪಾಲಿಥೀನ್ ಹೊದಿಕೆಯು ಕೀಟದ ಭಾದೆಯನ್ನು ಕಡಿಮೆ ಮಾಡಿರುತ್ತದೆ. ಬದನೆ, ದೊಣ್ಣೆ ಮೆಣಸಿನಕಾಯಿ ಹಾಗೂ ಸುಂಡೇ ಗಿಡ (ಸೋಲಾನಂ ವಾಹಿರಂ) ಈ ಕೀಟಕ್ಕೆ ಆಸರೆ ಸಸ್ಯಗಳಾಗಿರುವುದು ಸಮೀಕ್ಷೆಗಳಿಂದ ಕಂಡು ಬಂದಿದೆ ಹಾಗೂ ಇದು ಭಾರತದ ಮೊಟ್ಟೆ ಮೊದಲ ದಾಖಲೆಯಾಗಿದೆ.

ಪತಂಗಗಳು ನಸುಕು ಮತ್ತು ಮಸುಕಿನ ಅವಧಿಯಲ್ಲಿ ಸಕ್ರಿಯವಾಗಿದ್ದು, 10 ರಿಂದ 14 ದಿನಗಳನ್ನು ಜೀವಿಸುತ್ತವೆ ಮತ್ತು ನಾಲ್ಕರಿಂದ ಆರು ಭಾರಿ ಮಿಲನ ಹೊಂದುತ್ತವೆ. ಹೆಣ್ಣು ಪತಂಗಗಳು ಮೊಟ್ಟೆಯಿಡಲು ಸಸ್ಯದ ಮೆಲ್ಬಾಗವನ್ನು ಹೆಚ್ಚಾಗಿ ಆಯ್ಕೆ ಮಾಡಿಕೊಳ್ಳುತ್ತವೆ. ಒಂದು ಹೆಣ್ಣು ಪತಂಗವು ಸುಮಾರು 153 ರಿಂದ 163 ಮೊಟ್ಟೆಗಳನ್ನು ತನ್ನ ಜೀವಾನಾಧಿಯಲ್ಲಿ ಇಡುತ್ತವೆ. ಮೊಟ್ಟೆಗಳು ಸರಾಸರಿಯಾಗಿ 4.46 ದಿನಗಳ ಕಾವಿನ ನಂತರ ಮರಿಯಾಗುತ್ತವೆ. ಮರಿಹುಳುಗಳಲ್ಲಿ ನಾಲ್ಕು ಹಂತಗಳಿದ್ದು ಸರಾಸರಿ 9.49 ದಿನಗಳಲ್ಲಿ ಮರಿ ಹುಳುವಿನ ಹಂತವನ್ನು ಮುಗಿಸಿ ಕೋಶಾವಸ್ಥೆಗೆ ಹೋಗುತ್ತದೆ. ಕೋಶವಸ್ಥೆಯು ಆರರಿಂದ ಏಂಟು ದಿನಗಳಿರುತ್ತದೆ (ಸರಾಸರಿ 6.15). ಪ್ರಯೋಗಾಲಯದಲ್ಲಿ ಇದರ ಜೀವಿತಾವಧಿಯು ಸರಾಸರಿಯಾಗಿ 32.4 ದಿನಗಳು.

(ದೇವರಾಜ್, ಎ. ಎನ್.)

(ಪ್ರಸಾದ್ ಕುಮಾರ್)

ದಿನಾಂಕ: 16.09.2016

ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು

CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	
II	REVIEW OF LITERATURE	
III	MATERIAL AND METHODS	
IV	EXPERIMENTAL RESULTS	
V	DISCUSSION	
VI	SUMMARY	
VII	REFERENCES	
	APENDICES	

LIST OF TABLES

Table No.	Title	Page No.
1	Plant species recorded as host for <i>Tuta absoluta</i>	
2	A comprehensive list of predators reported worldwide on <i>Tuta absoluta</i>	
3	A comprehensive list of parasitoids reported worldwide on <i>Tuta absoluta</i>	
4	Mean per cent leaf infestation of <i>Tuta absoluta</i> on tomato crop in ten taluks of Southern Karnataka from July 2015 to April 2016	
5	Mean per cent fruit infestation of <i>Tuta absoluta</i> on tomato crop in ten taluks of Southern Karnataka from July 2015 to April 2016	
6	Multiple regression models for leaf and fruit infestation of <i>Tuta absoluta</i> with weather parameters in four districts of Southern Karnataka during July 2015 to April 2016	
7	Influence of mulching and crop stage on leaf infestation by <i>Tuta absoluta</i> in four districts southern Karnataka during July 2015 to April 2016	
8	Influence of mulching and crop stage on fruit infestation by <i>Tuta absoluta</i> in four districts southern Karnataka during July 2015 to April 2016	
9	Developmental duration of different life stages of <i>Tuta absoluta</i> on tomato under laboratory conditions	
10	Morphometry of life stages of <i>Tuta absoluta</i> on tomato under ambient laboratory conditions	

LIST OF FIGURES

Fig. No.	Title	Between Pages
1.	Survey map for the incidence of <i>Tuta absoluta</i> in selected locations of Southern Karnataka during July 2015 to April 2016	
2.	Mean per cent leaf infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Bengaluru Rural district and (b) overall mean of Bengaluru Rural district across different months from July 2015 to April 2016	
3.	Mean per cent leaf infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Chikkaballapura districts and (b) overall mean of Chikkaballapura district across different months from July 2015 to April 2016	
4.	Mean per cent leaf infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Kolar district and (b) overall mean of Kolar district across different months from July 2015 to April 2016	
5.	Mean per cent leaf infestation of <i>Tuta absoluta</i> on tomato crop in (a) villages of Mysuru district and (b) overall mean of Kolar district across different months from July 2015 to April 2016	
6.	Mean per cent fruit infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Bengaluru Rural district and (b) overall mean of Bengaluru Rural district across different months from July 2015 to April 2016	
7.	Mean per cent fruit infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Chikkaballapura district and (b) overall mean of Chikkaballapura district across different months from July 2015 to April 2016	
8.	Mean per cent fruit infestation of <i>Tuta absoluta</i> on tomato crop in (a) taluks of Kolar district and (b) overall mean of Kolar district across different months from July 2015 to April 2016	
9.	Mean per cent fruit infestation of <i>Tuta absoluta</i> on tomato crop in (a) villages of Mysuru district and (b) overall mean of Kolar district across different months from July 2015 to April 2016	
10.	Correlation between mean per cent leaf infestation and weather parameters in Bengaluru Rural district during July 2015 to April 2016	
11.	Correlation between mean per cent fruit infestation and weather parameters in Bengaluru Rural district during July 2015 to April 2016	

Fig. No.	Title	Between Pages
12.	Correlation between mean per cent leaf infestation and weather parameters in Chikkaballapura district during July 2015 to April 2016	
13.	Correlation between mean per cent fruit infestation and weather parameters in Chikkaballapura district during July 2015 to April 2016	
14.	Correlation between mean per cent leaf infestation and weather parameters in Kolar district during July 2015 to April 2016	
15.	Correlation between mean per cent fruit infestation and weather parameters in Kolar district during July 2015 to April 2016	
16.	Correlation between mean per cent leaf infestation and weather parameters in Mysuru district during July 2015 to April 2016	
17.	Correlation between mean per cent fruit infestation and weather parameters in Mysuru district during July 2015 to April 2016	
18.	Mean developmental duration of life stages of <i>Tuta absoluta</i> on tomato plants under ambient laboratory conditions	
19.	Distribution of <i>Tuta absoluta</i> eggs within the tomato plant	
20.	Body length of <i>Tuta absoluta</i> larval instar under ambient laboratory conditions	
21.	Body width of <i>Tuta absoluta</i> larval instar under ambient laboratory conditions	
22.	Head capsule width of <i>Tuta absoluta</i> larval instar under ambient laboratory conditions	
23.	Pupation site preference of <i>Tuta absoluta</i> larva under ambient laboratory conditions	
24.	Per cent survivability of different stages of <i>Tuta absoluta</i> from egg to adult under ambient laboratory conditions	

LIST OF PLATES

Plate No.	Title	Between Page No.
1	Different crop stages visited during survey	
2	Natural enemies collection and preservation	
3	Mass culturing of <i>Tuta absoluta</i> in polyhouse	
4	Cages used in study	
5	View of plants used in study	
6	Damaging symptoms of <i>Tuta absoluta</i> larva	
7	Natural enemies recorded of <i>Tuta absoluta</i> larva	
8	Plant species recorded as collateral host for <i>Tuta absoluta</i>	
9	Different life stages of <i>Tuta absoluta</i>	
10	Different life stages of <i>Tuta absoluta</i>	

I. INTRODUCTION

Tomato, *Solanum lycopersicum* L. belongs to the family Solanaceae, is one of the most important, popular and extensively grown vegetable crops consumed as both fresh fruit and also in the form of processed products. It is native to America and now distributed all over the world. In India, it is a very popular vegetable, which is available in the market round the year. Tomato is considered as an important source of dietary antioxidants, its components such as lycopene, phenols, flavonoids and vitamin-C are responsible for the antioxidant activity. The epidemiological studies have shown that high consumption of tomato fruit is consistently correlated with a reduced risk of cancer.

Tomato was introduced to India by English traders and East India Company in 1822. In India, it occupies an area of 767.32 thousand hectares with a production of 16,384.98 MT with a productivity of 21.35 tonnes per hectare. In Karnataka, it is grown in an area of 64.25 thousand hectares with a production of 2034.37 MT and average yield is 31.66 tonnes per hectare (Anon., 2015).

There are several biotic and abiotic constraints, which limits the production of tomato. Among biotic factors, insect pests like fruit borer, whiteflies, thrips, etc. causing greater damage to tomato production and newly invaded South American leaf miner, *Tuta absoluta* (Meyrick) is also become new threat. The South American tomato leaf miner belongs to the order Lepidoptera, suborder Glossata, superfamily Gelechioidea, family Gelechiidae, subfamily Gelechiinae and tribe Gnorimoschemini. It is commonly called as tomato pinworm or South American tomato leaf miner (SATLM).

Tuta absoluta is one of the most devastating pests of tomato in South America (Miranda *et al.*, 1998). This pest was initially reported in eastern Spain in late 2006 (Urbaneja *et al.*, 2007) and has subsequently spread throughout the Mediterranean Basin and Europe (Potting *et al.*, 2009). Since the time of its initial detection, the pest has caused serious damage to tomato in invaded areas (Germain *et al.*, 2009) and it is currently considered a key horticultural threat to Europe and North Africa. This pest spreads rapidly and its status in the world has completely changed within few years from a South American tomato pest to a major threat to world tomato production (Desneux *et al.*, 2010).

It is worth noting that the type specimen for *T. absoluta* was collected from the Andean region of Peru at an altitude of 10,650 feet (3,246 m) by Meyrick in 1917. It was estimated that, based on the current speed of spread in the mainland of Afro-Eurasian regions, *T. absoluta* may invade Iran during 2011–2012, India in 2013–2014, China in 2015–2016 and the pest would expected to reach the Pacific Coast around 2016–2017. This would mainly depends on measures that, the Indian and Chinese governments would take to slow down the spread in these countries (Desneux *et al.*, 2011). Actually it invaded Iraq in 2010 (Rassoul, 2014) and India in 2014 (Sridhar *et al.*, 2014), which is practically true for the estimate of Desneux *et al.* (2011).

This pest also attacks crop plants belongs to family Solanaceae namely potato, *Solanum tuberosum* (L.); eggplant, *Solanum melongena* (L.); bell pepper, *Capsicum annuum* (L.) and many solanaceous weeds like *Datura stramonium* (L.), *Lycium chilense* (L.), *Solanum nigrum* (L.) and *Nicotiana glauca* (L.) in Bulgaria (Harizanova *et al.*, 2009). Alfalfa (*Medicago sativa* L.) also serves as a host plant for *T. absoluta* in Iraq (Rassoul, 2014). It lays eggs on all above ground portions of the plant (leaves, shoots, flowers) including fruit. Tomato leaf miner is able to complete its development (from egg to adult stage) on *S. tuberosum*, *S. melongena*, *Solanum gracilius* (L.), *Solanum bonariense* (L.) and *Solanum sisymbriifolium* (L.), but development was interrupted (at larval instars I and II) on *Nicotiana tabacum* (L.) and *Solanum pseudo-capsicum* (L.).

In India, *T. absoluta* found mainly on tomato, which attacks leaves, buds, stems, and fruits. The larvae feed vigorously upon plant producing blotch like galleries in leaves. In Bengaluru North taluk, the incidence ranged from 0.08-14.08 larval mines per plant with up to 87 per cent infested plants and it is capable of causing a yield loss up to 100 per cent (Sridhar *et al.*, 2014).

Tuta absoluta is a multivoltine non-diapausing species with a high potential of population growth (Pereyra and Sanchez, 2006) and can complete a variable number of generations per year depending on

climatic conditions and quality of available hosts. Multivoltinism leads in the severe damage to crop since the tomato is grown throughout the year in Karnataka.

However, pesticides are only partially successful because of the general endophytic behaviour of the larval instars and rapid selection of resistant populations (Liotti *et al.*, 2005; Silva *et al.*, 2011). Occurrence of *T. absoluta* at increasing population levels led growers to extensively use insecticides, which could cause many ill-effects on natural enemies in tomato ecosystem (Desneux *et al.*, 2007; Biondi *et al.*, 2012). Several eco-sustainable control methods and integrated pest management (IPM) programs have been recently evaluated (Carrera and Morton, 2010; Molla *et al.*, 2011; Zappala *et al.*, 2012). In the IPM framework, a key role could be played by biological control agents (Desneux *et al.*, 2010).

Duration of the life cycle depends on environmental conditions, in particular the temperature, ranging from 76.3 days at 14°C to 23.8 days at 27°C (Barrientos *et al.*, 1998). Also there may be overlap generations and all the stages of the life cycle are found in field conditions (Souza and Reis, 1992). Temperature variations directly influence the development rate of insects and indirectly influence their development through effects of the host plant and plant quality as food resource (Baldwin, 2007).

Tuta absoluta is a new invasive pest that caused severe damages in Karnataka and Karnataka is one of the major tomato growing states of the country. Keeping all this background information, the present study was initiated to understand biology, ecology and behaviour of *Tuta absoluta* to serve as a base for designing effective management strategies with the following objectives.

1. Survey for the incidence of South American tomato leaf miner, *Tuta absoluta* in major tomato growing regions of Bengaluru rural, Kolar, Chikkaballapura and Mysuru districts.
2. Documentation of natural enemies and collateral hosts of South American tomato leaf miner, *Tuta absoluta*.
3. To study biology of South American tomato leaf miner, *Tuta absoluta* on tomato under ambient laboratory conditions.

II. REVIEW OF LITERATURE

Extensive survey was made to gather the available literature on *Tuta absoluta* (Meyrick) from various public domains and is compiled to suit the objectives of study and presented with following headings.

2.1 History of South American tomato leaf miner

2.1.1 Origin and Synonyms

South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is native to South America and the genus *Tuta* and its type species, *atriplicella*, were made available by Kieffer and Jorgensen in 1910 (Kieffer and Jorgensen, 1910). The species name, *absoluta* was described under genus *Phthorimaea* from a single adult male collected in Huancayo, Peru by Meyrick (Meyrick, 1917). Subsequently, the genus *Tuta* was placed in synonym with *Gnorimoschema*. Povolny (1964) described *Scrobipalpula* and transferred *absoluta* to this genus. Povolny (1987) described *Scrobipalpuloidea* as a new genus and transferred *absoluta* to this genus as a new combination. Later *T. atriplicella* considered being congeneric with the type species of *Phthorimaea*, *P. operculella* and thus these two genera were synonymized by Hodges and Becker (1990). Povolny (1993) reinstated *Tuta* as a valid genus without giving any morphological basis for doing so. In 1994, Povolny (Povolny 1994) transferred *absoluta* from *Scrobipalpuloidea* to *Tuta* as a new combination. The two genera were again synonymized by Lee *et al.* (2009) based on similarity of male genitalia of *Tuta atriplicella*, the type species and *Phthorimaea operculella*. However, a recent study of *Gnorimoschemini* of Europe (Huemer and Karsholt, 2010) has adopted a conservative approach to recognizing *Tuta* as a valid genus. Thus, *Tuta* is recognized as the valid genus for the species *absoluta*.

2.1.2 Geographical spread and Distribution

After its identification at Peru in 1917, the insect spread to other parts of South America. During 1980 and subsequent years, it was reported as a pest in Argentina (Garcia and Espul, 1982), Ecuador, Venezuela (Fernandez and Montagne, 1990; Povolny, 1994). A decade later in 2006, *T. absoluta* was detected in several greenhouses of the Spanish Mediterranean basin, causing serious damage to tomato. During 2008 and 2009, *T. absoluta* was reported in tomato crops from Italy, Southern France, Greece, Portugal, Morocco, Algeria and Tunisia (Potting *et al.*, 2009). Presence of this pest had been reported in Southern Germany and Cyprus (EPPO, 2010). Pest showed its presence in Saudi Arabia (Russell IPM, 2009). Then *T. absoluta* made a significance entry to Bhagdad province of Iraq in 2010 (Rassoul, 2014). By the middle 2014, it was observed in India (Sridhar *et al.*, 2014) even though there are undocumented reports of its occurrence in 2012 in Junagadh area of Gujarath (Dr. K. Charndrashekar, Sr. Scientist, IARI-Regional Station, Pune, deliberations in the meeting held at NBAIR, Bengaluru on 21st February 2015).

2.1.3 Intrusion into India

In India, *T. absoluta* was officially reported in October 2014. It was noticed in polyhouses around Pune for the first time in October, but the exact mode of entry to the country is not yet known. But the entry of pest through Plant Quarantine system has been ruled out (Dr. S. N. Sushil, Plant Protection Advisor, GOI, deliberation in the meeting held at NBAIR, Bengaluru on 21st February 2015). Then it was noticed in Karnataka during November around Bengaluru (Sridhar *et al.*, 2014) and a heavy damage in Malnad and Hyderabad-Karnataka parts (Kalleswaraswamy *et al.*, 2015). Real Time Pest Dynamics of Tomato (RTPD) a part of National Initiative on Climate Resilient Agriculture (NICRA) revealed its occurrence in Hyderabad during January to April 2015 (Kumari *et al.*, 2015).

2.2 Survey for the incidence of *Tuta absoluta*

2.2.1. Global scenario

During October 2009, an official statement was published on the website of Bulgarian National Service of Plant Protection (NSPP) about the presence of tomato leaf miner in several glasshouses and open fields of South Bulgaria based on a pheromone trap survey. Leaves were the most heavily damaged plant parts with an average of 9.42 and 8.75 mines per leaflet on middle and upper portion of plant canopy, respectively (Harizanova *et al.*, 2009).

Plant infestation increased more rapidly and reached higher levels during spring 2009 than in 2010 at Sardinia in Italy. Incidence of *T. absoluta* infestation exceeded 70 per cent by April in 2009 but, during 2010 similar level was reached a month later. During summer and autumn 2009, tomato borer infestation increased to over 70 per cent (Nannini *et al.*, 2011).

Survey revealed 21, 48 and 28 per cent of infestation in Behara, Dommiette and Aswan governorates of Egypt, respectively by *T. absoluta* on tomato during 2010. The corresponding values in 2011 were 50 per cent in Benisweef governorate to 100 per cent in El-Gharbia, El-Monifia, El-Dakahleia, Domitt, El-Qalubia, El-Sharkia and El-Isamliia governorates (Moussa *et al.*, 2013).

Density studies of *T. absoluta* on tomato, potato and *S. nigrum* in polyhouse conditions of Sardinia, Italy revealed that low incidence on potato (less than 0.3 mines per leaf), as well as on *S. nigrum* (0.16 mines per leaf). Conversely, a high pest infestation was observed in tomato leaves (3.8 mines per leaf) and fruits (27 per cent damaged fruits) (Cocco *et al.*, 2015).

Survey for the presence of *T. absoluta* in Duhok province, Kurdistan region, Iraq during 2012 revealed that the average number of mines per leaflet, larvae per leaf and larvae per fruit were 2.33, 0.34 and 0.61 respectively (Assaf *et al.*, 2015).

2.2.2 National status

Tuta absoluta was observed during regular surveillance on tomato at Indian Institute of Horticultural Research (IIHR) and adjoining farmers' fields in and around Bengaluru, Karnataka during November 2014. Surveys during November to January revealed its presence in six districts of Karnataka state viz., Bengaluru Rural, Bengaluru Urban, Kolar, Chikkaballapura, Ramanagara and Tumakuru. Incidence of *T. absoluta* has also been recorded on potato. Infestation of *T. absoluta* was up to 15 mines per plant in different tomato fields surveyed. In some of the fields up to 87 per cent of the tomato plants were infested by *T. absoluta* (Sridhar *et al.*, 2014). Survey from January to April 2015 revealed the presence of *T. absoluta* for the first time on tomato at Vegetable Research Station, Rajendranagar, Hyderabad, Telangana State during regular surveys of Real Time Pest Dynamics of Tomato (RTPD) under NICRA and leaf damage ranged from 14.4 to 97.9 per cent (Kumari *et al.*, 2015).

During January and February of 2015, *T. absoluta* was detected in Malnad (Shivamogga and Chikkamagaluru district) and Yadgiri district of Karnataka State on tomato and potato (Chikkamagaluru district) crops. Infestation ranged from 2.7-67.5 per cent leaf damage and 1.2 to 12.6 per cent fruit damage on tomato. In case of potato, the leaf infestation ranged from 3.3 to 5.1 per cent (Kalleshwaraswamy *et al.*, 2015).

2.2.3 Host range

An exhaustive list of host plants on which *T. absoluta* has been recorded is summarized in Table 1. Tomato leaf miner, *T. absoluta* can feed, develop and reproduce in the absence of tomato on alfalfa (*Medicago sativa* L.) in Baghdad Province of Iraq during 2010. This finding revealed that alfalfa also serves as a host plant for *T. absoluta* in Iraq (Rassoul, 2014).

Table 1. Plant species recorded as host for *Tuta absoluta*

Scientific Name	Common Name	Reference
<i>Amaranthus viridis</i> L.	Slender amaranth	Bayram <i>et al.</i> (2015)
<i>Capsicum annuum</i> L.	Pepper	Portakaldali <i>et al.</i> (2013)
<i>Datura quercifolia</i> Kunth syn	Long-spined thorn apple	EPPO (2005)
<i>Datura ferox</i> Kunth		EPPO (2005)
<i>Datura stramonium</i> L.	Jimson weed, devil's trumpet	Vargas (1970)
<i>Nicotiana tabacum</i> L.	Tobacco	Galarza (1984)
<i>Physalis angulata</i> L.	Cut leaf ground cherry	Galarza (1984)
<i>Physalis peruviana</i> L.	Cape gooseberry	Garzia <i>et al.</i> (2009)
<i>Phaseolus vulgaris</i> L.	Common bean	EPPO (2009)
<i>Solanum americanum</i> Miller	American nightshade	Fernandez and Montagne (1990)
<i>Solanum tuberosum</i> L.	Potato	Vargas (1970), Galarza (1984)
<i>Solanum bonariense</i> L.		Galarza (1984)
<i>Solanum elaeagnifolium</i> Cav.		Galarza (1984)
<i>Solanum gracilius</i> Herter		Galarza (1984)
<i>Solanum hirtum</i> Vahl		Fernandez and Montagne (1990)
<i>Solanum melongena</i> L.	Eggplant	Galarza (1984) Fernandez and Montagne (1990)
<i>Solanum nigrum</i> L.	Black nightshade	Vargas (1970)
<i>Solanum pseudo-capsicum</i> L.	Jerusalem cherry	Galarza (1984)
<i>Solanum sisymbriifolium</i> L.	Litchi tomato	Galarza (1984)
<i>Solanum woronowii</i> Pojark.		Bayram <i>et al.</i> (2015)
<i>Sorghum halepense</i> L.		Bayram <i>et al.</i> (2015)
<i>Xanthium strumarium</i> L.		Bayram <i>et al.</i> (2015)

An experiment on weeds grown in cultural areas of Konya, Turkey to determine the secondary hosts of *T. absoluta* revealed that the pest can feed, develop and reproduce in the absence of tomato. Typical feeding damages of tomato leaf miner, conspicuous mines and galleries between leaf epidermal layers which contained black larval frass, were observed on the leaves of *Chenopodium album* L. (Chenopodiaceae) (Ogur *et al.*, 2014).

Survey to determine alternative host plants of *T. absoluta* in the Eastern Mediterranean Region of Turkey revealed that, the plants of cultivated Solanaceae family *viz.*, tomato (*Solanum lycopersicum* L.), aubergine (*Solanum melongena* L.), potato (*Solanum tuberosum* L.), pepper (*Capsicum annuum* L.), pepino (*Solanum muricatum* Aiton) and non-cultivated Solanaceae *viz.*, black nightshade (*Solanum nigrum* L.), field bindweed (*Convolvulus arvensis* L.) of Convolvulaceae family and lamb's-quarters (*C. album*) of Chenopodiaceae family were identified as host plants of *T. absoluta* (Portakaldali *et al.*, 2013).

In absence of tomato as host; *T. absoluta* fed on potato and caused damage in economical level with the capture of 224 mature males trapped in one week with the help of pheromone trap (Unlu, 2012) indicating potato as a potential host in the absence of tomato.

Three each of cultivated and non-cultivated plants belonging to family Solanaceae (Tomato, potato, brinjal, black nightshade, *S. woroovii* and cut leaf groundcherry) (Table 1), slender amaranthus, jhonson grass and *Xanthium strumarium* L. served as hosts for the *T. absoluta* in Turkey and the record of non Solanaceae and non-cultivated Solanum plants excluding *S. nigrum* were first records from Turkey (Bayram *et al.*, 2015).

Observation in Chikamagaluru district of Karnataka showed that the main host of *T. absoluta* was tomato with an average, 2.7 to 60.7 per cent leaves per plant showing damage symptoms and 1.2 to 12.6 fruits per plant having pinholes. Incidence of the pest on potato was very minor, out of 3 potato fields surveyed, 2 were infested (Kalleswaraswamy *et al.*, 2015).

2.3 Natural enemies

A comprehensive list of predators (Table 2) and parasitoids (Table 3) recorded under field condition globally is summarized.

2.3.1 Predators

Prey suitability of *T. absoluta* eggs and larval instars was examined under laboratory conditions of Valencia, Spain to evaluate whether two predators, *Macrolophus pygmaeus* (Rambur) and *Nesidiocoris tenuis* Reuter (Hemiptera: Miridae), can accept this invasive pest. Both predators preyed actively on *T. absoluta* eggs and all larval stages, although they preferred first-instar larvae. Females consumed significantly more *T. absoluta* eggs than males in both the predator species but, the differences were differ non-significant (Urbaneja *et al.*, 2003).

A survey was carried out in tomato and tobacco fields and on wild plants located in cities of Brazil, to ascertain the natural enemy diversity of *T. absoluta*. Nymphs and adult mirid predators were collected on the plants and identified in the lab. Results revealed that one individual of a mirid *Calendula officinalis* L. was observed on the tomato plants and there were three mirid predators on tobacco plants namely *Campyloneuropsis infumatus* (Carvalho), *Engytatus varians* (Distant) and *Macrolophus basicornis* (Stal) has higher predation capacity than *N. tenuis* and *M. pygmaeus* under laboratory condition (Bueno *et al.*, 2013).

Three hemipterans predators, *Orius albidipennis*, *Orius* sp. (Hemiptera: Anthocoridae) and *N. tenuis* were recorded for the first time from Jordan on *T. absoluta* (Al-Jboory *et al.*, 2012).

Survey for the presence of *T. absoluta* and its dependants, in and around Bengaluru during November showed the presence of zoophytophagous mirid bug, *N. tenuis* as a predator on eggs and early larval stages of *T. absoluta* under field conditions (Sridhar *et al.*, 2014). *Nesidiocoris tenuis* was

Table 2. A comprehensive list of predators reported worldwide on *Tuta absoluta*

Order: Family	Predator	Stage of <i>T. absoluta</i> attacked	References
Mesostigmata:	<i>Amblyseius swirskii</i> Athias-Henriot	Eggs and larva	Molla <i>et al.</i> (2010)
Phytoseiidae	<i>Amblyseius cucumeris</i> (Oudemans)	Eggs and larva	Molla <i>et al.</i> (2010)
Hemiptera: Miridae	<i>Dicyphus</i> sp.	Eggs and young larvae	Biondi <i>et al.</i> (2013)
	<i>Dicyphus errans</i> (Wolff)	Eggs and larva	Ferracini <i>et al.</i> (2012)
	<i>Dicyphus maroccanus</i> Wagner	Eggs and young larvae	Molla <i>et al.</i> (2010)
	<i>Dicyphus tamaninii</i> Wagner	Eggs and young larvae	Guenaoui <i>et al.</i> (2011)
	<i>Macrolophus pygmaeus</i> (Rambur)	Eggs and young larvae	Molla <i>et al.</i> (2010)
	<i>Nesidiocoris tenuis</i> (Reuter)	Eggs and young larvae	Karabuyuk (2011) Al-Jboory <i>et al.</i> (2012)
Hemiptera:	<i>Orius</i> sp.	Not specified	Al-Jboory <i>et al.</i> (2012)
Anthocoridae	<i>Orius albidipennis</i> (Reuter)	Not specified	Al-Jboory <i>et al.</i> (2012)
Hymenoptera: Formicidae	<i>Tapinoma nigerrimum</i> (Nylander)	Larvae	Guenaoui <i>et al.</i> (2011)

recorded in huge number from SATLM infested tomato crops sprayed heavily with newer and conventional molecules of insecticides in Kolar district (Dr. Chandish R. Ballal, Principle Scientist, NBAIR, Bengaluru, deliberations in a meeting held at NBAIR, Bengaluru on 21st February 2015).

2.3.2 Parasitoids

Nine species of larval parasitoids emerged from field collected tomato leaves infested with *T. absoluta* in Italy. The most abundant *Necremnus artynes* (Walker) and *Necremnus tidius* (Walker) (Hymenoptera: Eulophidae) were tested in laboratory parasitism trials on first two instar larvae. Results revealed that there was no significant difference in killing of the larva by females of *N. artynes* (4.20 larva per female) and *N. tidius* (4.80 larva per female). But, both *Necremnus* spp. showed good adaptation to the invasive pest and observed a high larval mortality of *T. absoluta* under laboratory conditions (Ferracini *et al.*, 2012).

Decrease of egg and larval numbers of *T. absoluta* was significantly higher in plots where both, *Trichogramma evanescens* Westwood (Hymenoptera: Trichogrammatidae) and *N. tenuis* were released together than each one released separately on tomato grown under greenhouse in Mediterranean Region of Turkey (Oztemiz, 2013).

An experiment to develop control strategies under the conditions of the South-East of France with predator, *Macrolophus pygmaeus* and the parasitoid, *Trichogramma achaeae* alone and in combination revealed that, significant results were obtained when the two beneficial were released in combination than the individuals (Caudal *et al.*, 2012).

Laboratory tests were undertaken to evaluate the potential of 29 European strains of *Trichogramma* parasitoids and compared with commercially available *Trichogramma achaeae* for pest control in Europe. Out of 29, one strain of the *T. euproctidis* species (1) appeared promising with 68.7 per cent parasitism as compared to *T. achaeae* (35.4 per cent parasitism). But, same results were not obtained when *T. euproctidis* strain was tested on a larger scale in cages and greenhouses. Indeed the most efficient *Trichogramma* parasitoid against *T. absoluta* was still *T. achaeae* because of higher fertility, high proportion of females (thelytoky) and capacity to undergo diapause in cold storage of biocontrol company facilities (Chailleux *et al.*, 2012).

Under laboratory conditions of Almassa, Spain *Trichogramma achaeae* had parasitisation potential of 100 per cent of which only 83.3 per cent of the parasitized eggs developed until the black head stage (apparent parasitism). In greenhouse condition 91.74 per cent of damage reduction was observed when it was released at the rate of 30 adults per plant for every 3-4 days (Cabello *et al.*, 2009).

Nine parasitoid species representing four families of Hymenoptera were obtained in the larval mines of *T. absoluta* from a tomato greenhouse in Hatay, Turkey. The parasitoid, *Closterocerus clara* (Szelenyi) predominant major with 37 per cent parasitism, followed by *Bracon didemie* Beyarslan (7.0%), *Ratzeburgiela christatus* (Ratzeburg) (4.2%) and *R. incompleta* Boucek (2.8%) (Doganlar and Yigit, 2011).

A single parasitoid species of family Eulophidae was reared and identified as *Neochrysocharis formosus* (Westwood) which is also a parasitoid on serpentine leaf miner *Liriomyza trifolii* (Burgess) and forms the first report on *T. absoluta* in Iran (Sohrabi *et al.*, 2014).

Record of native ecto and endo parasitoids on *T. absoluta* belonging to 13 genera and 6 families from Southern Italy revealed identity of only ten species of which seven formed the first host-parasitoid association report (Zappala *et al.*, 2012).

Rate of parasitism of three species of parasites viz., *Bracon* sp. (Braconidae), *Earinus* sp. (Braconidae) and *Conura* sp. (Chalcididae) was 4.2, 0.2 and 2.6 per cent respectively. *Earinus* sp. was recorded for the first time parasitizing *Tuta absoluta* in Brazil (Marchiori *et al.*, 2004).

Table 3. A comprehensive list of parasitoids reported worldwide on *Tuta absoluta*

Family	Parasitoid	Stage of <i>T. absoluta</i> attacked	Reported by
Hymenoptera: Ichneumonidae	<i>Campoplex haywardi</i> (Blanchard)	Mature larvae– pupae	Colomo <i>et al.</i> (2002)
	<i>Diadegma</i> sp.	Mature larvae– pupae	Zappala <i>et al.</i> (2012)
	<i>Diadegma ledicola</i> Horstmann	Mature larvae– pupae	Ferracini <i>et al.</i> (2012)
	<i>Diadegma pulchripes</i> (Kokujev)	Mature larvae– pupae	Zappala <i>et al.</i> (2012)
	<i>Hyposoter didymator</i> (Thunberg)	Not specified	Boualem <i>et al.</i> (2012)
	<i>Temelucha anatolica</i> (Sedivy)	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Zoophthorus macrops</i> Bordera & Horstmann	Not specified	Gabarra <i>et al.</i> (2013)
Hymenoptera: Braconidae	<i>Agathis</i> sp.	Larvae not specified	Ferracini <i>et al.</i> (2012)
	<i>Agathis fuscipennis</i> Zetterstedt	Larvae not specified	Loni <i>et al.</i> (2011)
	<i>Apanteles</i> sp.	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Bracon</i> sp.	Mature larvae	Abbes <i>et al.</i> (2013)
	<i>Bracon</i> (=Habrobracon) <i>didemie</i> Beyarslan	Mature larvae	Doganlar and Yigit (2011)
	<i>Bracon</i> (=Habrobracon) <i>hebetor</i> Say	Mature larvae	Doganlar and Yigit (2011)
	<i>Bracon</i> (=Habrobracon) <i>nigricans</i> (=concolorans, concolor, mongolicus) Szepliget	Mature larvae	Al-Jboory <i>et al.</i> (2012) Urbaneja <i>et al.</i> (2012) Zappala <i>et al.</i> (2012)
	<i>Bracon</i> (=Habrobracon) sp. near <i>nigricans</i>	Mature larvae	Gabarra <i>et al.</i> (2013)
	<i>Bracon</i> (=Habrobracon) <i>osculator</i> (Nees)	Mature larvae	Ferracini <i>et al.</i> (2012) Zappala <i>et al.</i> (2012)
	<i>Chelonus</i> sp.	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Choeras semele</i> (Nixon)	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Cotesia</i> sp.	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Diolcogaster</i> sp.	Not specified	Gabarra <i>et al.</i> (2013)

Table 3.
Contd...

Contd...

	<i>Dolichogenidea litae</i> (Nixon)	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Earinus</i> spp.	Egg and larva	Colomo <i>et al.</i> (2002)
	<i>Orgilus</i> spp.	Egg and larva	Colomo <i>et al.</i> (2002)
	<i>Pseudapanteles dignus</i> (Muesebeck)	Egg and larva	Botto <i>et al.</i> (1999) Colomo <i>et al.</i> (2002)
Hymenoptera: Chalcididae	<i>Brachymeria secundaria</i> (Ruschka)	Larvae not specified	Doganlar and Yigit (2011)
	<i>Hockeria unicolor</i> (Walker)	Larvae not specified	Doganlar and Yigit (2011)
Hymenoptera Encyrtidae	<i>Copidosoma</i> sp.	Egg and larva	Colomo <i>et al.</i> (2002)
Hymenoptera: Eulophidae	<i>Baryscapus bruchophagi</i> (Gahan)	Not specified	Doganlar and Yigit (2011)
	<i>Chrysocharis</i> sp	Larvae not specified	Zappala <i>et al.</i> (2012)
	<i>Closterocerus clarus</i> (Szelenyi)	Larva	Doganlar and Yigit (2011)
	<i>Diglyphus crassinervis</i> Erdős	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Diglyphus isaea</i> (Walker)	Larvae not specified	Boualem <i>et al.</i> (2012) Gabarra <i>et al.</i> (2013)
	<i>Elachertus</i> sp.	Larvae not specified	Zappala <i>et al.</i> (2012)
	<i>Elachertus inunctus</i> species group	Larvae not specified	Zappala <i>et al.</i> (2012)
	<i>Elasmus</i> sp.	Larvae not specified	Zappala <i>et al.</i> (2012)
	<i>Elasmus phthorimaeae</i> Ferriere	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Hemiptarsenus zilahisebessi</i> Erdos	Larva	Guenaoui <i>et al.</i> (2011)
	<i>Necremnus</i> sp.	Larvae not specified	Zappala <i>et al.</i> (2012) Gabarra <i>et al.</i> (2013)
	<i>Necremnus artynes</i> (Walker)	Larva	Molla <i>et al.</i> (2010)
	<i>Necremnus nr.artynes</i>	Larva	Ferracini <i>et al.</i> (2012) Zappala <i>et al.</i> (2012)
	<i>Necremnus metalarus</i> Walker	Larva	Urbaneja <i>et al.</i> (2012)
	<i>Necremnus tidius</i> (Walker)	Larva	Riciputi (2011)

Table 3.
Contd...

Contd...

	<i>Necremnus nr. tidius</i>	Larva	Ferracini <i>et al.</i> (2012) Zappala <i>et al.</i> (2012)
	<i>Neochrysocharis</i> sp.	Larva	Boualem <i>et al.</i> (2012)
	<i>Neochrysocharis formosa</i> (Westwood)	Larva	Guenaoui <i>et al.</i> (2011)
	<i>Pnigalio</i> (=Ratzeburgiola) <i>cristatus</i> (Ratzeburg)	Larva	Ferracini <i>et al.</i> (2012)
	<i>Pnigalio</i> sp. <i>soemius</i> complex	Larva	Zappala <i>et al.</i> (2012)
	<i>Pnigalio soemius</i> (Walker)	Not specified	Gabarra <i>et al.</i> (2013)
	<i>Pnigalio incompletes</i> (Boucek)	Not specified	Doganlar and Yigit (2011)
	<i>Stenomesus</i> sp.	Larva	Guenaoui <i>et al.</i> (2011)
	<i>Stenomesus</i> sp. nr. <i>japonicas</i>	Larva	Gabarra and Arno (2010)
	<i>Sympiesis</i> sp.	Not specified	Boualem <i>et al.</i> (2012)
Hymenoptera: Pteromalidae	<i>Halticoptera aenea</i> (Walker)	Larvae not specified	Zappala <i>et al.</i> (2012)
	<i>Pteromalus intermedius</i> (Walker)	Larvae not specified	Doganlar and Yigit (2011)
	<i>Pteromalus semotus</i> (Walker)	Not specified	Gabarra <i>et al.</i> (2013)
Hymenoptera: Trichogrammatidae	<i>Trichogramma</i> spp.	Egg	Gabarra and Arno (2010) Boualem <i>et al.</i> (2012) Zappala <i>et al.</i> (2012)
Table 3. Contd...	<i>Trichogramma nerudai</i> Pintureau and Gerding	Egg	Botto, (1999)
	<i>Trichogramma rojasi</i> Nagaraja & Nagarkatti, <i>Trichogrammatoidea bactrae</i> Nagaraja	Egg	Colomo <i>et al.</i> (2002)
	<i>Trichogramma pretisoum</i> Riley	Egg	Caceres <i>et al.</i> (2011)
	<i>Trichogramma achaeae</i> Nagaraja & Nagarkatti	Egg	Biondi <i>et al.</i> (2013)
	<i>Trichogramma bourarachae</i> Pintureau & Babault	Egg	Zouba <i>et al.</i> (2013)

Contd...

Neochrysocharis formosa (Westwood) showed their presence only in organic outdoor and protected cultivation found to parasitize the larvae of *Tuta absoluta* in tomato crops in Northern Buenos Aires Province, Argentina and the parasitism rates varied from 1.5 to 5.0 per cent (Luna *et al.*, 2011). Parasitic wasp, *Bracon (Habrobracon) concolorans* (Hymenoptera: Braconidae) was recorded for the first time from Jordan (Al-Jboory *et al.*, 2012).

A high larval mortality of *T. absoluta* was encountered in Pest Management Laboratory (Federal University of Vicosa, Brazil) due to the presence of *Pyemotes* sp. The caterpillars and adults of *T. absoluta* were quickly paralyzed by the mite venom. A single *T. absoluta* could host many physogastric females (Oliveira *et al.*, 2007).

2.3.3 Entomopathogens

Twelve bacterial isolates were isolated from dead larvae of *Tuta absoluta* (4th instar) from tomato cultivated fields at Fayoum Governorate, Egypt were identified as *Bacillus* spp. and were tested against 4th instar larva for pathogenicity test and compared with Protecto[®] (A commercially available *Bacillus thuringiensis* product). Out of 12 isolates, B₁, B₂, B₃ and B₄ isolates showed high mortality of 93.3, 90.0, 86.7 and 80.0 per cent on day seven, respectively. There was a significant decrease in egg hatching percentage (F₁) (44.12 to 66.17%) compared with control and adult emergence (F₂) decreased from 69.28% to 5.16% (Youssef and Hassan, 2013).

2.4 Bio-ecology of SATLM

2.4.1 Fecundity

Highest egg laying was observed at 20°C being 162 eggs per female which decreased to 159 eggs per female at 15°C. At higher temperatures, the mean production was 128.9 and 115.3 eggs per female when reared at 25 and 30°C, respectively. On tenth, seventh, fifth and fifth day after the female emergence highest egg deposition at the four tested temperatures *viz.*, 15°C, 20°C, 25 and 30°C, respectively (Salama *et al.*, 2014) was recorded. Erdogan and Babaroglu (2014) reported that fecundity of *T. absoluta* was found to be 141.16 eggs per female and incubation period was 4.10 days at 25 to 26°C. Similarly Pereyra and Sanchez (2006) reported that the mean fecundity of *T. absoluta* on tomato plant was 132.78 at 25°C and at temperature 28°C it was 131.8 on tomato plant (Attwa *et al.*, 2015).

2.4.2 Incubation period

Mean incubation period ranged from 3.56 to 4.50 days at 25°C and was longest at 20/30°C alternating schedule on three varieties of tomato *viz.*, Vyta, Tex 317 and Bravo in the decreasing order. The difference between temperature regimes was non-significant with variety Tex 317 (Duarte *et al.*, 2015).

In a similar study with two varieties of tomato *viz.*, Bravo and Tex 317 at 25°C and altering 20/30°C temperatures, the egg development time of *T. absoluta* did not show significant differences between temperature regimes and tomato lines. Egg development period ranged from 3.6 to 4.1 days (Silva *et al.*, 2015).

Incubation period was 14.65 days at 15°C, which decreased to 8.70, 5.61 and 3.70 days with increase of temperature to 20, 25 and 30°C, respectively and the decrease was significantly differed at all temperatures (Salama *et al.*, 2014). Attwa *et al.* (2015) reported an incubation period was 3.9 days at 25°C on tomato plant.

2.4.3 Total larval and pupal period

Larval duration (8.91 to 10.50 days) and pupal duration (6.00 to 8.00 days) did not differ between temperature of 25°C and alternating temperature of 20/30°C regimes and tomato varieties (Vyta, Bravo and Tex 317) (Duarte *et al.*, 2015).

When the experiment was conducted on two different varieties (Bravo and Tex 317) of tomato at 25°C and altering 20/30°C temperatures, the larval period was long in case of Tex 317 at altering 20/30°C temperature (10.00 days), followed by the Bravo variety at 25°C temperature (8.91 days) and the results were significantly different from each other (Silva *et al.*, 2015). Male pupal period was longer in case of both the varieties of tomato at altering 20/30°C temperature (7.85 and 7.57 days), followed by Tex 317 at 25°C temperature (6.14 days).

Tuta absoluta passed through four larval instars with total larval duration of 31.98 days at 15°C. Increase of temperature shortened significantly the larval duration being 21.40, 14.56 and 9.20 days at 20, 25 and 30°C, respectively. The pupal period was 22.13 days at 15°C, as compared to 16.58, 10.93 and 6.48 days for the pupae kept at 20, 25 and 30°C, respectively and the difference was highly significant at all tested temperatures (Salama *et al.*, 2014).

Total larval duration of *T. absoluta* was found to be 10.97 days and the pupal period was 9.53 days at 25 to 26°C and it was 13.75 and 6.53 days at 28°C, respectively (Erdogan and Babaroglu, 2014; Attwa *et al.*, 2015). Pereyra and Sanchez (2006) reported a mean larval period of 12.14 days on tomato plant at 25°C.

2.4.4 Adult longevity

Adult longevity was longer (22.67 days) at alternating temperature 20/30°C on Tex 317 variety when compared to that on other varieties and at 25°C temperature (Duarte *et al.*, 2015). Male longevity was 21.6, 16.3, 10.1 and 6.7 days at 15, 20, 25 and 30°C tested temperatures, respectively and the differences were statistically significant. On the other hand, the female longevity lasted longer (25.8 days) at 15°C and which decreased with mean in temperature at 20, 25 and 30°C was 21.3, 14.3 and 11.9 days respectively (Salama *et al.*, 2014).

Adult male and female longevity was significantly longer in case of Tex 317 at both 25°C and altering 20/30°C temperatures (21.07 and 23.00 days for males 21.53 and 22.67 days for females) (Silva *et al.*, 2015). Adult longevity for male and female individuals was 15.80 and 18.16 days, respectively at 25 to 26°C and it was statistically indifferent (Erdogan and Babaroglu, 2014).

Cuthbertson *et al.* (2013) reported that the newly emerged adult *T. absoluta* survived 40 days at 10°C, when offered with honey solution as a food source and was significantly longer than the shorter survival rates noted at 19°C (16 days) and 23°C (17 days). When supplied with food, *T. absoluta* adult lived for 13.6 days (Attwa *et al.*, 2015).

2.4.5 Pre-oviposition, oviposition and oviposition period

Pre-mating, oviposition and post-mating period of *T. absoluta* was longer on the variety Tex 317 at alternating temperature 20/30°C, followed by the temperature at 25°C when compared to other varieties (Duarte *et al.*, 2015). The pre-oviposition duration of *T. absoluta* at tested temperatures of 15, 20, 25/30°C was 4.6, 4.0, 2.9 and 2.3 days, respectively (Salama *et al.*, 2014).

Pre-oviposition period was same (1.13 day) and did not show significant difference in both the varieties of tomato and also at both 25°C and altering 20/30°C temperatures. Ovipositional duration was significantly low with Bravo variety at 25°C (10.87 days). Tex 317 variety at both the temperature regimes showed the significant difference (2.0 to 6.2 days) in case of post oviposition period from the other treatments (6.20 at altering 20/30°C temperature and 5.07 at 25°C temperature) (Silva *et al.*, 2015).

Pre-oviposition, oviposition and post oviposition periods of *T. absoluta* at 25-26°C was 1.28, 7.88 and 5.52 days, respectively (Erdogan and Babaroglu 2014) while they were 2.9, 8.1 and 2.4 days, respectively at 28°C (Attwa *et al.*, 2015).

III. MATERIAL AND METHODS

Studies on biological aspects of South American tomato leaf miner (SATLM), *Tuta absoluta* were carried out at Department of Entomology, College of Horticulture, UHS campus, GKVK, Bengaluru during 2015-2016. Bengaluru is situated in Eastern dry region (Zone-5) of Karnataka at an altitude of 930 meter above the mean sea level. Average rainfall is 779.7 mm and average temperature prevailing throughout the year is around 31 °C. The material and the methods followed during the course of the present studies are detailed in this chapter. Survey work was conducted in four district of Southern Karnataka which are distributed in Eastern dry zone of Karnataka.

3.1 Survey for the incidence of South American tomato leaf miner, *Tuta absoluta* in major tomato growing regions of Bengaluru Rural, Kolar, Chikkaballapura and Mysuru districts

Field survey was carried out from July 2015 to April 2016 in four district of Southern Karnataka. Ten tomato growing taluks (Fig. 1) of Bengaluru Rural, Kolar, Chikkaballapura and Mysuru districts were surveyed and the incidence of South American tomato leaf miner was assessed. In each district a minimum of three tomato fields were visited at monthly intervals.

A proforma was developed for the survey (Appendix I) including several parameters such as date of observation, details of locations and farmers, cultivation system, cropping pattern, source of seedlings, varietal/hybrid details, age and stage of crop at the time of visit (Plate 1), care and management of crop and plot history were collected.

Pest incidence was recorded from randomly selected ten plants in a plot. In each selected plant was divided into three parts for assessing the damage *i.e.*, a) apical part b) middle part and c) bottom part of plant. The plot where the plants were younger than 15 days after planting, the entire leaves in the plants were counted and the damage was assessed.

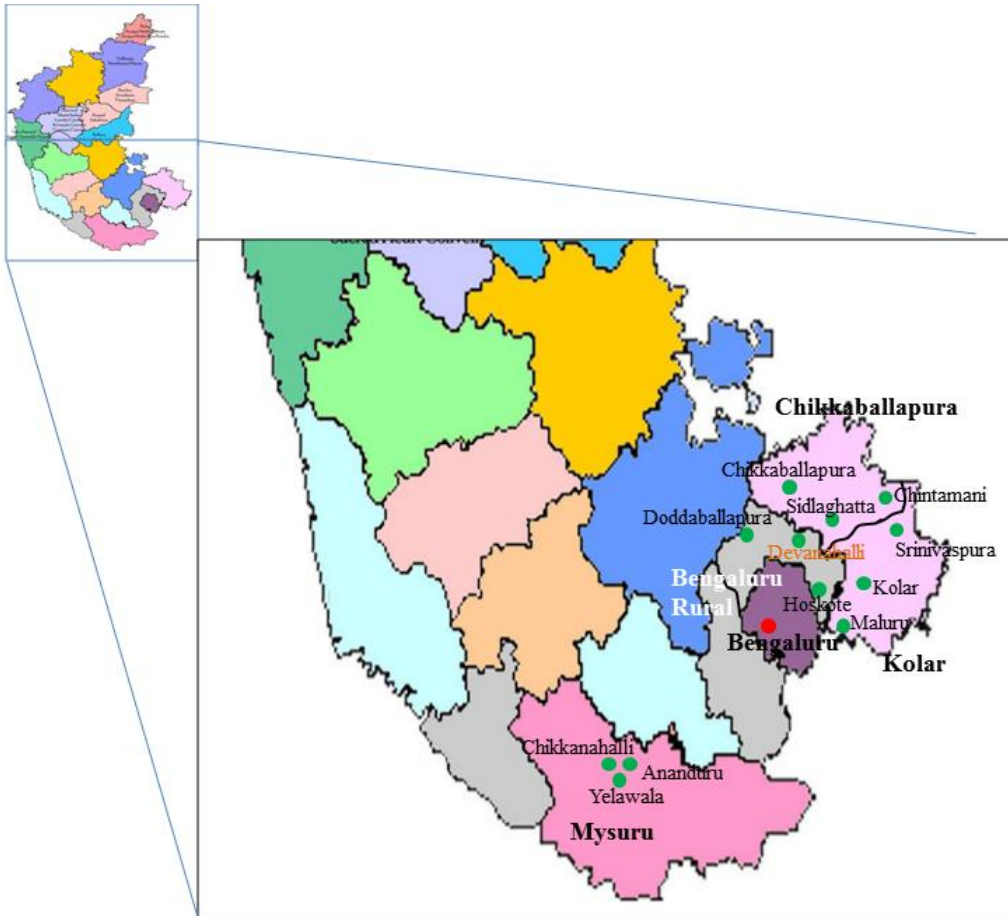


Fig. 1. Survey map for the incidence of *Tuta absoluta* in selected locations of Southern Karnataka during July 2015 to April 2016



a) Less than 30 days



b) 30 to 60 days



c) 60 to 90 days



d) More than 90 days

Plate 1. Different crop stages visited during survey

Plants were observed for the typical symptoms *viz.*, leaf blotches and pin holes on fruits. Total number of leaves in five compound leaves and infested leaves were counted and percentage of infestation was calculated. Weather data of present study area from July 2015 to April 2016 is presented in Appendix II.

$$\text{Per cent leaf infestation} = \frac{\text{Number of leaves infested}}{\text{Total number of leaves observed}} \times 100$$

To assess the fruit damage, total number of fruits in a plant and fruit damaged by *T. absoluta* larvae were counted and the per cent damage was calculated by using the formula.

$$\text{Per cent fruit infestation} = \frac{\text{Number of fruits infested}}{\text{Total number of fruits observed}} \times 100$$

3.2 Documentation of natural enemies and host plants of South American tomato leaf miner, *Tuta absoluta*

Survey was carried out for occurrence of natural enemies and the collateral host plants in tomato growing regions of the study area. Different stages *viz.*, egg, larvae and pupae were collected individually and labeled in the field itself. A known (20) number of infested larva of early and late instar larvae of *T. absoluta* were collected randomly depending the availability of the stages at the field visit. The samples were brought to laboratory intact along with the infested leaf, fruits and were reared for parasitoid or pathogen associated. Predators were collected with the help of aspirator and they were preserved in the alcohol and labeled (Plate 2). Such collected parasitoids and predators were got identified from in National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru.

3.3 Studies on biology of South American tomato leaf miner, *Tuta absoluta* on tomato

The biology of the *T. absoluta* was studied on tomato under ambient laboratory conditions in the Department of Entomology, College of Horticulture, UHS Campus, GKVK Post, Bengaluru during July 2015 to April 2016 (Appendix III).

Mass culturing of *Tuta absoluta*

Tomato plants were used as the host for rearing of *Tuta absoluta* as it was the preferred host for its development. To initiate the culture in the polyhouse, naturally infested leaves with live larva were collected from the field and introduced on tomato potted plants in polyhouse. A continuous supply of 30 to 60 days old plants in pots were ensured for population in polyhouse (Plate 3). Full grown larva of *T. absoluta* would pupate in soil or in leaf itself, therefore the full grown larvae with pinkish tinge on the abdomen were collected from polyhouse and were left on trifoliolate leaf of tomato plugged with cotton and immersed in the Eppendoff tubes of 1.5 ml capacity in insect cages kept in lab. These tubes were inserted in the thermocol and placed in trays containing a thin layer of sand at the base. Thus pupated larva were collected and sexed based on the genital slits on the abdominal portion of the pupa. Adult emerged from pupa were maintained by giving 10 per cent honey solution.



a) Collection of infested samples



b) Samples kept in laboratory for parasitoid emergence



c) Preservation of parasitoid and predator in alcohol

Plate 2. Natural enemies collection and preservat

For studying the biology of *Tuta absoluta* the tomato hybrid, Abhinav (F₁ Syngenta® hybrid) was used. Seedling were brought from the nursery, and planted in small plastic pots to carry out the laboratory experiment.

3.3.1 Adult

Tuta absoluta biology was studied on tomato plant of 35 days old under ambient laboratory conditions. Tomato plants was kept in the rearing cage of size 45×45×50 cm³ (Plate 4a), and freshly emerged adult pair (one female and one male) was released in to cage with glass door and mesh on all the sides. Adults were given with the 10 per cent honey solution as adult food. From the day of adult emergence they were observed daily twice 7.00 to 10.00 am, 6.00 to 8.00 pm and recorded the pre-mating, mating, post mating, pre-oviposition, oviposition, post-oviposition periods and fecundity. With the same pair of adults, daily fecundity was recorded and plant was replaced every day till cessation of oviposition. These observations were made on 20 pair of adults in ambient laboratory conditions.

3.3.2 Oviposition preference within plant height

Oviposition preference was studied in the polyhouse condition. Cages of size 0.60 × 0.60 × 1 m³ (Plate 4b) was prepared using the CPVC pipe as a frame and nylon mesh of size 40 mm was used for covering the cage. A single plant of fifty days old was placed in a cage. Every day plants were replaced with a new plant in each cage and a pair of freshly emerged adults was left in each cage. Adults were given with the 10 per cent honey solution as adult food on a cotton roll. Numbers of eggs laid were counted carefully with a hand lens.



Plate 3. Mass culturing of *Tuta absoluta* in polyhouse



a

a) Laboratory biology



b

b) Ovipositional preference of adult

Plate 4. Cages used in study

3.3.3 Incubation period of egg

Laboratory experiment was carried out with 100 eggs of with four replications *T. absoluta* which were collected from polyhouse on the day of oviposition and labeled (Plate 5a). The mean incubation period of 100 eggs with four replications and per cent egg hatching were recorded. Morphometric observation of egg was carried using binocular (Labomed CZM4, IS 500 capture) stereoscope fitted with ocular micrometer which was standardized with stage micrometer.

3.3.4 Larval duration

Larval duration of each instar was recorded by watching the larvae daily from the day of hatching till the pupation by removing from the mine. Head capsule was collected as and when they were available to demark the instar.

3.3.5 Morphometry of Larva

In each stage larvae were frozen at -1.9 °C for making them inactive and they were measured by using the binocular stereoscope fitted with the camera and ocular micrometer. Different larval instars required different freezing time. The following freezing durations were used:

I st instar lava	1.30 minutes
II nd instar larva	2.30 minutes
III rd instar larva	3.30 minutes
IV th instar larva	4.00 minutes

3.3.6 Head capsule measurement

The head capsule of different stage larvae from the mine were collected by inspecting the mine every day and preserved in 70 per cent alcohol and were measured as above.

3.3.7 Pupation site

Full grown larvae with pinkish tinge on the abdomen were collected from the plant and were left in trifoliolate leaf plugged in the cotton and immersed in the Eppendoff tubes of 1.5 ml capacity. These tubes were inserted in the thermocol and kept in the tray containing a thin layer of sand (Plate 5b). Percentage of pupation site in leaf or soil is calculated by using following formula.

$$\text{Per cent pupation in soil or in leaf} = \frac{\text{Number of larvae pupated in soil or in leaf}}{\text{Total number of larvae pupated}} \times 100$$



a) Growth of different larval instar



b) Preference of pupation site

Plate 5. View of plants used in study

3.3.8 Pupal period

Pupal period was recorded from day of last moult till the adult emergence. Pupae were removed from the cocoon and differentiated as male and female by seeing the gentile slots in the abdomen and preserved for further studies.

3.3.9 Survivability

Survival of each stage of the SATLM was recorded from a set of 100 eggs with four replications which were maintained till death of adults and per cent survivability was calculated.

Statistical analysis

Data pertaining to incidence parameters of SATLM gathered from the filed survey was averaged with standard deviation and range using Windows Microsoft Excel 2010[®]. Effect of weather parameters *viz.*, maximum and minimum temperature, maximum and minimum relative humidity, wind speed and rainfall on the incidence were subjected to correlation (Snedecor and Cochran, 1967) and multiple regression analysis using Statistical XL[®] tool.

Data pertaining to biology was also averaged with standard deviation and range using Windows Microsoft Excel 2010.

IV. EXPERIMENTAL RESULTS

Results of the studies on “Bio-ecology of South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)” with the objectives entitled in chapter I conducted during 2015-16 at COH, Bengaluru, Karnataka are presented in this chapter.

4.1 Seasonal incidence of South American tomato leaf miner, *T. absoluta* in selected four districts of Southern Karnataka

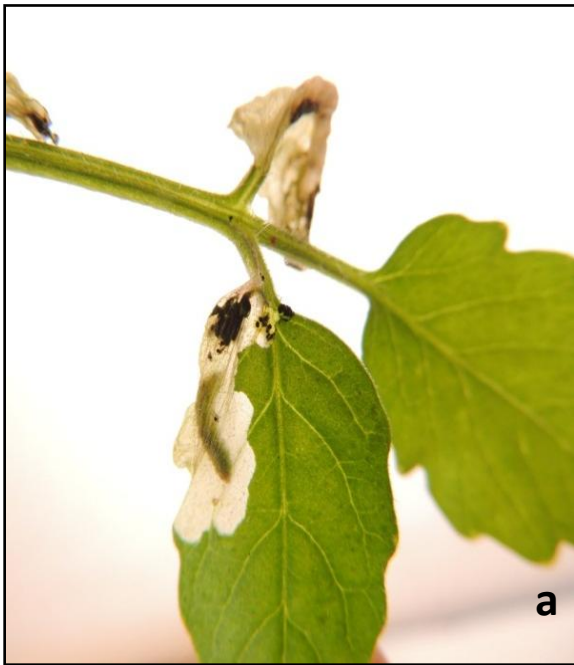
Roving field surveys were conducted for the incidence of SATLM in selected ten taluks of four districts in South Karnataka namely, Bengaluru Rural, Chikkaballapura, Kolar and Mysuru districts during July-2015 to April-2016. Observations on infestation were recorded on leaves and fruits and later per cent infestation was worked out.

Nature of Damage

Larvae of *T. absoluta*, mines into the leaf lamina leaving behind a blotch or mine of an irregular shape with the faecal matter inside the mine which later become necrotic. Larvae consumed the mesophyll leaving the epidermis intact. In the later stage it also bore into the twigs and the main stem. The fruits are attacked as soon as they were formed, and the galleries bored inside them were occasionally invaded by secondary pathogens leading to fruit rot. Damage by these larvae showed the pinhole symptoms on the surface of the fruit, but which was not bored to the core of the fruit and the affected fruit lost their commercial value. Larval damage to terminal buds of plant led to yield losses or obstruct the growth (Plate 6).

4.1.1 Leaf infestation

The leaf infestation in tomato by *T. absoluta* during July 2015 to April 2016 in the ten taluks of four districts in Southern Karnataka ranged from a minimum of 11.95 per cent in Ananduru to a maximum of 17.45 per cent in Chikkaballapura (Table 4). There was very narrow difference among Bengaluru Rural, Chikkaballapura, Kolar and Mysuru districts in terms of leaf infestation. Mean monthly leaf infestation levels on tomato ranged from a minimum of 5.92 per cent during November 2015 to a maximum of 24.72 per cent during February 2016. It followed bi model distribution from July 2015 to April 2016 with two peaks of 18.82 and 24.72 per cent, respectively during October and February.



a) Leaf



b) Twig



c) Flower buds



d) Fruits

Plate 6. Damaging symptoms of *Tuta absoluta* larva

Table 4. Mean per cent leaf damage of *Tuta absoluta* on tomato crop in ten taluks of Southern Karnataka from July 2015 to April 2016

Locations		Mean per cent leaf infestation										
Districts	Taluks	July 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016	Average
Bengaluru	Doddaballapura	14.27	16.25	10.84	20.11	4.81	19.43	23.53	25.92	17.82	12.82	16.58±6.2
	Devanahalli	10.41	12.25	8.92	19.31	6.76	18.01	24.23	24.38	16.58	11.31	15.22±6.2
	Hosakote	7.35	14.62	13.49	14.67	7.30	20.29	23.61	28.65	17.06	13.68	16.07±6.7
Bengaluru Rural		10.68±3.4	14.37±2.0	11.09±2.2	18.03±2.9	6.29±1.3	19.24±1.1	23.79±0.3	26.32±2.1	17.15±0.6	12.60±1.2	15.96±1.7
Chikkaballapura	Chikkaballapura	12.42	13.25	10.98	20.74	6.18	21.94	25.77	31.91	17.76	13.56	17.45±7.7
	Shidlaghatta	10.94	20.86	5.89	21.63	4.95	20.49	23.26	24.67	18.65	15.27	16.66±7.1
	Chintamani	10.13	13.85	11.67	20.31	3.52	22.45	20.04	30.53	19.95	15.94	16.84±7.5
Chikkaballapura		11.16±1.1	15.99±4.2	9.51±3.1	20.89±0.6	4.88±1.3	21.63±1.0	23.03±2.8	29.04±3.8	18.78±1.1	14.92±1.2	16.98±2.0
Kolar	Kolar	8.19	15.20	11.67	20.77	4.07	13.38	16.89	20.22	16.12	15.14	14.17±5.1
	Srinivaspura	12.35	9.47	11.76	22.25	5.71	17.05	13.69	18.87	14.35	17.16	14.27±4.8
	Maluru	11.83	15.11	14.40	19.91	9.87	16.38	18.93	23.36	16.85	14.74	16.14±3.9
Kolar		10.79±2.2	13.26±3.2	12.61±1.5	20.98±1.1	6.55±2.9	15.60±1.9	16.50±2.6	20.82±2.3	15.77±1.2	15.68±1.3	14.86±2.0
Mysuru taluk	Chikkanahalli	8.35	12.65	9.70	16.02	6.00	16.99	16.15	23.32	14.25	15.04	13.85±4.9
	Ananduru	6.00	10.95	7.92	14.15	6.00	14.32	15.23	20.95	14.32	9.65	11.95±4.7
	Yelawala	7.89	13.23	11.38	16.00	5.92	17.52	19.38	23.90	15.23	18.05	14.85±5.4
Mysuru		7.41±1.2	12.28±1.1	9.67±1.7	15.39±1.0	5.97±0.0	16.28±1.7	16.92±2.1	22.72±1.5	14.60±0.5	14.25±4.2	13.55±4.9
Overall mean across locations		10.01±3.4	13.97±3.4	10.72±2.6	18.82±4.2	5.92±1.8	18.19±3.4	20.50±4.2	24.72±4.7	16.58±2.5	14.36±1.7	15.38±3.1

* Observations on average of three plots per month per taluk

4.1.1.1 Bengaluru Rural district

Results of the roving survey on tomato leaf infestation by *T. absoluta* in three selected taluks of Bengaluru Rural district revealed that the mean per cent leaf infestation followed a similar trend in all the three taluks of the district (Table 4; Fig. 2a and 2b). Mean per cent infestation in the Bengaluru Rural district across the months varied from 6.29 during November 2015 to 26.32 per cent during February 2016. Mean per cent leaf infestation was maximum in Doddaballapura taluk, irrespective of the months (16.58%) and the minimum was recorded in Devanahalli taluk (15.22%). Across all the taluks the minimum per cent leaf infestation observed was 4.81, 6.76 and 7.30 respectively, in Doddaballapura, Devanahalli and Hosakote taluk during November 2015 and was maximum viz., 24.38, 25.92 and 28.65 per cent respectively, in Devanahalli, Doddaballapura and Hosakote during February 2016.

Leaf infestation increased gradually from July (10.68%) to October (18.03%) which decreased to a low during November (6.29%) which again gained momentum and reached maximum in the month of February (26.32%) and then onwards which tend to decline (Fig. 2b).

4.1.1.2 Chikkaballapura district

Results of the roving survey on leaf infestation in three taluks of Chikkaballapura district revealed that the mean per cent leaf infestation followed similar trend in all the three taluks of the district and also same was reflected in overall mean per cent infestation of Chikkaballapura district (Table 4; Fig. 3a and 3b). Mean per cent infestation was found maximum in Chikkaballapura taluk irrespective of the months (17.45%) and the minimum was recorded in Hosakote taluk (16.66%). Mean per cent leaf infestation in the Chikkaballapura district varied from 4.88 during November 2015 to 29.0 per cent during February 2016. Across all the taluks minimum per cent leaf infestation observed were 3.52, 4.95 and 6.18, respectively at Chintamani, Shidlaghatta and Chikkaballapura taluks during November 2015 and was maximum viz., 24.67, 30.53 and 31.91 per cent, respectively in Shidlaghatta, Chintamani and Chikkaballapura taluks.

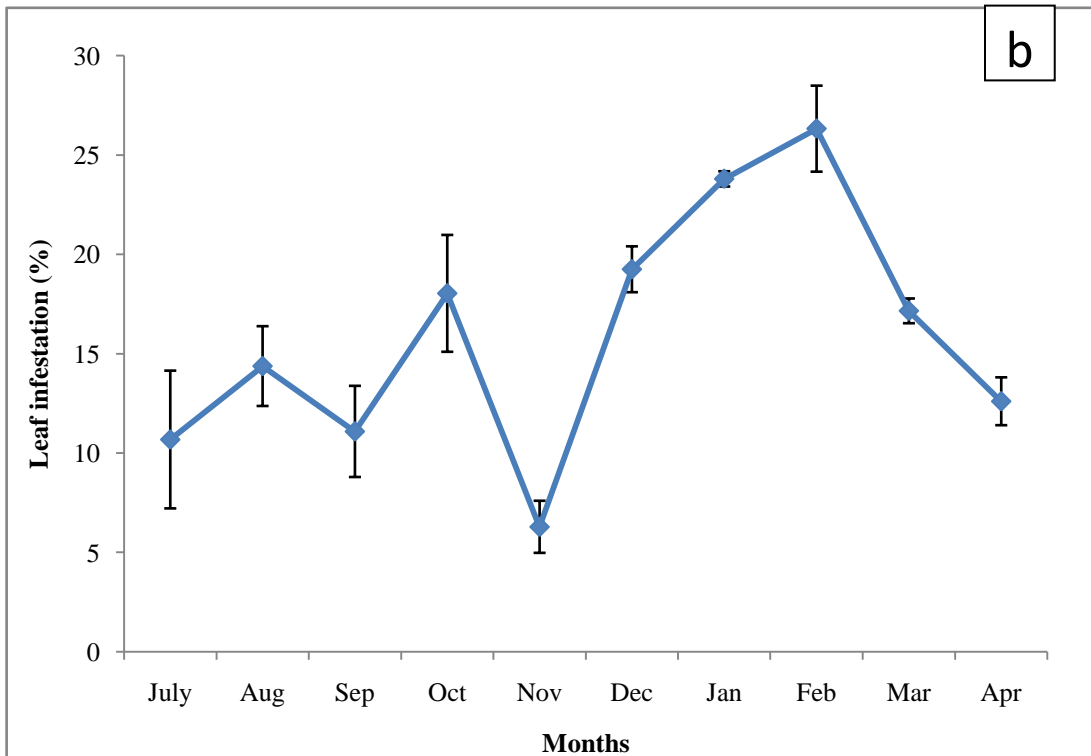
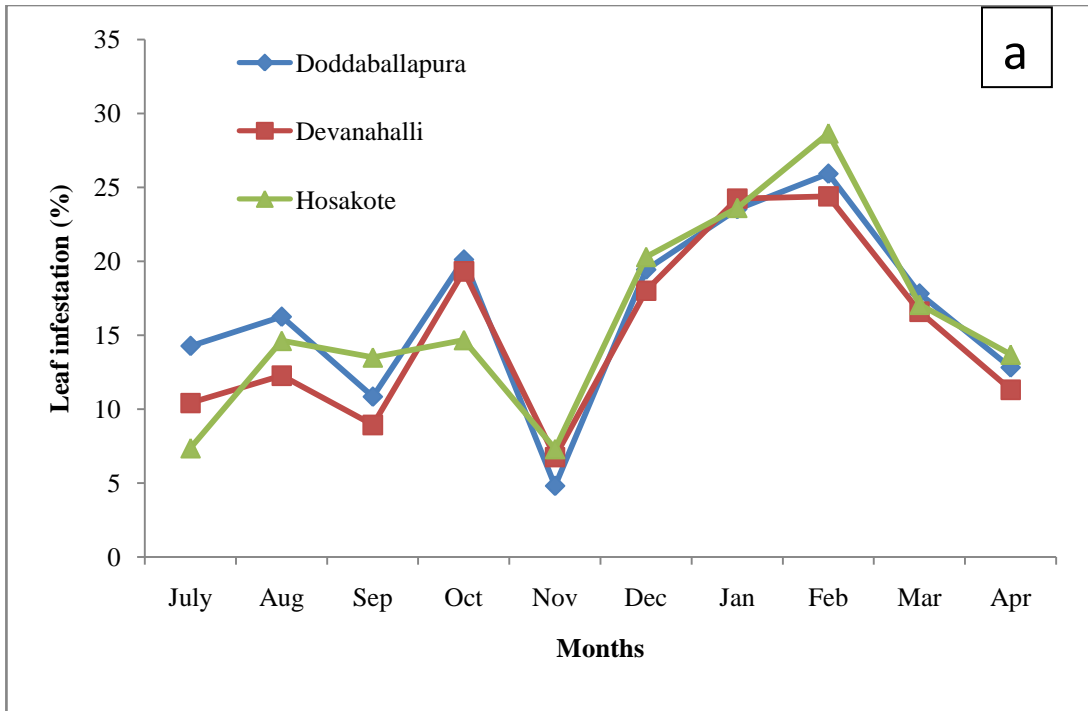


Fig. 2. Mean per cent leaf infestation of *Tuta absoluta* on tomato crop in (a) taluks of Bengaluru Rural district and (b) overall mean of Bengaluru Rural district across different months from July 2015 to April 2016

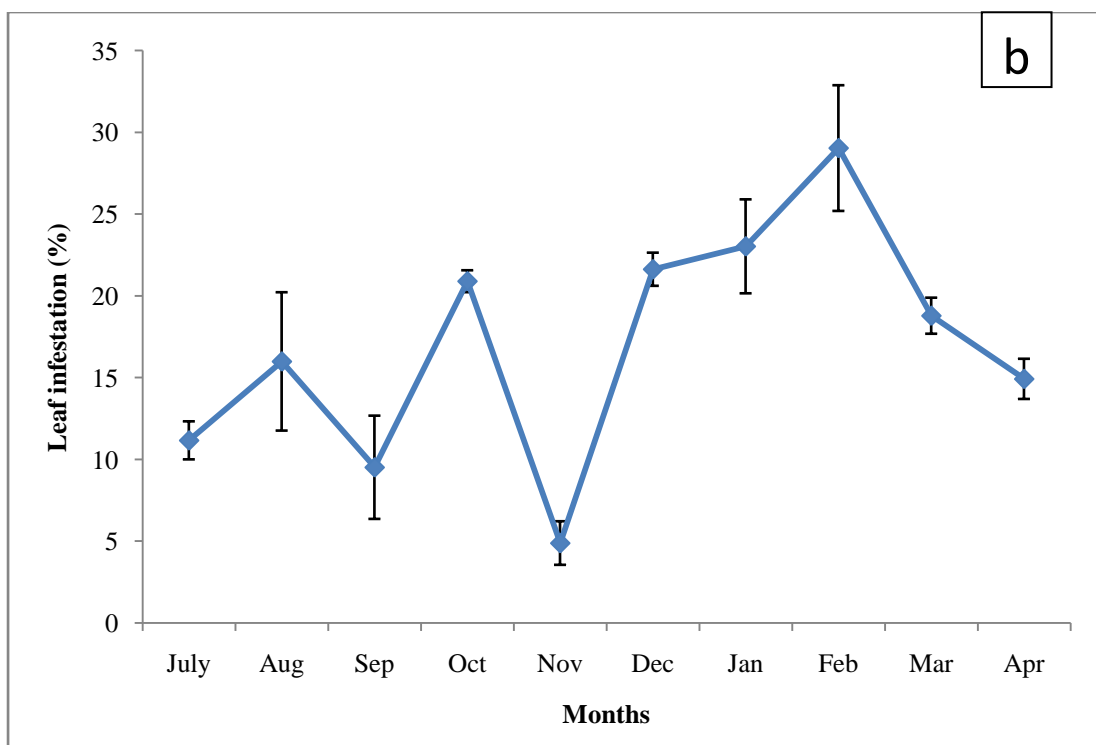
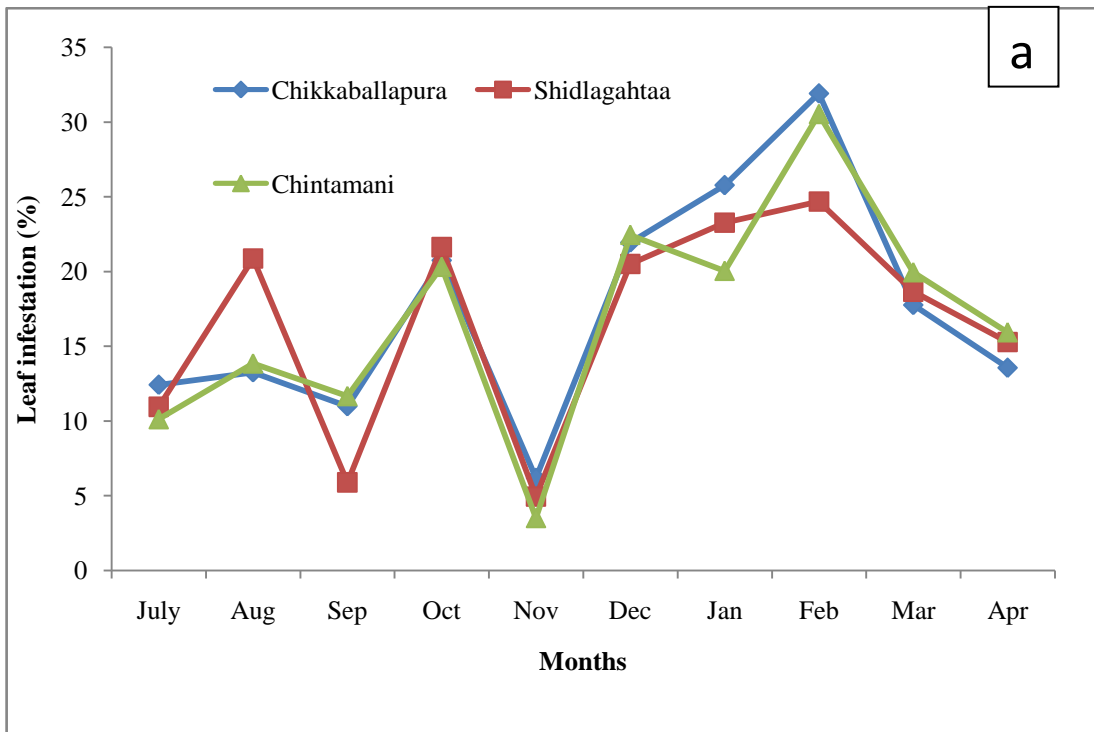


Fig. 3. Mean per cent leaf infestation of *Tuta absoluta* on tomato crop in (a) taluks of Chikkaballapura districts and (b) overall mean of Chikkaballapura district across different months from July 2015 to April 2016

Leaf infestation increased gradually from July (10.13%) to October (20.89%) which reached a low during November (4.88%) which again gained momentum and reached maximum in the month of February (29.04%) and then onwards which tend to decline (Fig. 3b).

4.1.1.3 Kolar district

Results of the survey on leaf infestation in three taluks of Kolar district revealed that the mean per cent leaf infestation followed similar trend for minimum incidence in all the three taluks of the district and same reflected in overall mean per cent infestation of Kolar district (Table 4; Fig. 4a and 4b). Mean per cent leaf infestation in the Kolar district across the month varied from 6.55 during November 2015 to 20.82 per cent in February 2016. Mean per cent infestation was maximum in Maluru taluk irrespective of months (16.14%) and minimum was recorded in Kolar taluk (14.17%). Across all the taluks minimum per cent leaf infestation observed was 4.07, 5.71 and 9.87, respectively in Kolar, Srinivaspura and Maluru taluks during November 2015. Mean per cent leaf infestation tend to increase gradually from November and reached the maximum level of 23.36 per cent in Maluru during February. But in the remaining taluks mean of per cent infestation of leaf showed highest during the month of October 2015 viz., 20.77 and 22.25 per cent, respectively in Kolar and Srinivaspura taluks

Leaf infestation increased gradually from July (10.79%) to October (20.98%) which reached a low during November (6.55%) which again gained momentum and reached maximum in the month of February (20.82%) and then onwards was declined (Fig. 4b).

4.1.1.4 Mysuru district

Results of the rowing survey on leaf infestation in three villages of Mysuru district revealed that, the mean per cent leaf infestation followed the similar trend in the entire three villages and the same was reflected in the overall mean per cent infestation of Mysuru district (Table 4; Fig. 5a and 5b). Mean per cent infestation was found maximum in Yelawala village irrespective of the months (14.85 %) and the minimum was recorded in Ananduru village (11.95%). Mean per cent infestation in the Mysuru district was varied from 5.97 per cent during November 2015 to 22.72 per cent during February 2016. Across all the villages, minimum per cent leaf infestation observed was 5.92, 6.00 and 6.00 per cent at Yelawala, Ananduru and Chikkanahalli respectively during November 2015. And the maximum mean per cent infestation of 20.95, 23.32 and 23.90 per cent was recorded at Ananduru, Chikkanahalli and Yelawala respectively during February 2016.

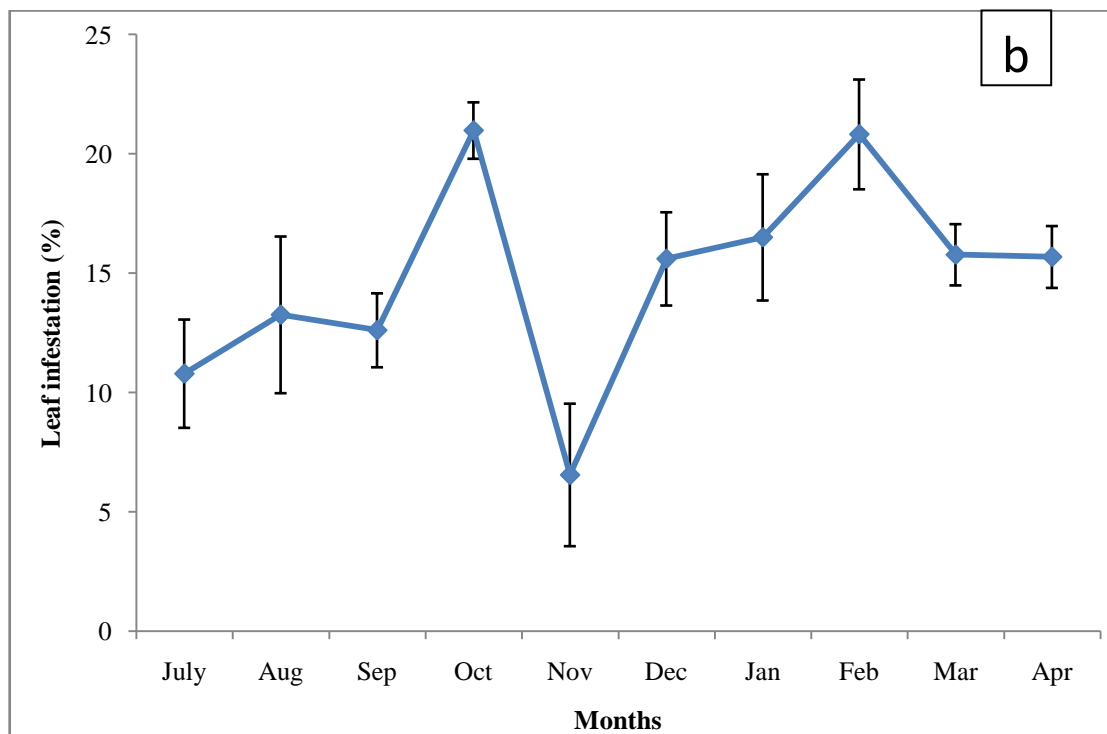
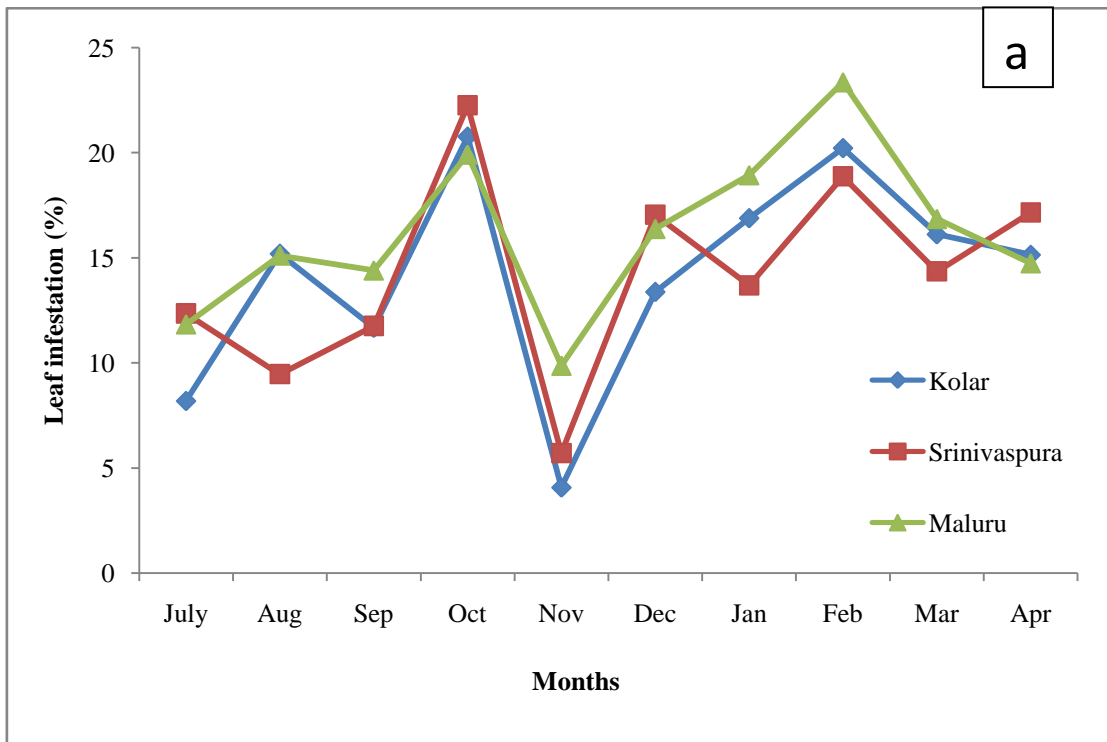


Fig. 4. Mean per cent leaf infestation of *Tuta absoluta* on tomato crop in (a) taluks of Kolar district and (b) overall mean of Kolar district across different months from July 2015 to April 2016

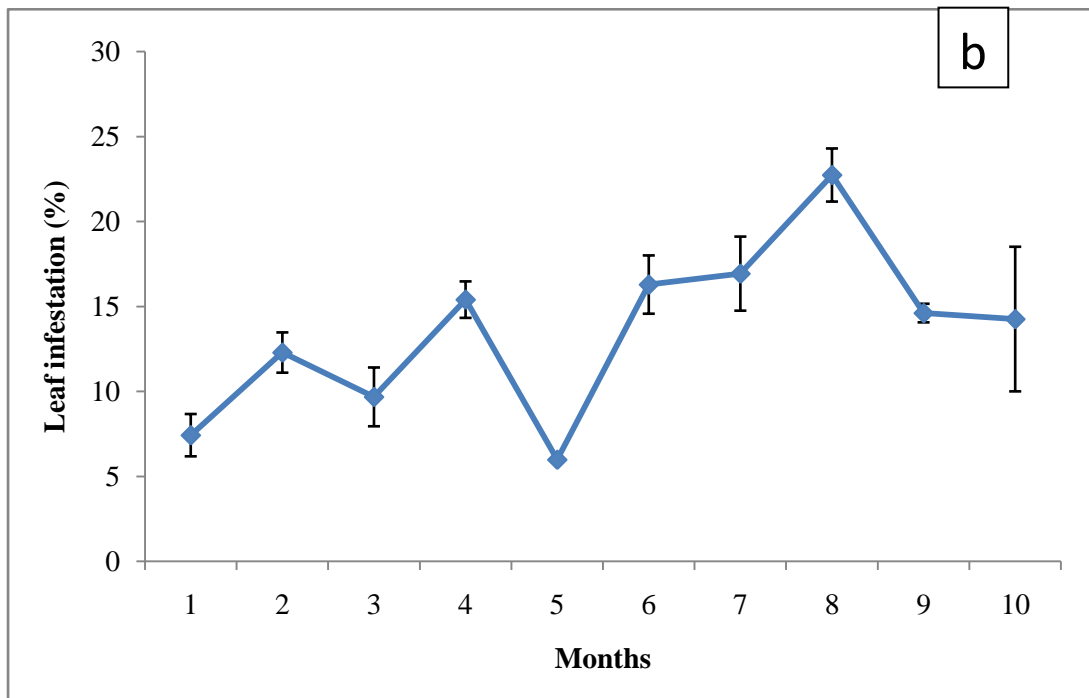
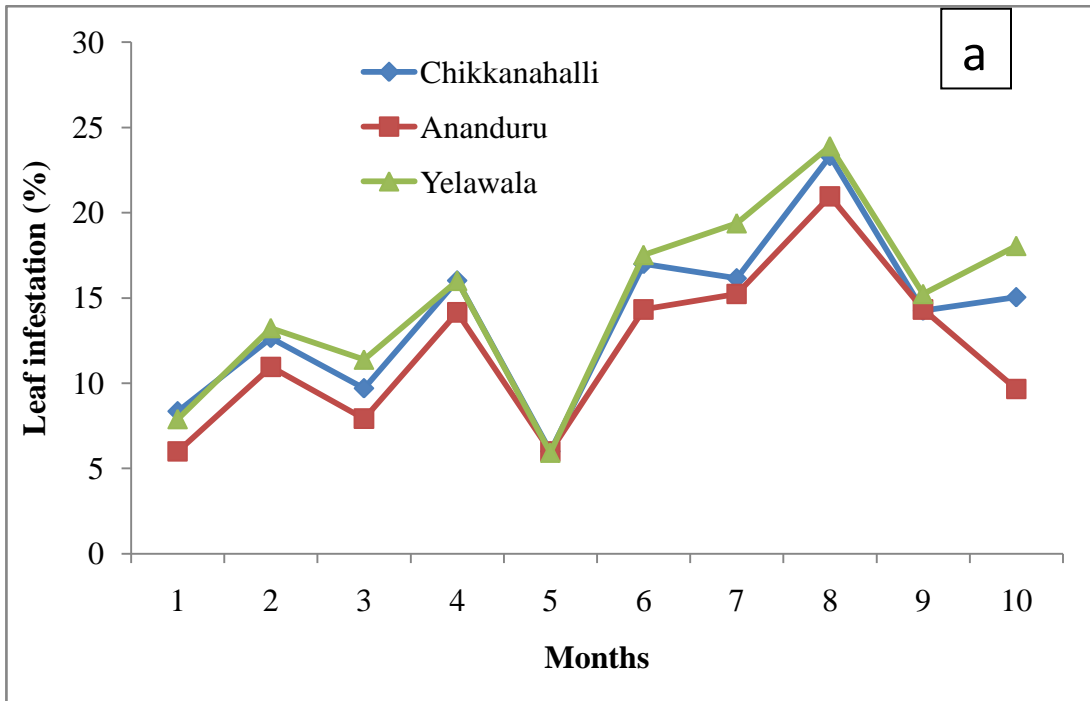


Fig. 5. Mean per cent leaf infestation of *Tuta absoluta* on tomato crop in (a) villages of Mysuru district and (b) overall mean of Kolar district across different months from July 2015 to April 2016

Leaf infestation increased gradually from July 2015 (7.4 %) to 15.39 per cent during October 2015. Thereafter a steady decline in leaf infestation was recorded with a minimum of 5.97 per cent in November 2015. The infestation gained momentum for a while till February 2016 recording a maximum per cent infestation of 22.72 per cent which then tend to decline.

4.1.2 Fruit infestation

Fruit infestation in tomato by *Tuta absoluta* during July 2015 to April 2016 in ten taluks of four districts in Southern Karnataka ranged from a minimum of 3.95 per cent in Ananduru to a maximum of 8.76 per cent in Shidlaghatta. There was very narrow difference in Bengaluru Rural, Chikkaballapura, Kolar and Mysuru districts in terms of fruit infestation. Monthly fruit infestation levels on tomato ranged from a minimum of 1.59 per cent during July 2015 to a maximum of 13.99 per cent during February 2016 (Table 5).

4.1.2.1 Bengaluru Rural district

Results of the survey on per cent fruit infestation in three taluks of Bengaluru Rural district revealed that the mean per cent fruit infestation in Bengaluru Rural district varied from 0.63 per cent during July 2015 to 15.42 per cent during February 2016 (Table 5; Fig. 6a and 6b). Maximum mean per cent fruit infestation observed in Doddaballapura (6.37%) irrespective of months and minimum was noticed in Devanahalli taluk (5.7%). Individual taluks showed a wide range of variation in infestation level from zero to 17.09 per cent; where it showed nil damage in Doddaballapura and Hosakote taluks during July 2015. During September also no fruit infestation was recorded in Doddaballapura. Apart from this mean per cent fruit infestation showed similar trend for all three taluks of Bengaluru Rural district and same was reflected in overall mean per cent fruit infestation of Bengaluru Rural district (Table 5; Fig. 6a and 6b). Mean per cent fruit infestation increased gradually from November 2015 and reached the maximum level viz., 13.69, 15.48 and 17.09 per cent, respectively in Hosakote, Devanahalli and Doddaballapura during February 2016. Then the infestation started declining from February onwards and again reached minimum 4.76 per cent in Bengaluru Rural district during April 2016 (Fig. 6b).

Table 5. Mean per cent fruit damage of *Tuta absoluta* on tomato crop in ten taluks of Southern Karnataka from July 2015 to April 2016

Locations		Mean per cent fruit infestation										
Districts	Taluks	July 2015	Aug 2015	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016	Average
Bengaluru	Doddaballapura	0.00	6.52	0.00	5.07	3.96	5.62	13.51	17.09	8.35	5.32	6.37±5.5
	Devanahalli	1.89	4.92	2.69	6.28	3.65	8.45	8.97	15.48	4.31	4.03	5.76±4.2
	Hosakote	0.00	5.26	4.65	5.60	3.50	8.13	8.28	13.69	7.44	4.94	5.92±3.7
Bengaluru Rural		0.63±1.1	4.20±2.1	2.45±2.3	5.65±0.6	2.72±0.4	7.40±1.5	10.25±2.8	15.42±1.7	6.70±2.1	4.76±0.7	6.02±1.5
Chikkaballapura	Chikkaballapura	3.90	7.59	5.25	5.10	3.65	9.96	13.85	17.24	6.91	5.21	7.49±4.8
	Shidlaghatta	3.07	7.52	1.63	13.69	4.48	13.24	11.71	16.39	12.86	3.90	8.76±5.4
	Chintamani	0.00	4.60	3.50	5.96	0.00	7.87	9.09	14.02	9.26	3.02	5.41±4.3
Chikkaballapura		2.33±2.1	6.12±1.4	3.46±1.8	7.35±5.6	2.46±2.2	10.36±2.7	11.55±2.4	15.88±1.7	8.90±3.5	3.81±1.3	7.22±2.4
Kolar	Kolar	1.13	6.78	5.04	5.60	1.34	6.49	6.33	8.33	5.39	4.98	5.00±2.2
	Srinivaspura	2.22	1.68	4.77	8.44	4.50	6.08	8.00	10.90	5.71	8.94	5.97±3.0
	Maluru	3.11	7.35	5.03	5.19	4.92	4.38	9.52	13.42	5.95	5.91	5.97±3.1
Kolar		2.15±1.0	4.18±2.2	4.95±0.1	6.28±1.9	3.16±1.6	5.65±1.1	7.95±1.6	10.88±2.5	4.78±0.6	6.48±2.2	5.65±1.4
Mysuru taluk	Chikkanahalli	1.20	0.00	3.55	5.07	0.00	7.96	10.25	13.25	4.60	4.73	5.06±4.3
	Ananduru	0.68	0.00	2.73	3.04	0.00	5.02	8.72	14.20	2.24	2.84	3.95±4.4
	Yelawala	1.92	0.00	5.36	6.08	0.00	8.60	11.38	13.90	4.48	5.67	5.74±4.5
Mysuru		1.27±0.6	0.00±0.0	3.88±1.3	4.73±1.5	0.0±0.0	7.19±1.9	10.12±1.3	13.78±0.4	3.77±1.3	4.41±1.4	4.92±4.4
Overall mean across locations		1.59±1.4	4.35±2.3	3.68±1.7	6.26±2.9	2.50±1.6	7.65±2.5	9.97±2.4	13.99±2.8	6.46±2.7	4.96±1.6	6.14±2.2

* Observations on average of three plots per month per taluk

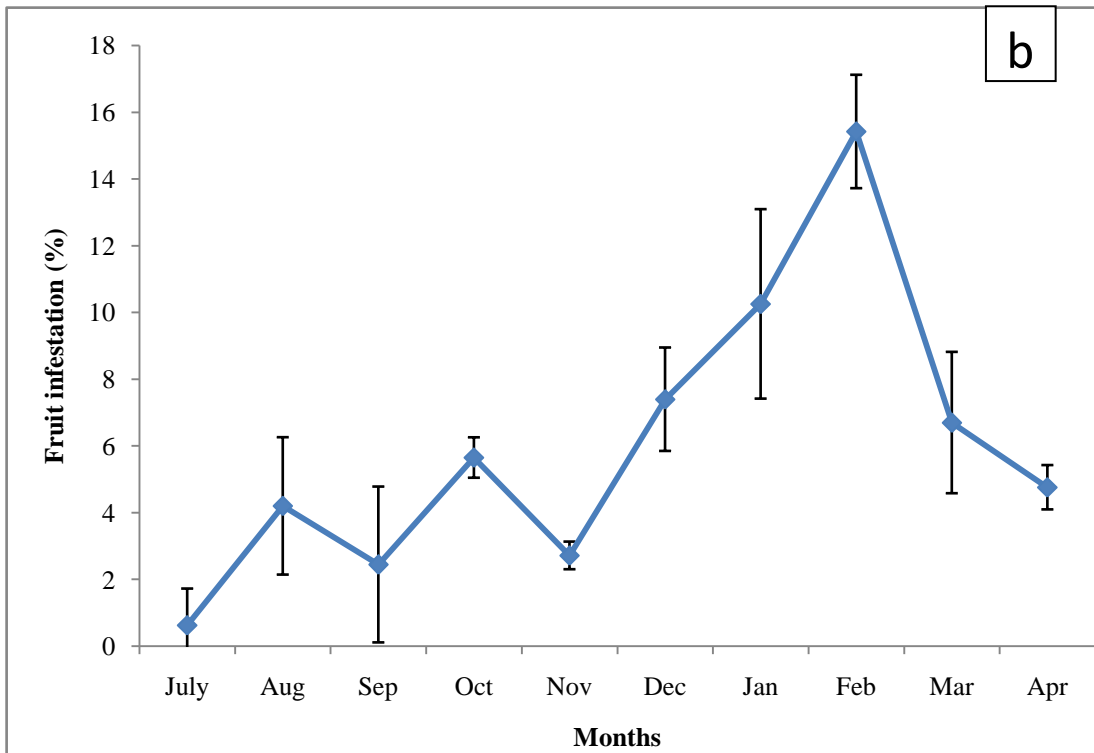
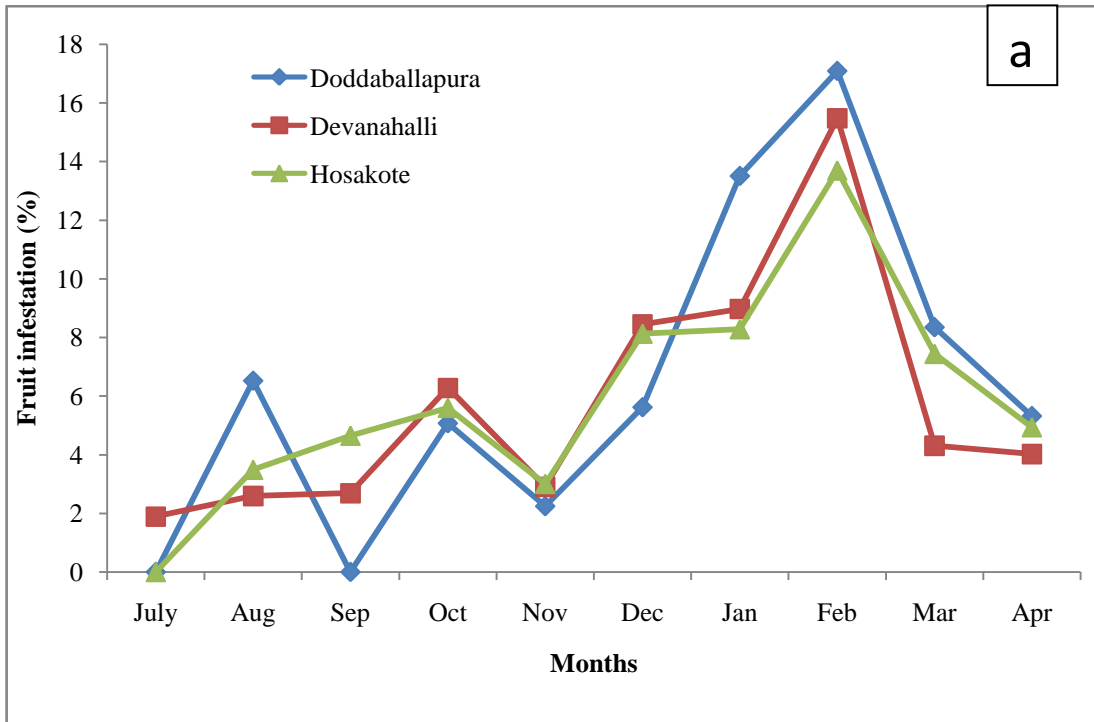


Fig. 6. Mean per cent fruit infestation of *Tuta absoluta* on tomato crop in (a) taluks of Bengaluru Rural district and (b) overall mean of Bengaluru Rural district across different months from July 2015 to April 2016

4.1.2.2 Chikkaballapura district

Results of the survey on per cent fruit infestation in three taluks of Chikkaballapura district revealed that the mean per cent fruit infestation was found to follow similar trend in taluks of Chikkaballapura district and same was reflected in overall mean of the Chikkaballapura district except in Shidlaghatta taluk (Table 5; Fig. 7a and 7b). Maximum mean per cent fruit infestation was observed in Shidlaghatta with infestation of 8.76 per cent fruits and minimum was noticed in Chintamani with 5.41 per cent fruits damaged irrespective of the months. District mean per cent fruit infestation was minimum (2.33%) during July 2015 and maximum (15.88%) during February 2016. Mean per cent fruit infestation was minimum (2.33%) during July 2015 and was maximum (15.88%) during February 2016 in Chikkaballapura district. Mean per cent fruit infestation showed no infestation during July and November 2015 in Chintamani taluk. In Chikkaballapura taluk, lowest mean per cent infestation was recorded in the month of November 2015 (3.01 %) and in Shidlaghatta taluk minimum fruit infestation was noticed in the month of September 2015 (1.63%). Mean per cent fruit infestation increased gradually from November 2015 and reached maximum level viz., 14.02, 16.39 and 17.24 per cent, respectively in Chintamani, Shidlaghatta and Chikkaballapura taluks during February 2016. Mean per cent infestation started declining from February onwards and reached a minimum of 3.81 per cent during April 2016 (Fig. 7b).

4.1.2.3 Kolar district

Results of the survey on per cent fruit infestation in three taluks of Kolar district revealed that the maximum mean per cent fruit infestation was found in Maluru with 5.97 per cent irrespective of month and minimum was recorded in Kolar taluk with 5.00 per cent (Table 5; Fig. 8a and 8b). Kolar district mean per cent fruit infestation varied from 2.15 during July 2015 to 10.88 during February 2016. Infestation was found to be minimum viz., 1.13 and 3.11, respectively at Kolar and Maluru taluks during July 2015. In Maluru the minimum mean per cent fruit infestation was recorded during August 2015 (1.68%). Mean per cent fruit infestation increased gradually from November 2015 and reached maximum level viz., 8.33, 10.90 and 13.42 per cent respectively in Kolar, Srinivaspura and Maluru taluks during February 2016. Mean per cent infestation started declining from February onwards and reached minimum 4.78 in the month of March and then it started to increase in the month of April 2016 (Fig. 8b).

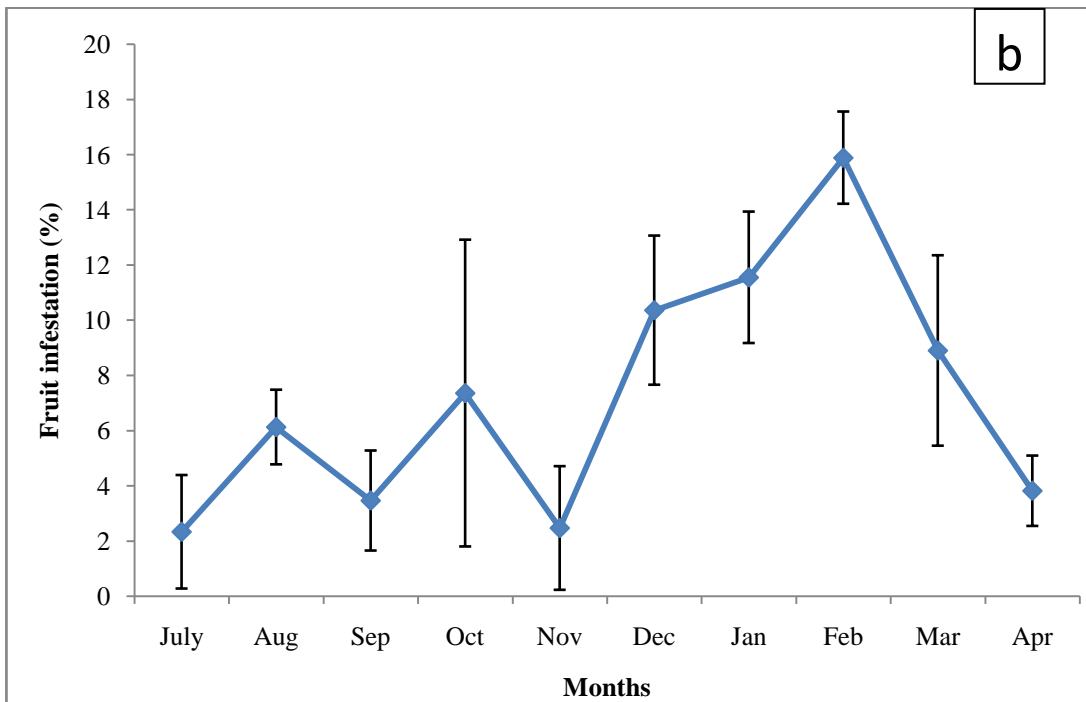
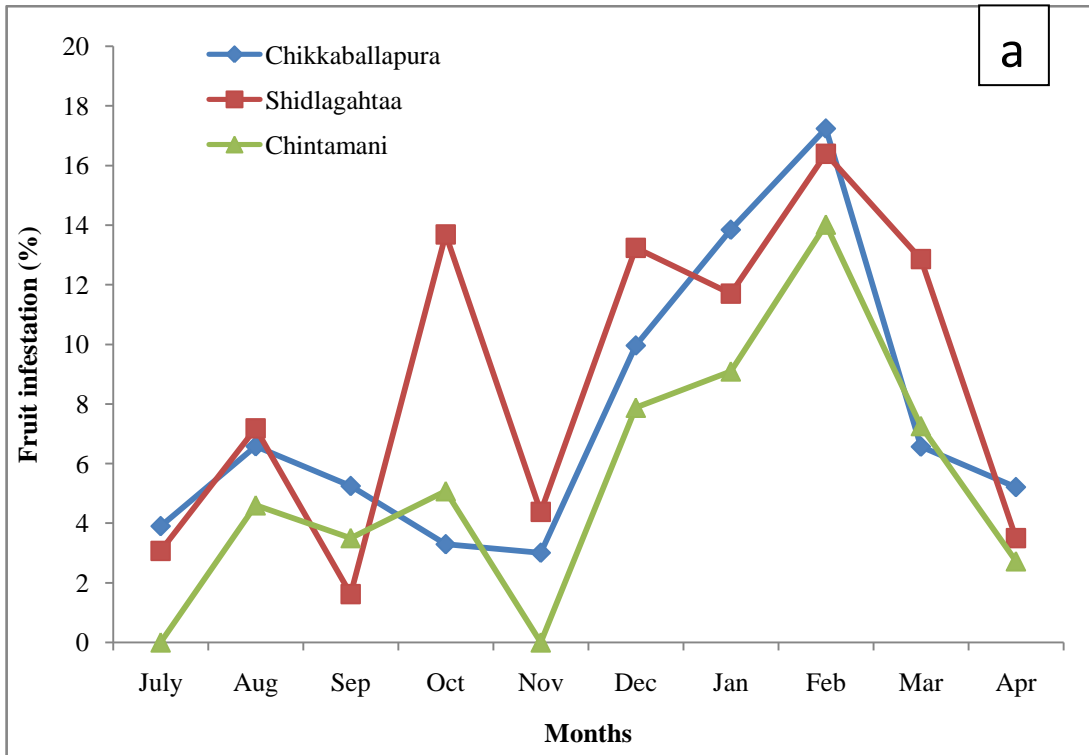


Fig. 7. Mean per cent fruit infestation of *Tuta absoluta* on tomato crop in (a) taluks of Chikkaballapura district and (b) overall mean of Chikkaballapura district across different months from July 2015 to April 2016

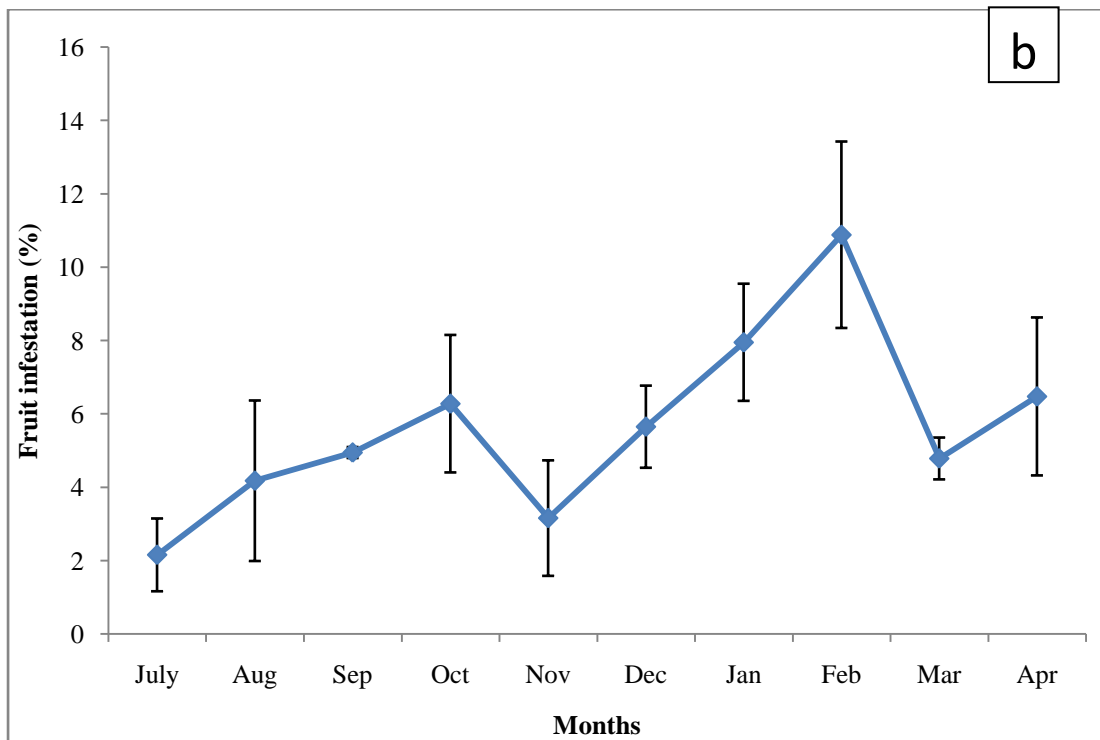
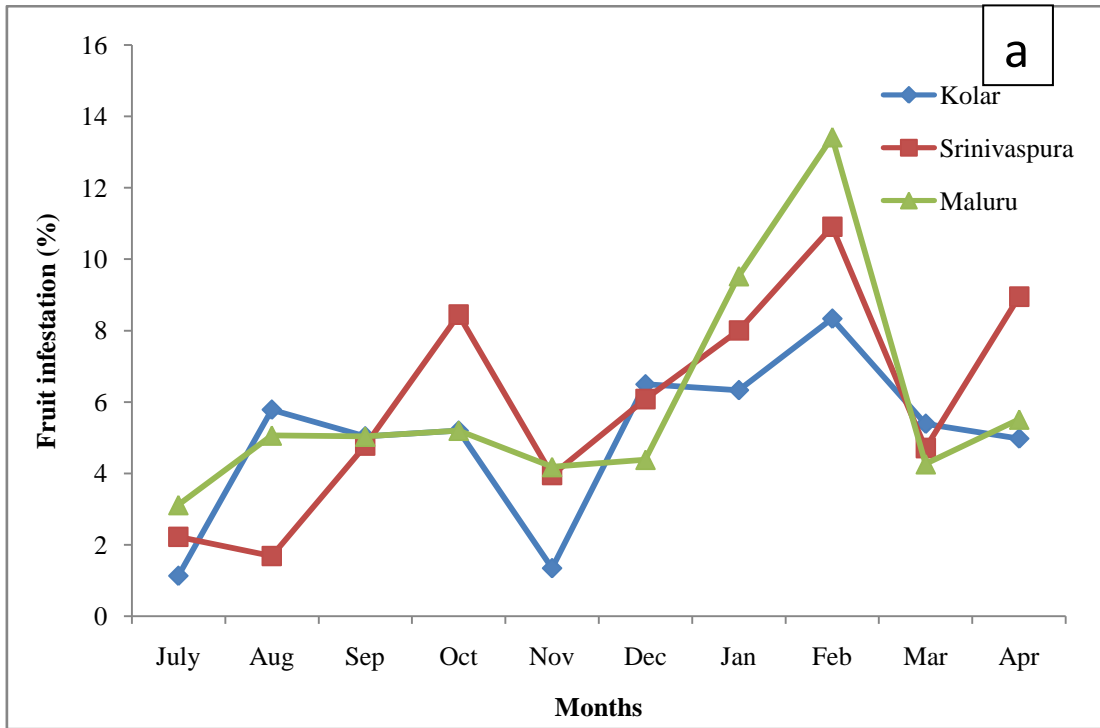


Fig. 8. Mean per cent fruit infestation of *Tuta absoluta* on tomato crop in (a) taluks of Kolar district and (b) overall mean of Kolar district across different months from July 2015 to April 2016

4.1.2.4 Mysuru district

Results of the rowing survey on fruit infestation in three villages of Yelowala hobli of Mysuru district revealed a very narrow difference in fruit infestation (Table 5; Fig. 9a and 9b). Mean per cent fruit infestation was found maximum in Yelowala village irrespective of the months (5.74 %) and the minimum was recorded in Ananduru village (3.95 %). Mean per cent fruit infestation in the Mysuru district was varied from zero per cent during August and November 2015 to 13.78 per cent during February 2016. Across all the villages, nil fruit damage was observed at Yelowala, Ananduru and Chikkanahalli during August and November 2015. And the maximum mean per cent fruit infestation of 13.25, 13.90 and 14.20 per cent was recorded at Ananduru, Chikkanahalli and Yelowala, respectively during February 2016.

Mean per cent fruit infestation was recorded minimum of zero per cent during August and November 2015. The maximum mean per cent fruit infestation was found 13.78 per cent during February 2016, which decreased considerably thereafter.

4.2 Influence of weather factors on incidence of SATLM at four districts of Southern Karnataka

Attempt was made to know the influence of weather parameters on the incidence of *T. absoluta* on tomato crop in four districts of South Karnataka, viz., Bengaluru Rural, Chikkaballapura, Kolar and Mysuru districts during the study period from July 2015 to April 2016. Correlation results revealed that the weather factors had contributed in varying the leaf and fruit infestation level of *T. absoluta* throughout the study period. Maximum temperature had a positive influence on leaf and fruit infestation in all the districts of the study area. Significant positive relation was observed only in Bengaluru Rural district. Rainfall had influenced significantly the leaf and fruit infestation negatively in all the four districts.

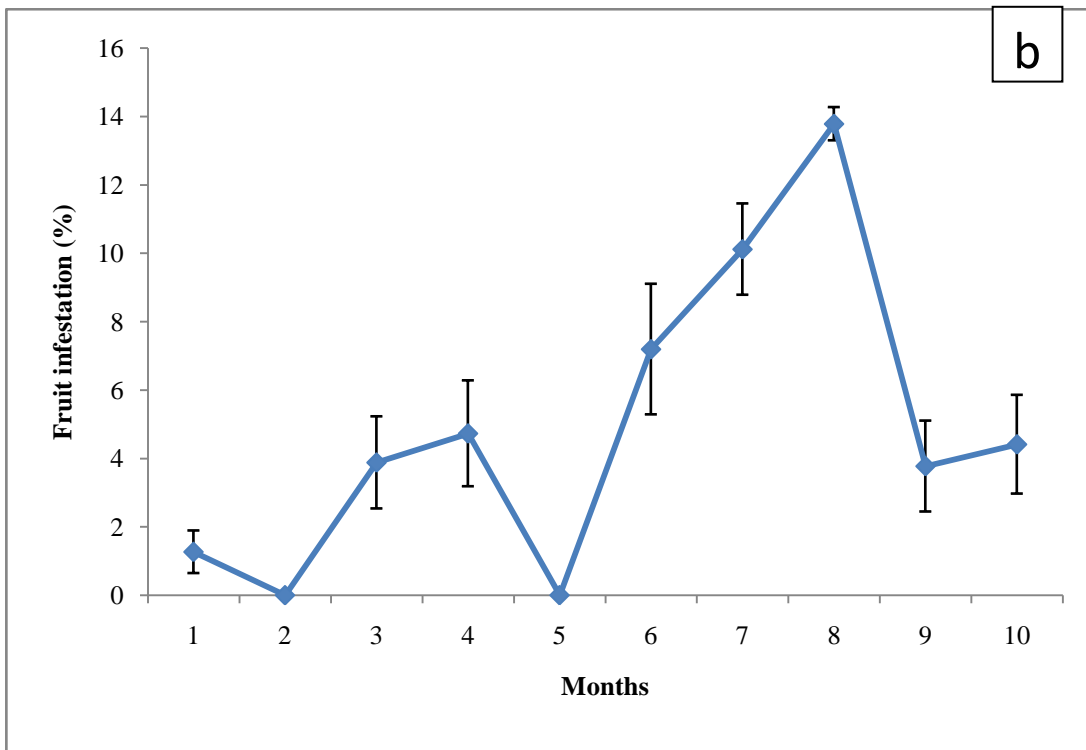
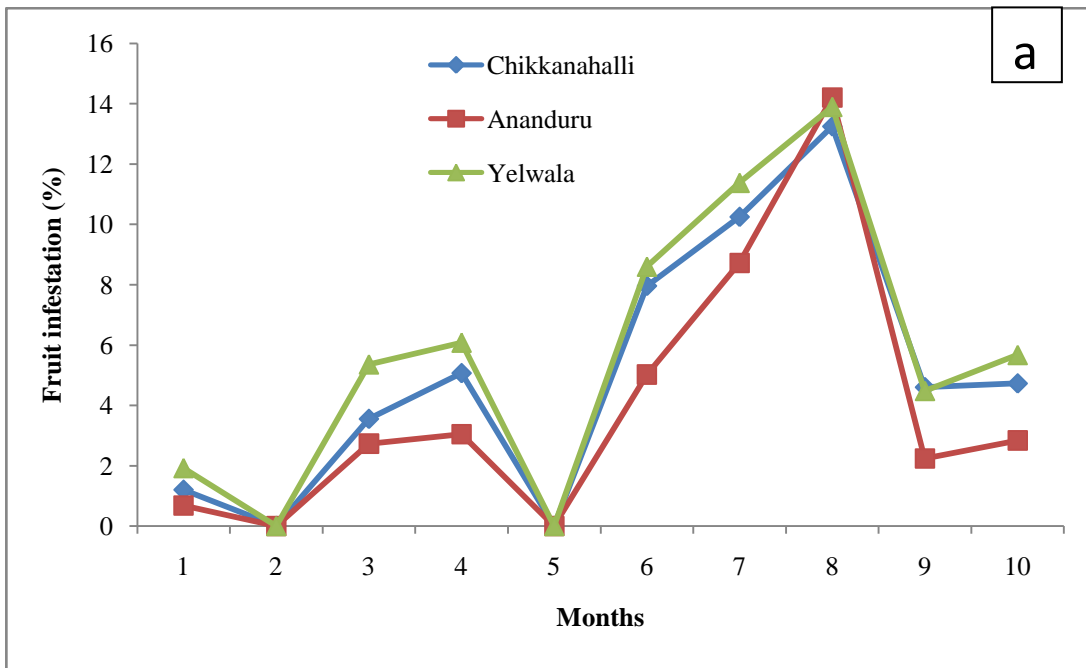


Fig. 9. Mean per cent fruit infestation of *Tuta absoluta* on tomato crop in (a) villages of Mysuru district and (b) overall mean of Kolar district across different months from July 2015 to April 2016

4.2.1 Bengaluru Rural district

4.2.1.1 Correlation between per cent leaf infestation and weather parameters

Results of the correlation analysis between the per cent leaf infestation and four weather parameters in Bengaluru Rural showed that, the incidence was positively and significantly correlated with maximum temperature ($r=0.329$; $p>0.05$; $df=28$) and negative significant correlation with minimum temperature ($r=-0.394$; $p<0.05$; $df=28$), negatively correlated with maximum and minimum relative humidity ($r=-0.114$; $p>0.05$; $df=28$ and $r=-0.615$; $p<0.01$; $df=28$), significant negative correlation was found with wind speed ($r=-0.425$; $p<0.05$; $df=28$) and with rainfall ($r=-0.678$; $p<0.01$; $df=28$) (Fig. 10).

4.2.1.2 Correlation between per cent fruit infestation and weather parameters

Results of the correlation analysis between per cent fruit infestation and four weather parameters in Bengaluru Rural showed that, the incidence was found to be positively correlated with maximum temperature ($r=0.308$; $p>0.05$; $df=28$) and negative significant correlation with minimum temperature ($r=-0.454$; $p<0.05$; $df=28$), negatively correlated with maximum and minimum relative humidity ($r=-0.078$; $p>0.05$; $df=28$ and $r=-0.575$; $p<0.05$; $df=28$) and negatively correlated with wind speed ($r=-0.461$; $p<0.05$; $df=28$) and significant negative correlation was found with rainfall ($r=-0.561$; $p<0.01$; $df=28$) (Fig. 11).

4.2.2 Chikkaballapura district

4.2.2.1 Correlation between per cent leaf infestation and weather parameters

Results of the correlation analysis between the per cent leaf infestation and four weather parameters registered a positive correlation with maximum temperature ($r=0.271$; $p>0.05$; $df=28$) and negative significant correlation with minimum temperature ($r=-0.488$; $p<0.01$; $df=28$), negatively correlated with maximum and minimum relative humidity ($r=-0.075$; $p>0.05$; $df=28$ and $r=-0.562$; $p<0.01$; $df=28$) and wind speed ($r=-0.206$; $p>0.05$; $df=28$) and it had significant negative correlation with rainfall ($r=-0.740$; $p<0.01$; $df=28$) (Fig. 12).

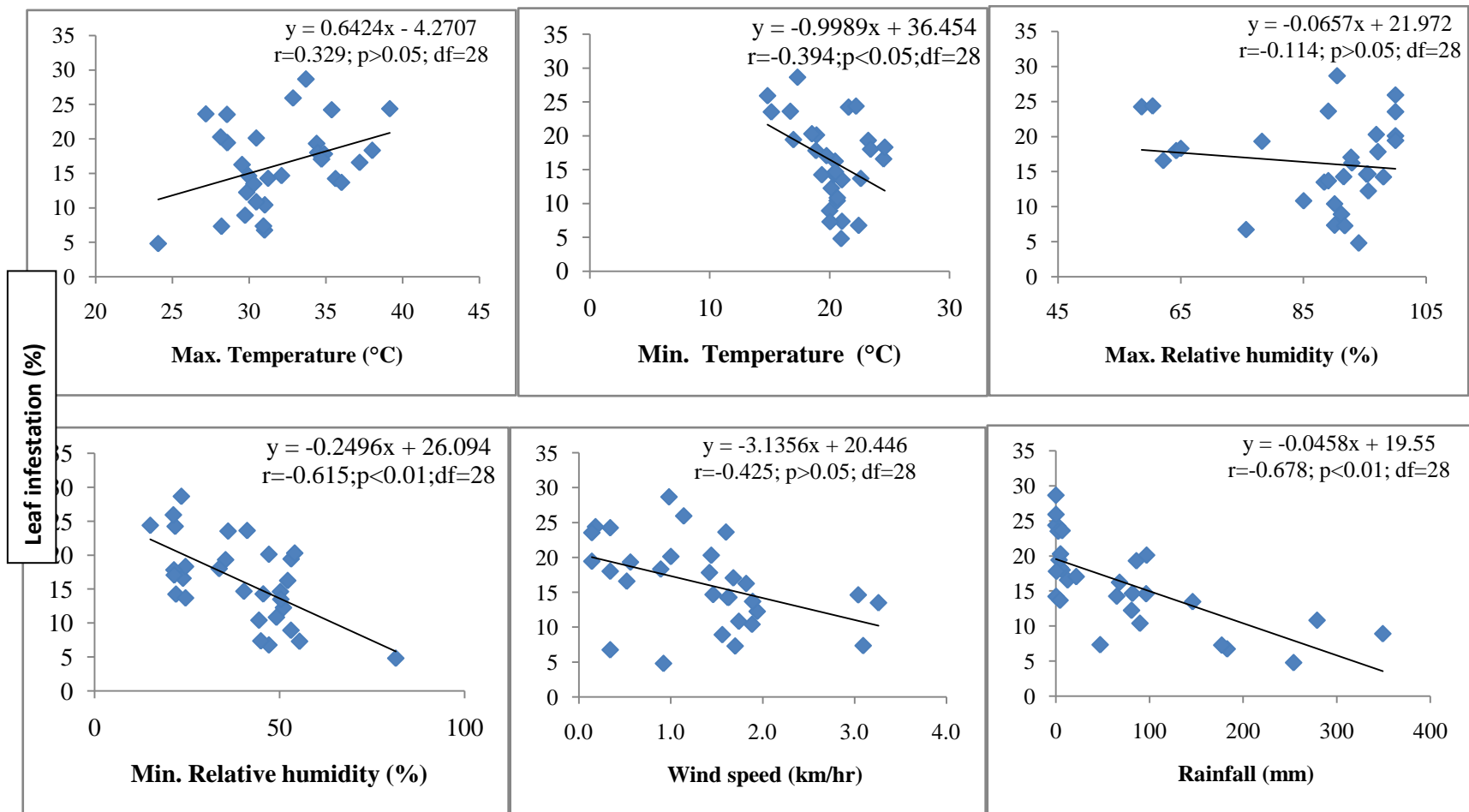


Fig. 10. Correlation between mean per cent leaf infestation and weather parameters in Bengaluru Rural district during July 2015 to April 2016

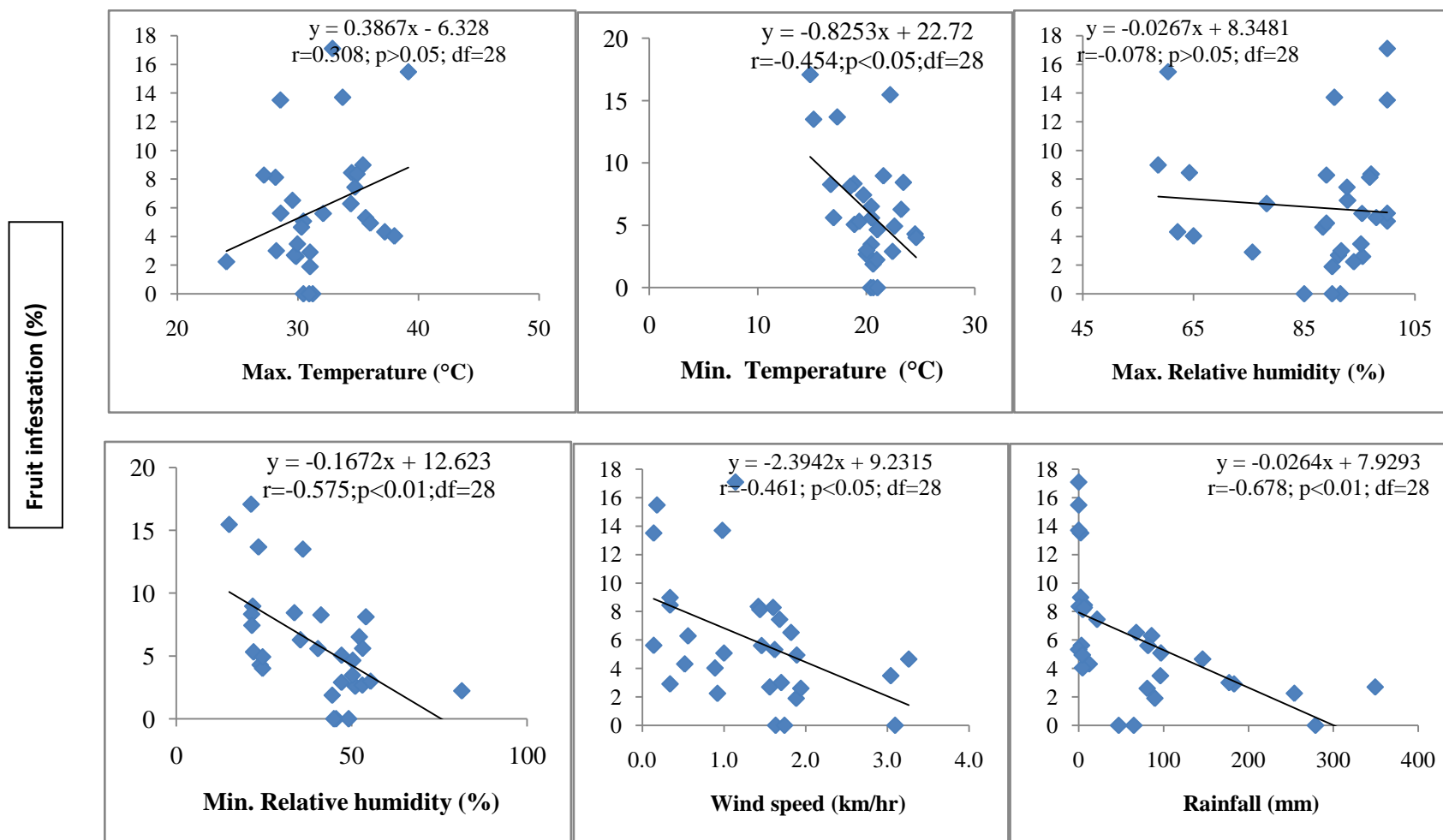


Fig. 11. Correlation between mean per cent fruit infestation and weather parameters in Bengaluru Rural district during July 2015 to April 2016

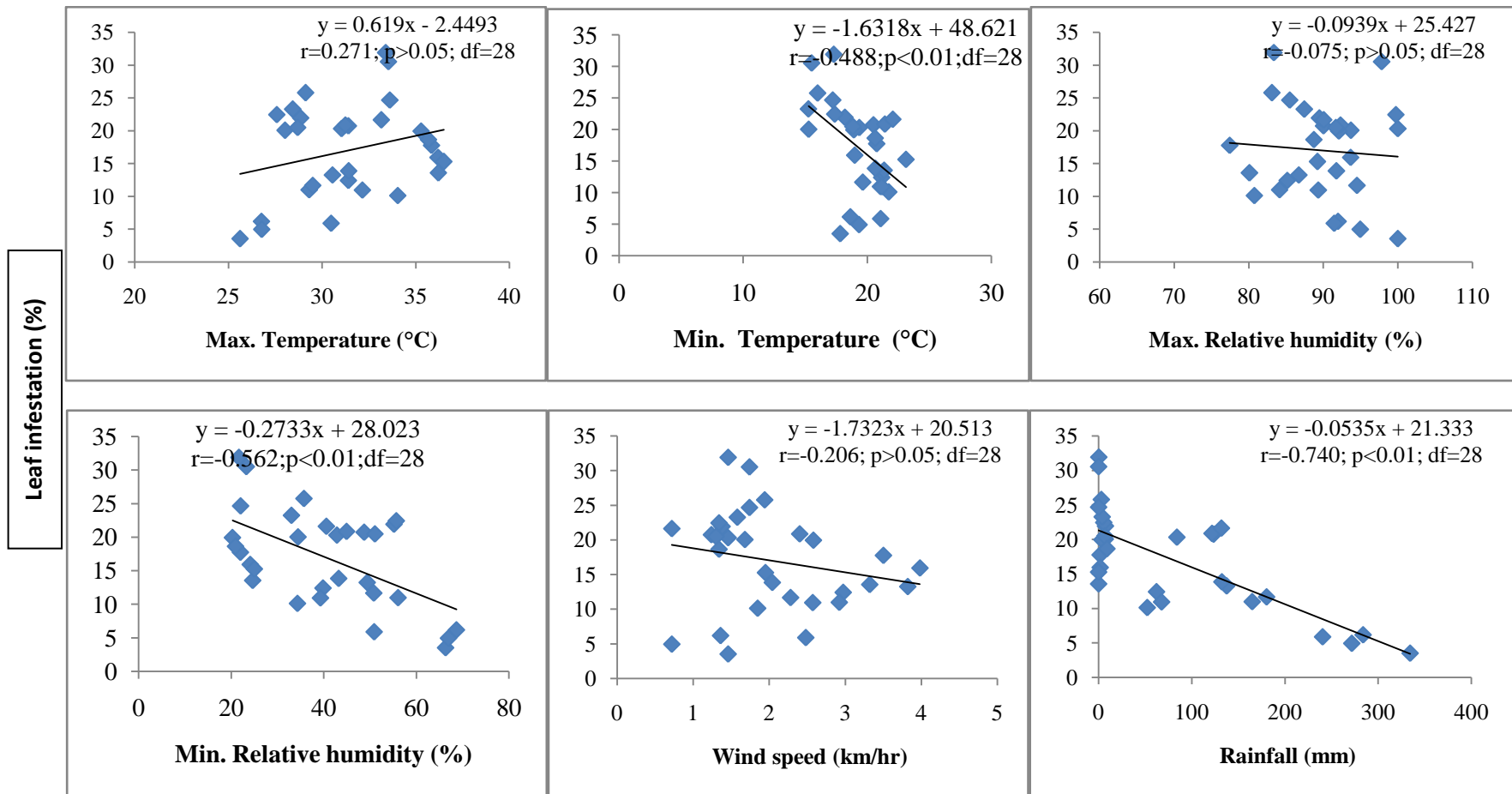


Fig. 12. Correlation between mean per cent leaf infestation and weather parameters in Chikkaballapura district during July 2015 to April 2016

4.2.2.2 Correlation between per cent fruit infestation and weather parameters

Correlation of fruit infestation and weather parameters followed the same trend as leaf infestation, which was positively correlated with maximum temperature ($r=0.104$; $p>0.05$; $df=28$) and negative significant correlation with minimum temperature ($r=-0.506$; $p<0.01$; $df=28$), negatively correlated with maximum and minimum relative humidity ($r=-0.156$; $p>0.05$; $df=28$ and $r=-0.418$; $p<0.05$; $df=28$) also with wind speed ($r=-0.329$; $p>0.05$; $df=28$). Fruit infestation in Chikkaballapura district was negatively and significantly correlated with rainfall ($r=-0.543$; $p<0.01$; $df=28$) (Fig. 13).

4.2.3 Kolar district

4.2.3.1 Correlation between per cent leaf infestation and weather parameters

Correlation results between the leaf infestation and four weather parameters revealed that, the incidence was positively and significantly correlated with maximum temperature ($r=0.404$; $p<0.05$; $df=28$) and negative correlation with minimum temperature ($r=-0.295$; $p>0.05$; $df=28$), negatively correlated with maximum and minimum relative humidity ($r=-0.110$; $p>0.05$; $df=28$ and $r=-0.544$; $p<0.01$; $df=28$) and with wind speed ($r=-0.244$; $p>0.05$; $df=28$). Negative and significant correlation was recorded with rainfall ($r=-0.663$; $p<0.01$; $df=28$) in Kolar district (Fig. 14).

4.2.3.2 Correlation between per cent fruit infestation and weather parameters

Fruit infestation in Kolar district has a non-significant positive correlation with maximum temperature ($r=0.187$; $p>0.05$; $df=28$) and negative significant correlation with minimum temperature ($r=-0.645$; $p<0.01$; $df=28$), while it was negative with maximum and minimum relative humidity ($r=-0.326$; $p>0.05$; $df=28$ and $r=-0.461$; $p<0.05$; $df=28$) and also with wind speed ($r=-0.333$; $p>0.05$; $df=28$). The negative correlation influence of rainfall was significant ($r=-0.465$; $p<0.01$; $df=28$) (Fig. 15).

4.2.4 Mysuru district

4.2.4.1 Correlation between per cent leaf and fruit infestation and weather parameters

Correlation studies of the per cent leaf and fruit infestation by *T. absoluta* in Mysuru district recorded that they were positively correlated with maximum temperature and negatively correlated with minimum temperature also with maximum and minimum relative humidity. On the other hand both leaf and fruit infestations were negatively and significantly correlated with the wind speed and rainfall in Mysuru district (Fig. 16 and 17).

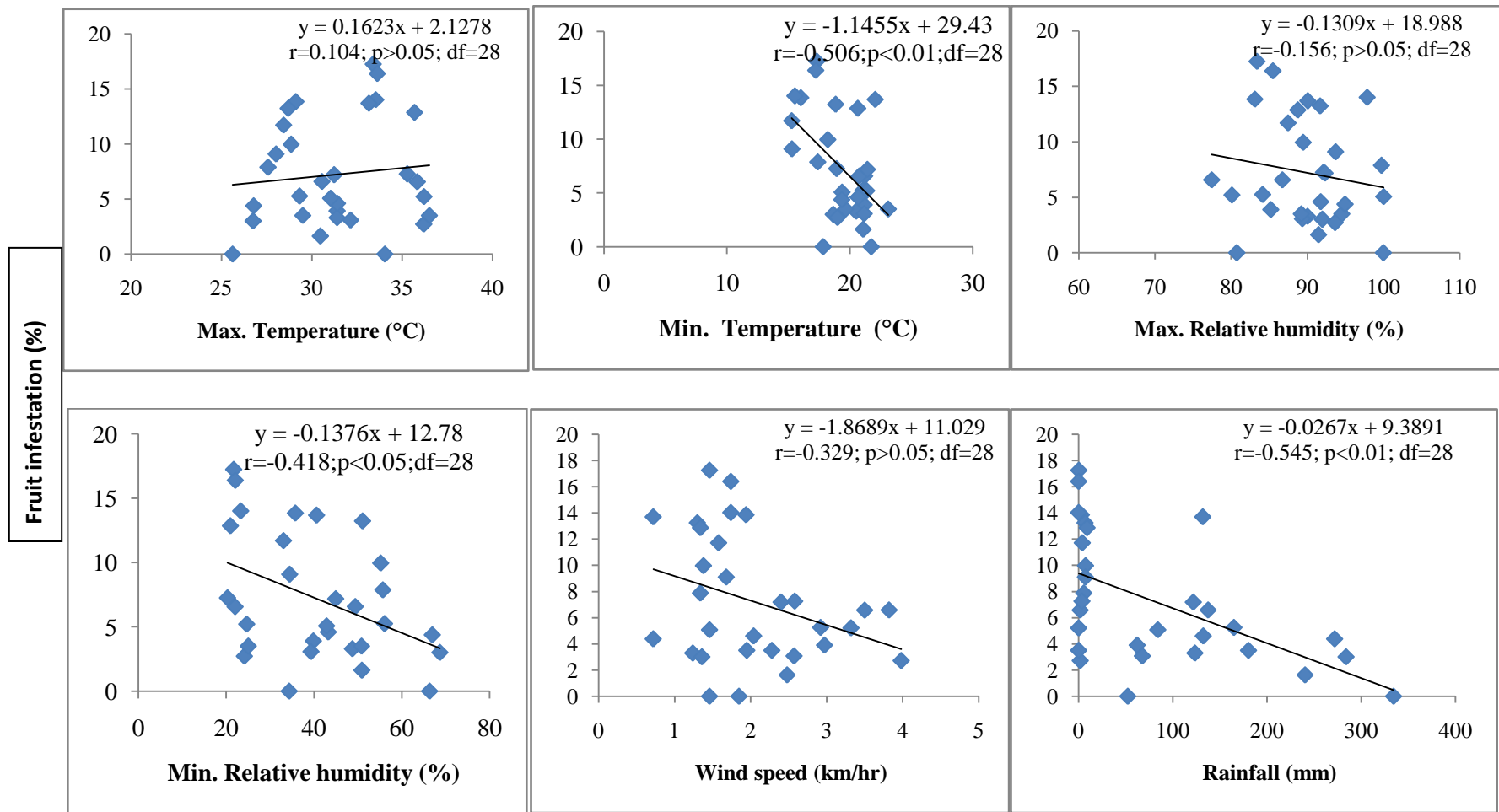


Fig. 13. Correlation between mean per cent fruit infestation and weather parameters in Chikkaballapura district during July 2015 to April 2016

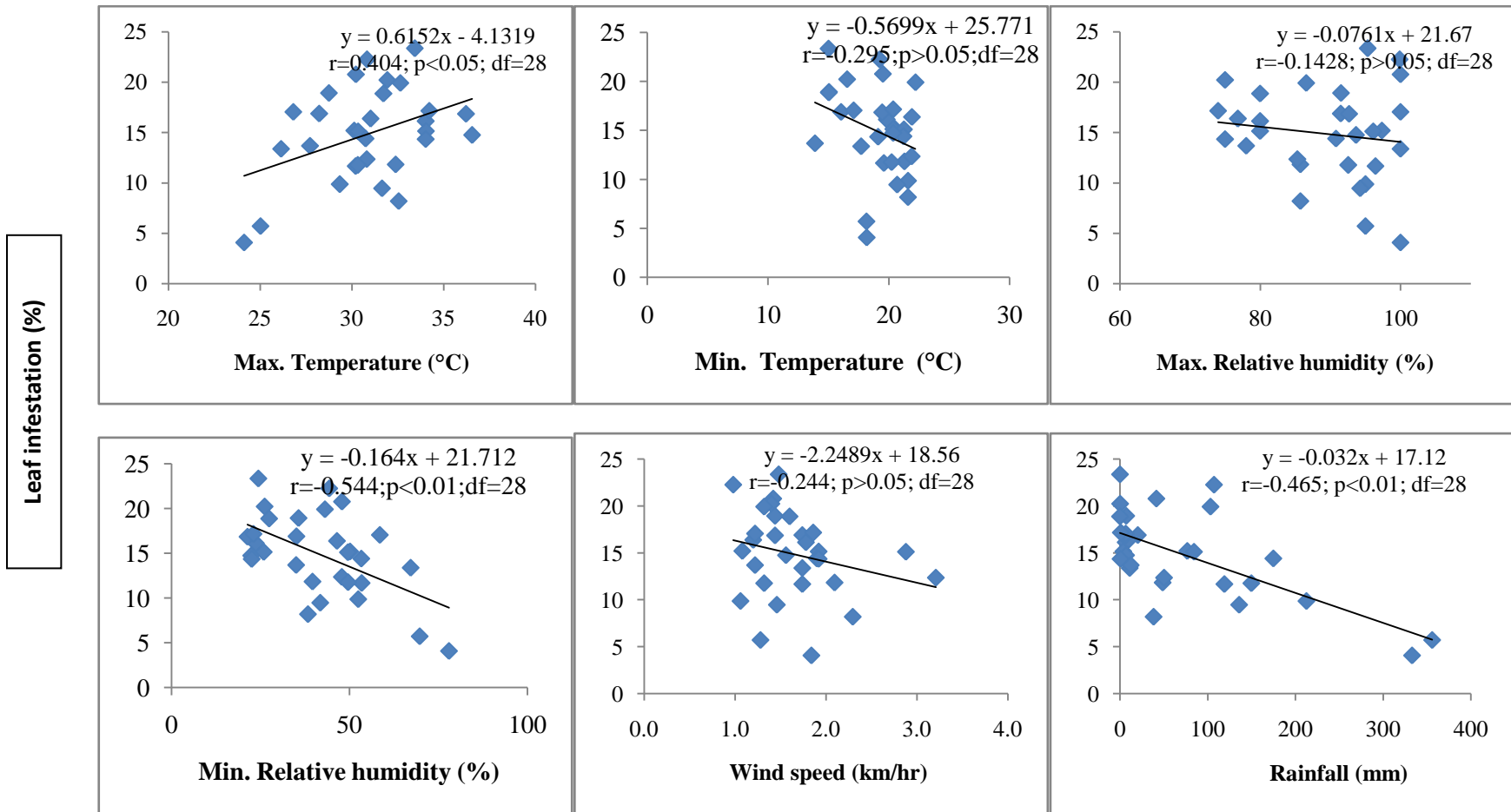


Fig. 14. Correlation between mean per cent leaf infestation and weather parameters in Kolar district during July 2015 to April 201

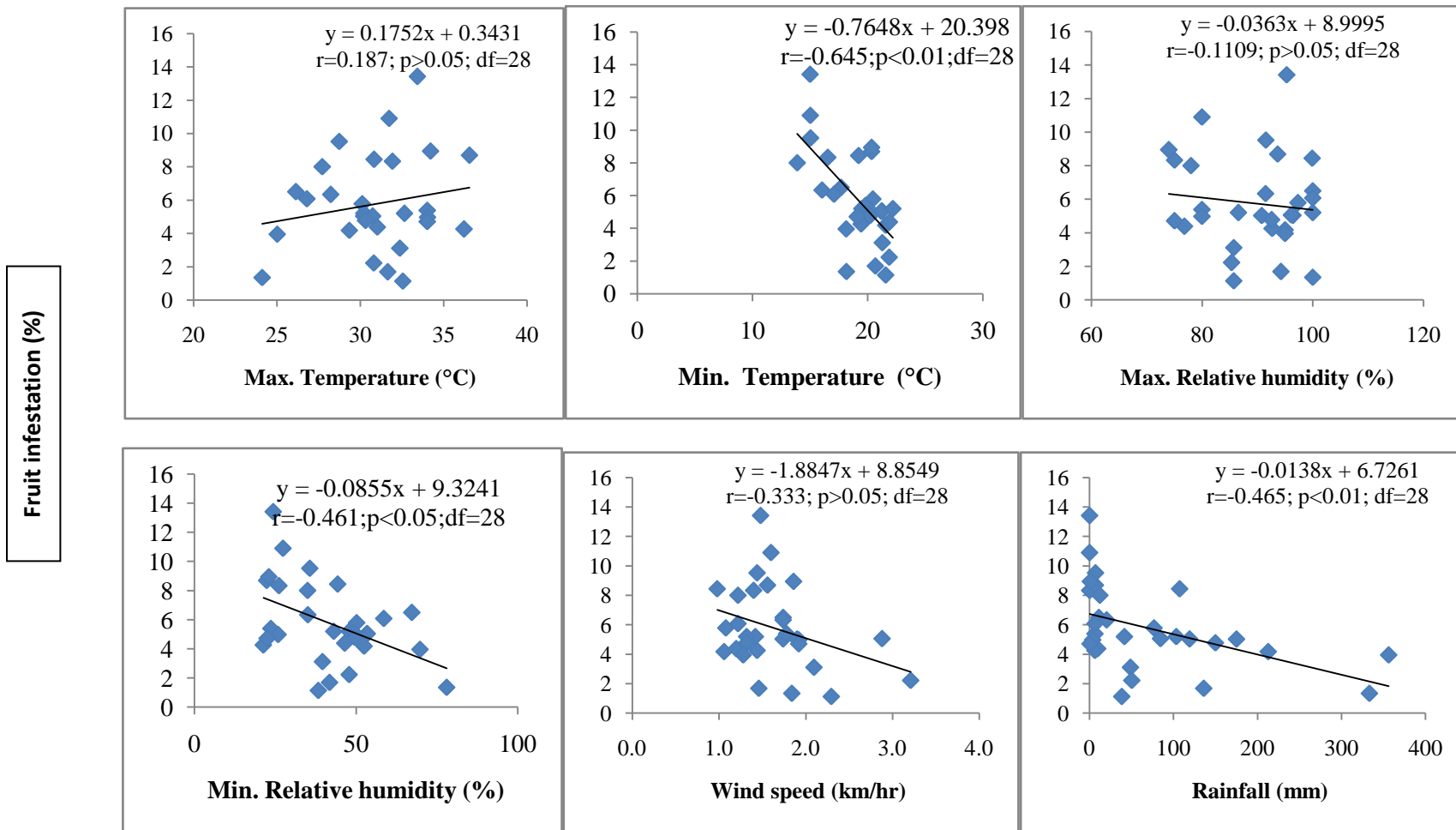


Fig. 15. Correlation between mean per cent fruit infestation and weather parameters in Kolar district during July 2015 to April 2016

4.3 Multiple regression models with weather parameters

Multiple regression models comprising of four weather parameters in four districts of southern Karnataka had higher probability and fairly reliable R^2 values (Table 6) for both leaf and fruit infestation by *T. absoluta* on tomato. Models observed for the Mysuru district were highly significant while the models were significant for other three districts for both leaf and fruit infestation. Influence of four weather parameters on leaf and fruit infestation in tomato ranged from 45 to 72 per cent. In the multiple regression models obtained for Chikkaballapura and Mysuru district temperature had a negative influence on the leaf and fruit damage. Rainfall and wind speed consistently contributed negatively for leaf and fruit damage by *T. absoluta* in all the four districts. Mean model obtained for ten taluks of southern Karnataka revealed a negative contribution of temperature for fruit damage which was positive for leaf damage.

4.4 Influence of mulching and crop stage on infestation of SATLM in four districts of south Karnataka

4.4.1 Leaf infestation

Polythene mulched crop showed less infestation than the non-mulched crops across different crop stage and months. Mean per cent leaf infestation in the polythene mulched crop was 11.26 per cent and in non-mulched crops registered 17.03 per cent infestation. Among the months, during February highest leaf infestation in both polythene mulched crop (18.83%) and in non-mulched crop (25.66%) across the different crop stages (Table 7).

With respect to crop stage, the developmental period between 30 to 60 days old crop showed more leaf infestation in both mulched (12.75%) and non-mulched (19.35%) situations across the different months of observations (Table 7).

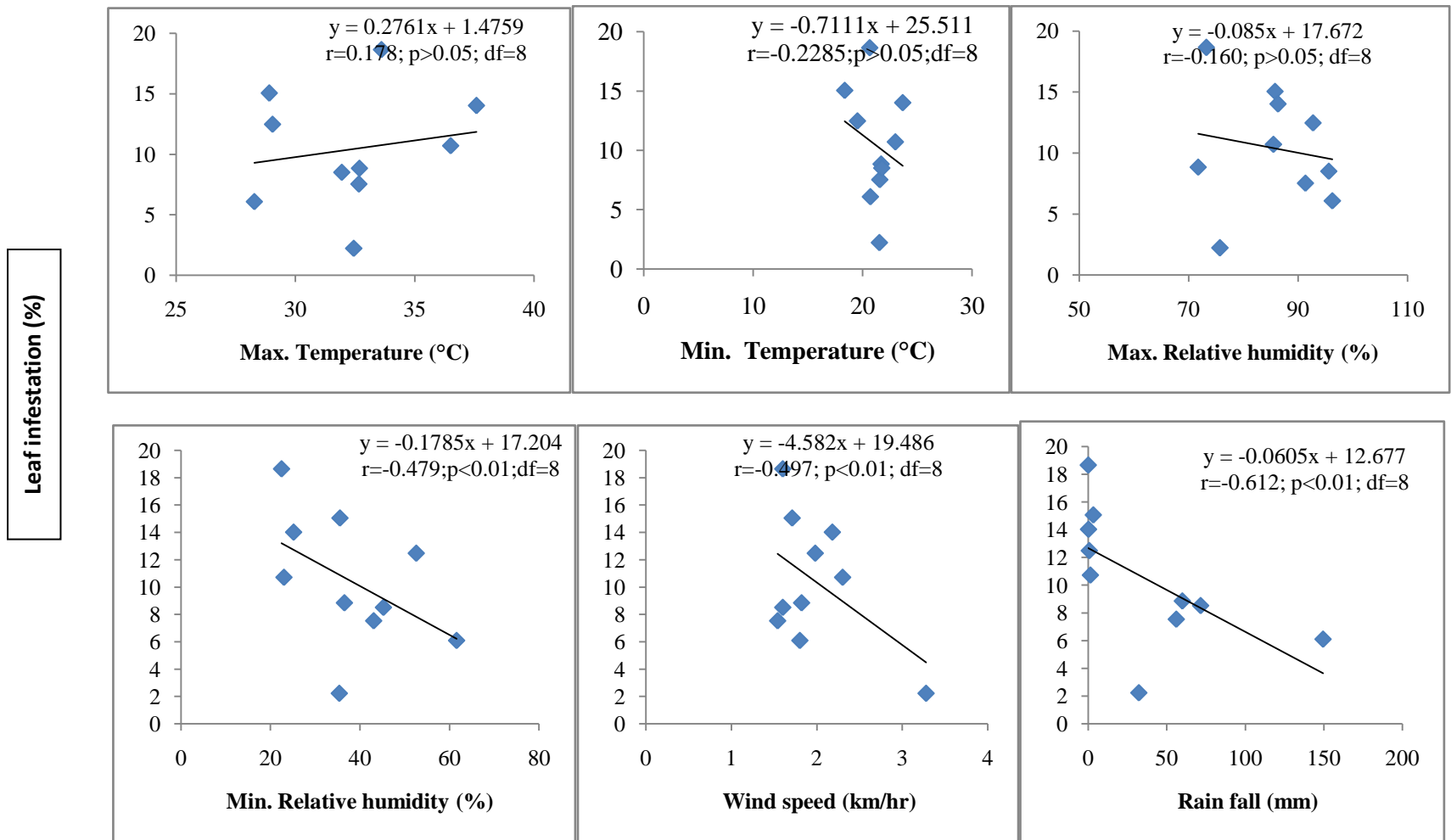


Fig. 16. Correlation between mean per cent leaf infestation and weather parameters in Mysuru district during July 2015 to April 2016

Fruit infestation (%)

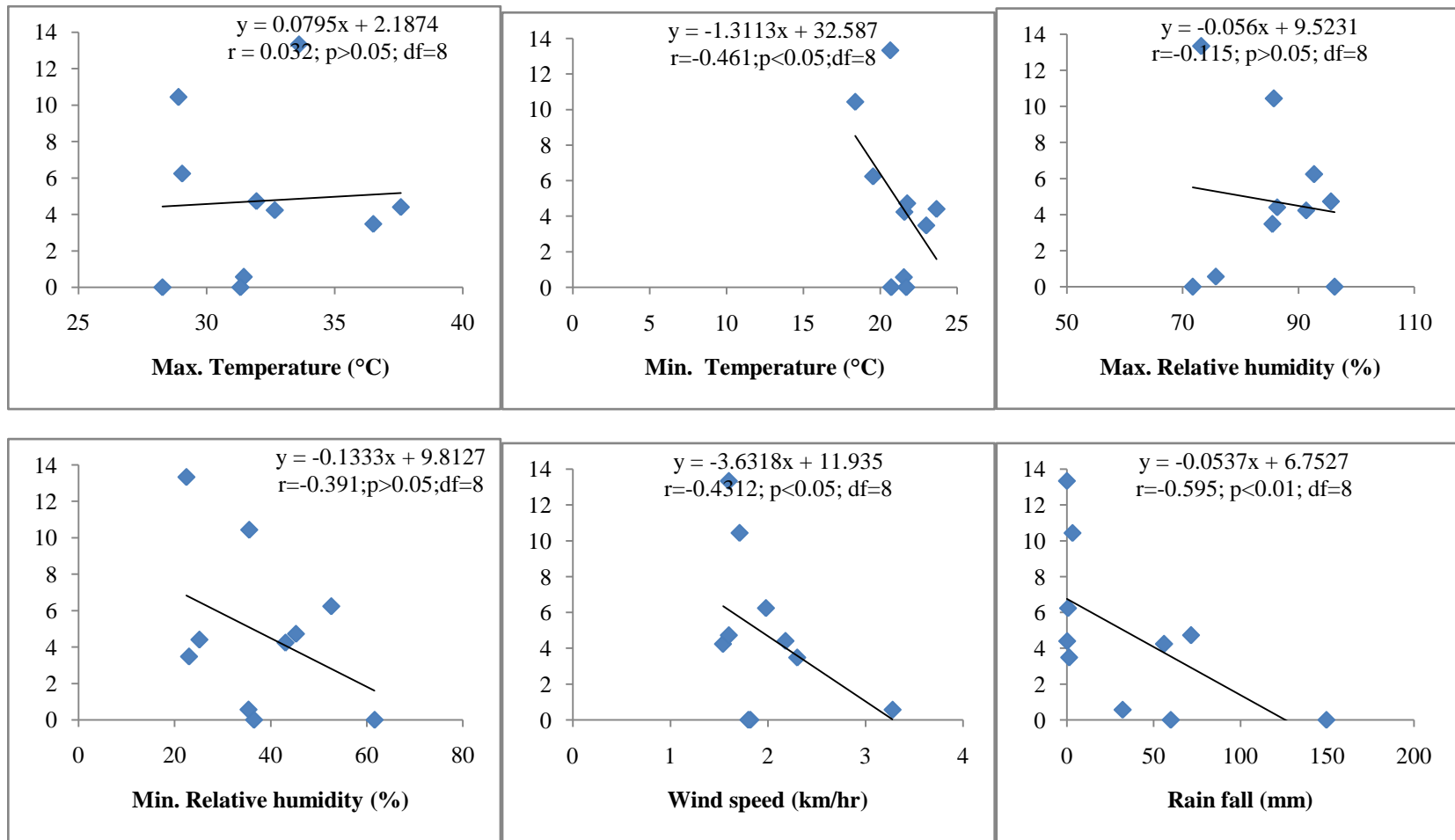


Fig. 17. Correlation between mean per cent fruit infestation and weather parameters in Mysuru district during July 2015 to April 2016

Table 6. Multiple regression models for leaf and fruit infestation of *Tuta absoluta* with weather parameters in four districts of Southern Karnataka during July 2015 to April 2016

Districts	Plant part	Model	R ²	F-value	p-value
Bengaluru Rural	Leaf	$Y=15.625+0.074X_1+0.050X_2-2.345X_3-0.040X_4$	0.572	8.34	0.0002**
	Fruit	$Y=-1.940+0.165 X_1+0.082 X_2-2.226 X_3-0.020 X_4$	0.461	5.338	0.003**
Chikkaballapura	Leaf	$Y=20.98-1.104 X_1+0.103 X_2-2.467 X_3-0.061 X_4$	0.667	12.498	0.000**
	Fruit	$Y=34.982-0.229 X_1-0.144 X_2-2.498 X_3-0.031 X_4$	0.507	6.423	0.001**
Kolar	Leaf	$Y=6.622+0.199 X_1+0.096 X_2-2.884 X_3-0.030 X_4$	0.563	8.062	0.0002**
	Fruit	$Y=-4.305+0.039 X_1+0.141 X_2-1.988 X_3-0.015 X_4$	0.458	5.276	0.003**
Mysuru	Leaf	$Y=30.905-0.017 X_1-0.057 X_2-6.258 X_3-0.071 X_4$	0.729	4.760	0.059*
	Fruit	$Y=29.020-0.319 X_1-0.021 X_2-4.818 X_3-0.072 X_4$	0.716	3.157	0.120*
Mean	Leaf	$Y=14.776+0.064 X_1+0.063 X_2-2.404 X_3-0.041 X_4$	0.469	20.997	0.000**
	Fruit	$Y=9.963-0.058 X_1+0.030 X_2-1.769 X_3-0.024 X_4$	0.350	12.773	0.000**

X₁: Temperature (°C) X₂: Relative humidity (%) X₃: Wind speed (km per hour) X₄: Rainfall (mm)

*: Significant at p=0.05

** : Significant at p=0.01

Table 7. Influence of mulching and crop stage on leaf infestation by *Tuta absoluta* in four districts of Southern Karnataka during July 2015 to April 2016

Months	Leaf Infestation (%)									
	0-30 DAP		30-60 DAP		60-90 DAP		90 DAP		Mean	
	Mulch	Non-mulch	Mulch	Non-mulch	Mulch	Non-mulch	Mulch	Non-mulch	Mulch	Non-mulch
July 2015	4.52 (4)	6.48 (4)	7.47 (3)	11.47 (3)	8.23 (2)	13.36 (4)	10.32 (4)	16.54 (2)	7.64	11.96
Aug 2015	10.32 (3)	14.62 (3)	10.28 (3)	20.15 (4)	12.98 (3)	17.55 (3)	0.00 (3)	0.00 (3)	8.40	13.08
Sep 2015	4.90 (2)	8.92 (3)	8.54 (3)	15.21 (2)	9.52 (3)	14.32 (2)	12.36 (3)	15.32 (2)	8.83	13.44
Oct 2015	14.23 (2)	18.70 (4)	15.32 (3)	21.23 (3)	13.62 (3)	19.32 (1)	9.32 (2)	18.65 (1)	13.12	19.48
Nov 2015	3.29 (2)	8.21 (3)	5.32 (3)	9.52 (2)	2.32 (1)	6.98 (2)	6.32 (2)	10.37 (4)	4.31	8.77
Dec 2015	14.30 (3)	18.29 (2)	14.26 (2)	20.35 (2)	17.52 (3)	21.32 (3)	12.35 (2)	18.65 (2)	14.61	19.65
Jan 2016	17.23 (2)	21.98 (2)	15.24 (3)	25.32 (3)	17.32 (3)	24.96 (1)	10.25 (1)	28.35 (3)	15.01	25.15
Feb 2016	22.43 (3)	26.98 (2)	19.23 (2)	26.35 (3)	18.32 (3)	29.32 (3)	15.32 (2)	19.98 (1)	18.83	25.66
Mar 2016	9.23 (4)	15.21 (2)	18.21 (3)	24.53 (1)	13.26 (1)	20.95 (4)	3.64 (1)	9.54 (3)	11.09	17.56
Apr 2016	8.94 (3)	13.23 (1)	13.65 (3)	19.35 (3)	11.35 (3)	18.36 (3)	9.32 (3)	11.20 (4)	10.82	15.54
Mean	10.94±6.12	15.26±6.46	12.75±4.65	19.35±5.70	12.44±4.90	18.64±6.24	8.92±4.51	14.86±7.62	11.26±4.24	17.03±5.56

DAP: Days after planting

*Values in parenthesis are sample size

4.4.2 Fruit infestation

Similar to that in leaf infestation, polythene mulched crop showed less fruit infestation than the non-mulched crops across different crop stage month. Mean per cent fruit infestation in the polythene mulched crop was 5.12 per cent compared to 8.19 per cent in non-mulched crops. Among the months, February revealed highest fruit infestation in both polythene mulched crop (10.68%) as well as in non-mulched crop (14.72%) irrespective of different crop stages observed (Table 8).

With respect to crop stage, the developmental period between 30 to 60 days old crop showed more fruit infestation in non-mulched (8.74%) while in polythene mulched crop the crop period of ≥ 90 days had highest infestation (5.81%) across the different months (Table 8).

4.5 Documentation of natural enemies of SATLM

During the survey for the incidence of pest, observations on natural enemies were also made. Known numbers of specimens were collected randomly in the field with infested plant parts, they were brought to lab, kept in meshed boxes for the emergence of parasitoids. Only one species of parasitoid was emerged from samples collected from the fields in Maluru taluk of Kolar district during October 2015. The parasitoid was infecting the fourth instar larva kept for adult emergence. Thus emerged adults were collected and preserved in 70 per cent alcohol. The predator bugs which were abundantly available in the tomato ecosystem were collected and both parasitoid and predator were got identified by Dr. Ankitha Guptha, Scientist, NBAIR, Bengaluru. The predator was identified as *Nesidiocoris tenuis* Reuter (Miridae: Hemiptera), and the parasitoid was identified as *Bracon* sp. (Braconidae: Hymenoptera) (Plate 7).

During the survey population of predator *N. tenuis*, was abundant in the tomato field, it was observed that, this predator when present ranged from between 2 to 7 per twig of plant were present when there was *T. absoluta*.

Table 8. Influence of mulching and crop stage on fruit infestation by *Tuta absoluta* in four districts of Southern Karnataka during July 2015 to April 2016

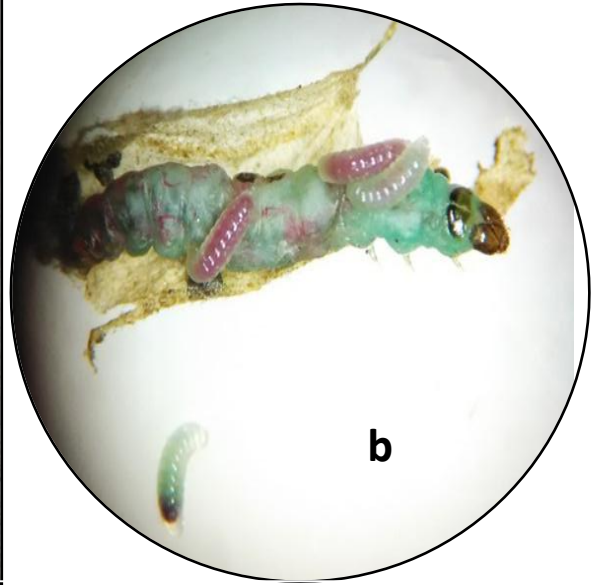
Months	Fruit Infestation (%)							
	30-60 DAP		60-90 DAP		90 DAP		Mean	
	Mulch	Non-mulch	Mulch	Non-mulch	Mulch	Non-mulch	Mulch	Non-mulch
July 2015	2.65 (3)	5.32 (3)	2.01 (2)	5.32 (4)	3.65 (4)	7.56 (4)	2.77	6.07
Aug 2015	6.35 (3)	10.35 (4)	6.32 (3)	8.98 (3)	0.00 (3)	0.00 (3)	4.22	6.44
Sep 2015	1.03 (3)	5.32 (2)	3.68 (3)	3.65 (2)	3.65 (3)	7.35 (1)	2.79	5.44
Oct 2015	4.32 (3)	8.65 (2)	8.95 (1)	11.23 (1)	0.00 (4)	0.00 (2)	4.42	6.63
Nov 2015	1.94 (3)	2.35 (2)	2.98 (3)	5.32 (2)	0.00 (3)	0.00 (3)	1.64	2.56
Dec 2015	3.00 (1)	5.32 (3)	6.32 (3)	10.65 (3)	8.32 (2)	12.65 (4)	5.88	9.54
Jan 2016	6.94 (3)	11.23 (3)	7.75 (3)	10.23 (1)	10.65 (1)	16.23 (2)	8.45	12.56
Feb 2016	6.86 (2)	10.86 (3)	13.62 (4)	17.35 (3)	11.56 (2)	15.95 (2)	10.68	14.72
Mar 2016	2.03 (3)	6.32 (1)	3.26 (2)	7.65 (4)	13.25 (4)	16.32 (3)	6.18	10.10
Apr 2016	3.29 (3)	6.32 (3)	2.35 (2)	6.98 (3)	6.98 (3)	10.25 (2)	4.21	7.85
Mean	3.84±2.17	7.20±2.93	5.72±3.66	8.74±3.94	5.81±5.06	8.63±6.79	5.12±2.77	8.19±3.60

DAP: Days after planting

*Values in parenthesis are sample size



a) *Bracon* sp. adult



b) *Bracon* sp. adult
Bracon sp. maggots
feeding on *Tuta absoluta*



c) Predator *Nesidiocoristenius* (Reuter)

Plate 7. Natural enemies recorded of *Tuta absoluta* larva

4.6 Other hosts plants

Studies on the host plants of *T. absoluta* in four districts of Southern Karnataka revealed that it has both wild and cultivated plants other than the tomato during the survey from July 2015 to April 2016.

In the month of January, *T. absoluta* was observed on potato (*Solanum tuberosum* L.) crop in Doddaballapura and Chikkaballapura taluks when the crop was in flowering stage corresponding per cent leaf infestation recorded was 7.76 in and 4.88 respectively.

Tuta absoluta was recorded on brinjal (*Solanum melongena* L.) and bell pepper (*Capsicum annuum* L.) in a research plot of CIB department at College of Horticulture, GKVK, Bengaluru. Another non-cultivated species of solanaceae viz., *Solanum viarum* L. (weed plant) was also noticed as a host for *T. absoluta* and it had caused six to eight mines per leaf on brinjal and weed host (Plate 8).

4.7 Biology of SATLM, *Tuta absoluta*

Biology of SATLM was studied in the ambient laboratory conditions, Department of Entomology, College of Horticulture, GKVK, Bengaluru. The mean temperature during the study period was $30.00 \pm 1.30^\circ\text{C}$ and relative humidity was 51.25 ± 3.30 per cent (Appendix III).

4.7.1 Pre-oviposition, Oviposition and post ovipositional period

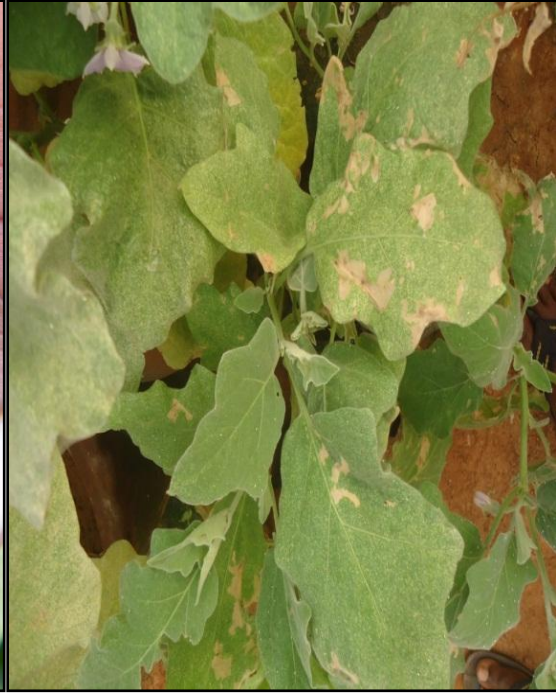
Female moth had a waiting period of 1.2 days on an average, after the first mating even though it started to lay the eggs from the day of mating itself. Ovipositional period ranged from 10 to 12 days with a mean of 10.8 days. After completing the ovipositional period females lived for 1.4 days (Table 9; Fig. 18).

4.7.2 Fecundity

Fecundity ranged from 153-163 eggs per female with an average of 159.6 eggs. Female moth preferred to lay the eggs on the apical portion (three to four apical compound leaves) of the plant with an average of 72.57 per cent of eggs followed by middle portion (18.69%) and least preference was showed towards the bottom portion of the plant with an average of 8.73 per cent eggs (Fig. 19).



a) Potato



b) Brinjal



c) Bell pepper



d) Weed host (*Solanum viarum*)

Plate 8. Plant species recorded as collateral host for *Tuta absoluta*

Table 9. Developmental duration of different life stages of *Tuta absoluta* on tomato under ambient laboratory conditions

Life Stage	Duration in days	
	Mean \pm SD	Range
Incubation period	4.46 \pm 0.05	4-5
I instar	1.38 \pm 0.48	1-2
II instar	2.08 \pm 0.32	2-3
III instar	2.28 \pm 0.45	3-4
IV instar	3.89 \pm 0.54	3-5
Total larval duration	9.49 \pm 0.64	8-10
Pupa	6.15 \pm 0.84	5-8
Total developmental duration	20.10 \pm 1.53	17-23
Pre ovipositional period	1.20 \pm 0.44	1-2
Ovipositional period	10.80 \pm 1.30	10-14
Post ovipositional period	1.40 \pm 0.54	1-2
Adult longevity female	13.00 \pm 1.00	11-14
Adult longevity of male	11.60 \pm 0.54	10-12
Average adult longevity	12.30 \pm 0.77	10-14
Total life cycle	33.10 \pm 2.53	28-37

*In each life stage an average of 100 samples were taken

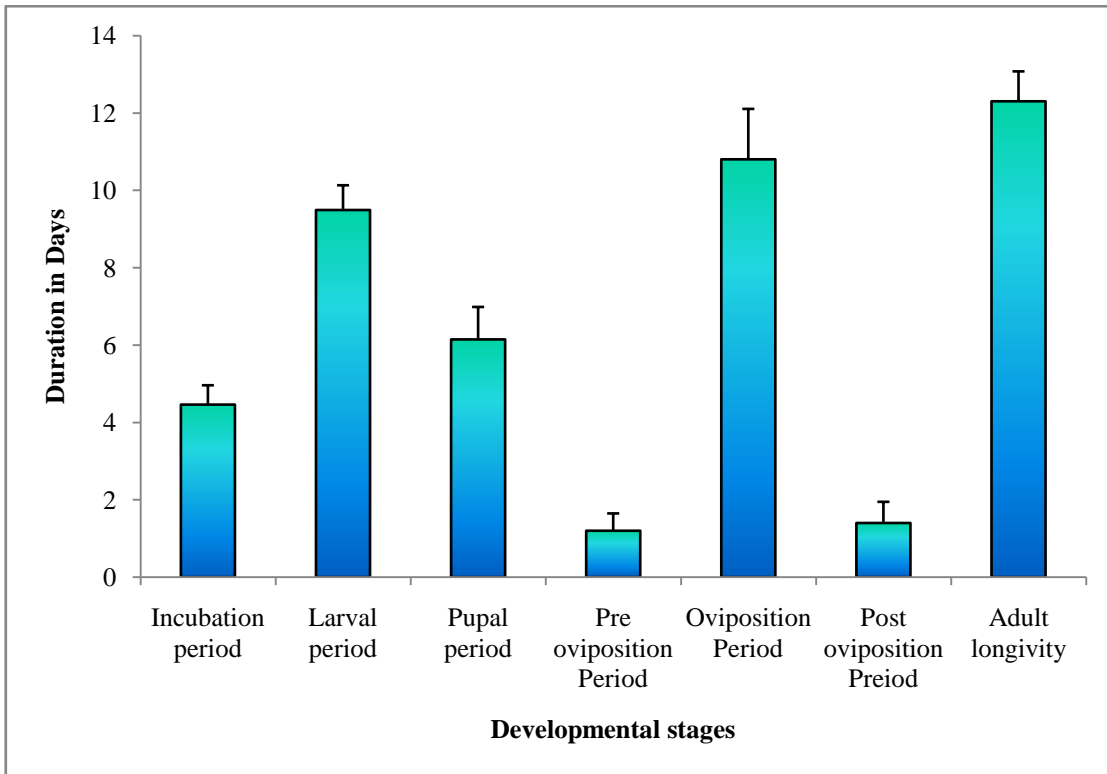


Fig. 18. Mean developmental duration of life stages of *Tuta absoluta* on tomato plants under ambient laboratory conditions

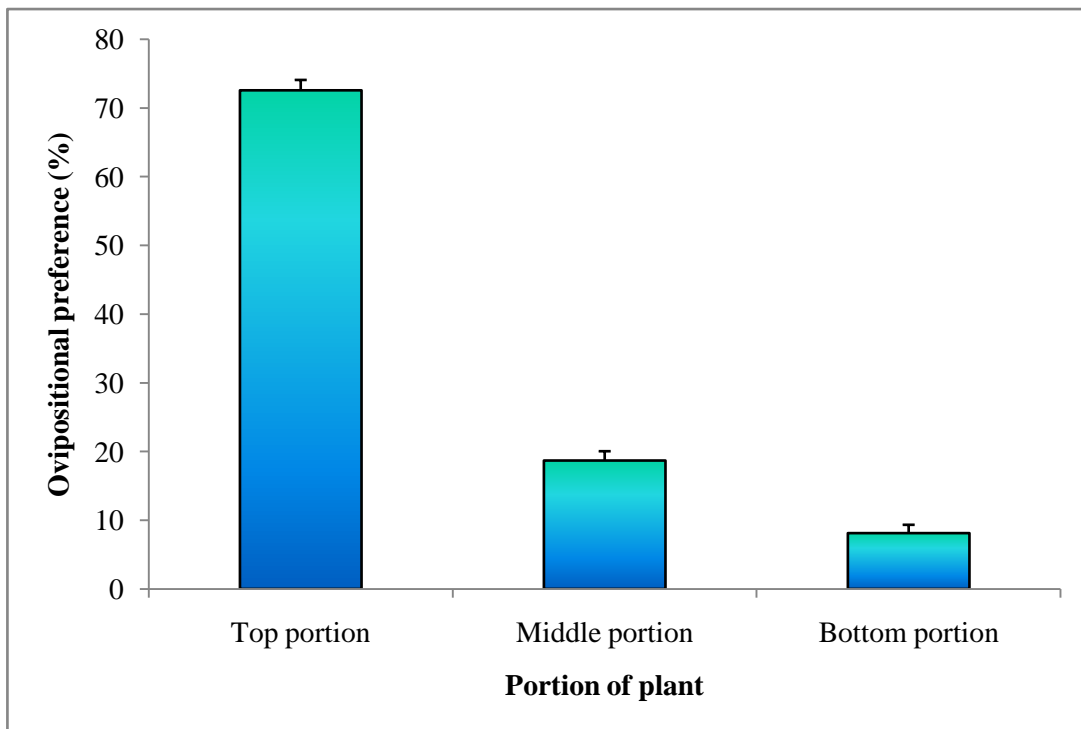


Fig. 19. Distribution of *Tuta absoluta* eggs within tomato plant

4.7.3 Egg

Eggs were oval in shape and the freshly laid eggs are creamy white in colour which gradually turned yellow and yellow-orange with the development. When mature, eggs turned to dark colour and the outline of the larval head capsule was visible through the transparent chorion. Eggs measured on average 0.38 mm long and 0.20 mm wide (Table 10). Adult females deposited eggs either singly or in groups of four to six (Plate 9a). They were laid on both the surface of the leaf, leaf petiole, main stem and sepals of fruit. Studies in ambient laboratory conditions revealed that the mean incubation period was 4.46 days on tomato plant during November to March (Table 9; Fig. 18).

4.7.4 Larva

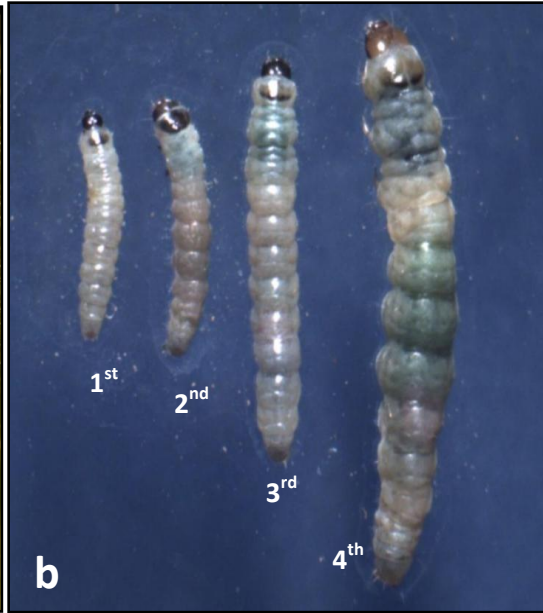
Studies revealed that there were four larval instars in SATLM and the total larval duration lasted for 9.49 days, which differed in size and colour at each stage of the larva. Presence of a black coloured characteristic prothoracic shield was the key identification mark of SATLM larva (Plate 9b).

Neonate larvae were creamy white in colour and have minute setae distributed all over on the body. After hatching, the larvae moved for about five to 20 minutes before mining in to the leaf to find the suitable mining site. Neonate larvae preferred the leaf rather than the twigs or fruits. Duration of the first instar was 1.38 days (Table 10). Mean length and width of first instar larva was found to be 1.65 mm and 0.15 mm (Fig. 20 and 21), respectively with a mean head capsule width of 0.15 mm (Table 10; Fig. 22).

Freshly moulted second instar larva was creamy white in colour which found always within the leaf mine. This was the very active stage of larva which moves to other leaves or if the larval density is more with in the particular plant part, it used silken threads to reach to other leaves or parts of the plant. They bore into the twig or main stem at this and in subsequent stages. Mean duration of second instar larva was 2.08 days (Table 9). Mature second instar larva measured 3.15 mm long and 0.28 mm wide (Table 10; Fig. 20 and 21) with a mean head capsule width of 0.25 mm (Fig. 22).



a) Eggs laid in group



b) Four larval instar



c) Female and male pupa



d) Adult

Plate 9. Different life stages of *Tuta absoluta*

Table 10. Morphometry of different life stages of *Tuta absoluta* on tomato under ambient laboratory conditions

Life stage	Length (mm)		Width (mm)		Head capsule (mm)
	Length (Mean±SD)	Range	Width (Mean±SD)	Range	Width
Egg	0.36 ± 0.01	0.36-0.40	0.19 ± 0.08	0.18-0.20	
I instar	1.64 ± 0.28	1.17-1.86	0.15 ± 0.01	0.14-0.16	0.1502 ± 0.009
II instar	3.15 ± 0.18	2.9-3.6	0.28 ± 0.038	0.23-0.32	0.2568 ± 0.135
III instar	6.30 ± 0.36	5.62-7.91	0.54 ± 0.074	0.42-0.61	0.3962 ± 0.024
IV instar	8.63 ± 0.51	7.89-9.32	0.91 ± 0.019	0.82-0.94	0.84 ± 0.071
Female pupa	4.67 ± 0.23	4.61-4.71	1.37 ± 0.07	1.32-1.41	-
Male pupa	4.27 ± 0.24	4.16-4.31	1.23 ± 0.08	1.20-1.28	-

*In each life stage an average of 100 samples were taken

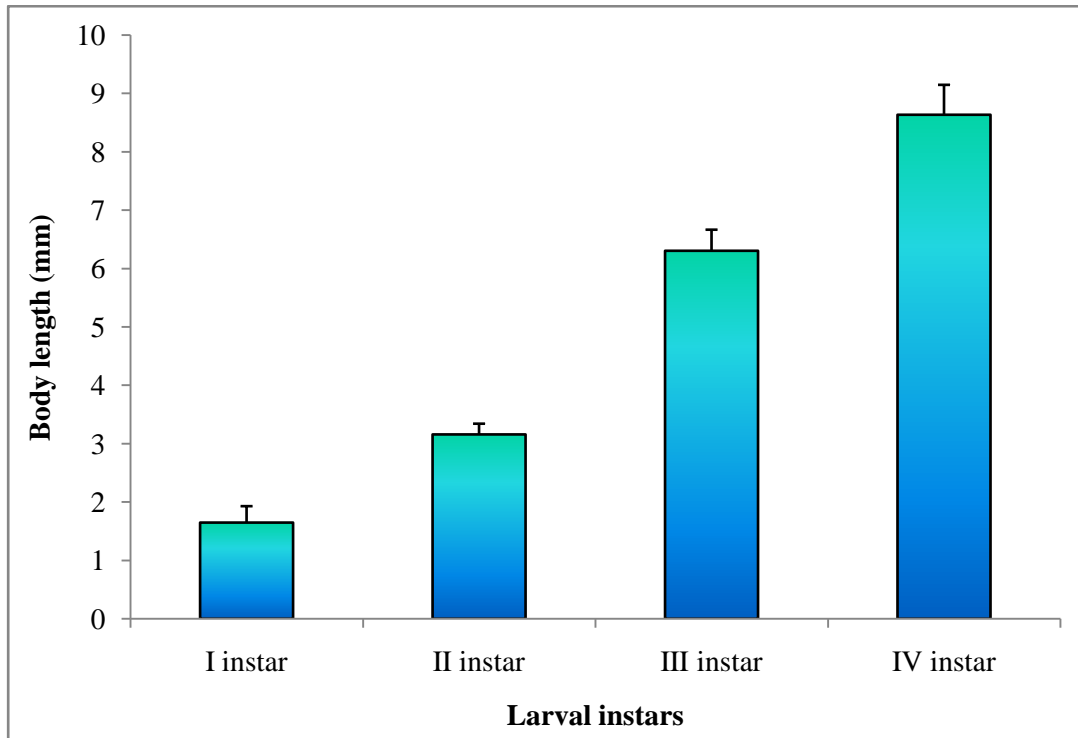


Fig. 20. Body length of *Tuta absoluta* larval instar under ambient laboratory conditions

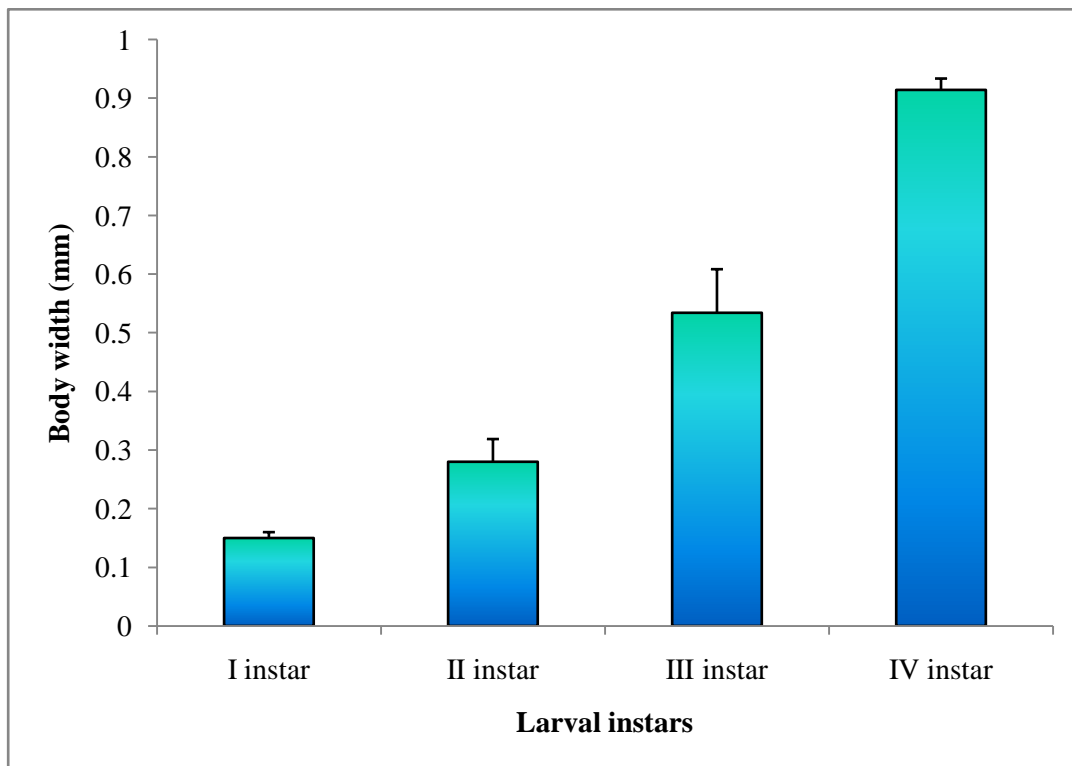


Fig. 21. Body width of *Tuta absoluta* larval instar under ambient laboratory conditions

Freshly moulted third instar larva green in colour, which may be due to voracious feeding on leaves (Chlorophyll contents). There was no much difference in the duration of second and third instar larvae, which lasted for 2.28 days (Table 9) which measured 6.30 mm long and 0.54 mm wide (Table 10; Fig. 20 and 21) with head capsule width of 0.39 mm (Fig. 22).

The green fourth instar larvae appeared larger than the third instar larvae. Early fourth instar larvae were longer and gradually became robust and stopped feeding before moulting into a pupa. At this stage larvae turned pinkish in colour before pupating. Mean duration of fourth instar larva was 3.89 days to complete the instar (Table 9). The mean length and width of this stage was found to be 8.63 and 0.91 mm, respectively (Table 10; Fig. 20 and 21). Head capsule width of the fourth instar larvae ranged from 0.74 mm to 0.95 mm with a mean of 0.84 mm (Fig. 22).

4.7.5 Pupa

Full grown larvae pupated in a silken web on leaf surface or they used silken threads to drop down on to the ground and pupated in a soil by forming cocoon. Initially, the pupa appeared green colour and with the genital slits were easily seen at this stage. Later they gradually turned to dark brown colour. The mean pupal duration lasted for 6.15 days (Table 9; Fig.18) which ranged from five to eight days. Mean length and width of male pupae was 4.27 mm and 1.23 mm, respectively (Table 10). In case of female the mean length and width was found to be 4.67 mm and 1.37 mm, which clearly explained that the female pupa are larger than the male in size which is universal to insects in general (Plate 9c).

4.7.6 Preference of site for pupation

Tuta absoluta larva preferred to pupate in soil rather than tomato leaf with 80.95 per cent dropping down to soil for pupation (Plate 10a) and only 19.05 per cent pupated on the leaf in ambient laboratory condition (Fig. 23 and Plate 10 c and d).

4.7.7 Adults

Moths were tiny and dark grey in colour, males are comparatively smaller than the females. Abdomen was slender in males than females. Anterior wings with black spot and hind wings with a row of fringed hairs. Adult moths were had the wing expansion of about one centimetre wide. The labial palpi will be held upward and antenna was filiform with bicoloured. The prominent character is that they had a long tibial spur on the mid and hind leg. Adult lifespan was 11.8 days with a range of 10 to 14 days (Table 9 and Plate 9d).

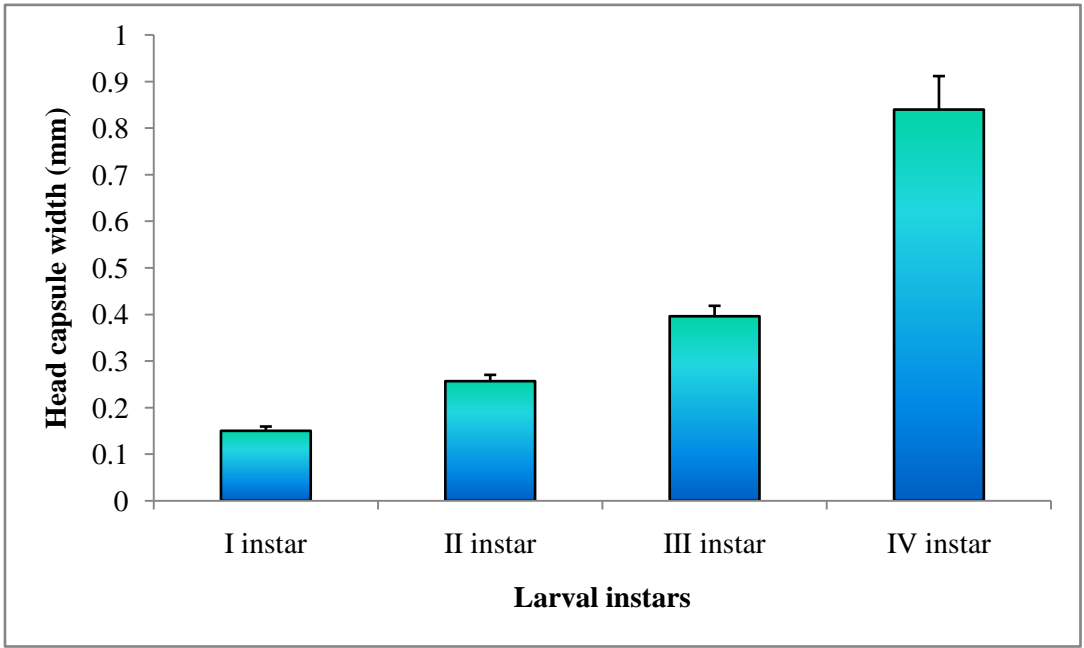


Fig. 22. Head capsule width of *Tuta absoluta* larval instar under ambient laboratory conditions

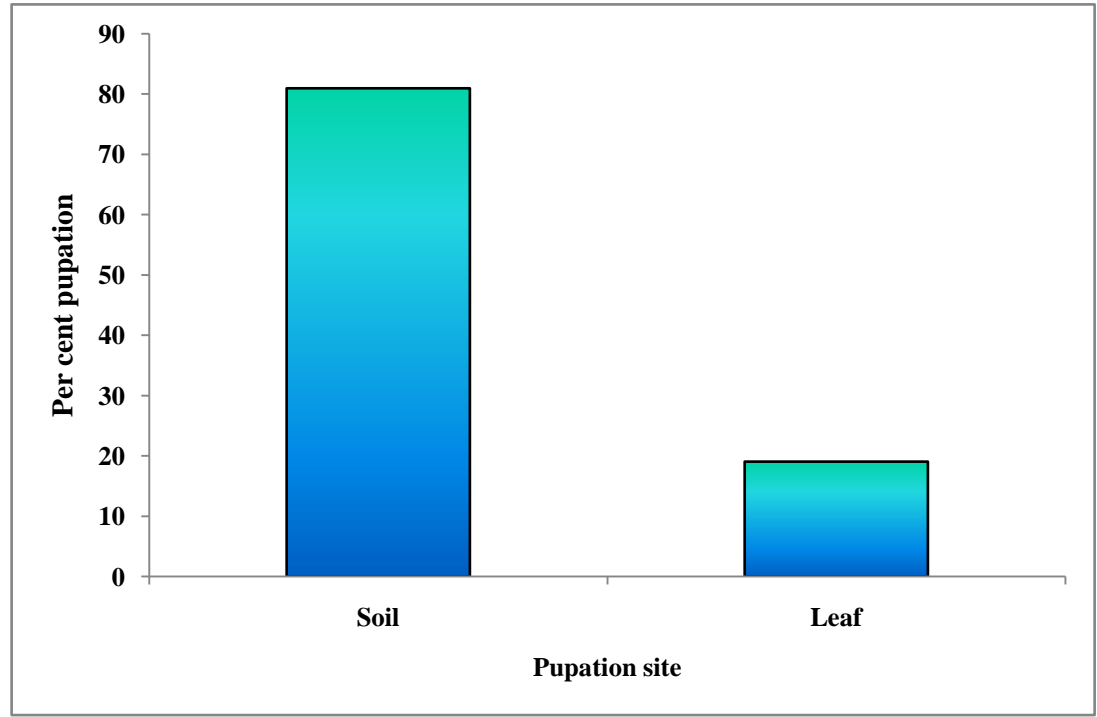


Fig. 23. Pupation site preference of *Tuta absoluta* larva under ambient laboratory conditions



a) Dropping down of larva from leaf to soil by silken thread for



b) Pupation on leaf



c) Pupation in soil



d) Mating pair of adult

Plate 10. Different life stages of *Tuta absoluta*

There was no obvious sexual dimorphism observed although the abdomen in male moths was narrower and pointed posteriorly, while that of females was wider and bulkier. Adult male moth life span was 10.8 days (Table 9) with a range of 10 to 12 days of longevity.

Adult female was bigger compared to male. Female span was 12.8 days with a range of 11 to 14 days. The pre oviposition period was 1.2 days with ovipositional duration of 12.8 days (Table 9; Fig. 18). The post ovipositional period was 1.4 days before the death of moth.

4.7.8 Mating

Adults were active during the dawn (6.30 to 10 am) and dusk hours (4.30 to 6.00 pm), mating took place in the morning hours only. The mating lasted from several minutes to two hours. The mating was occurred on the next day of adult emergence. Multiple mating up to six times was also observed with an average of 5.60 times (Plate 10d).

4.7.9 Total life cycle

In general, the female *T. absoluta* lived longer (33.1 days) than the males (31.7 days). However, the total life cycle is completed in duration of 32.4 days (Average of male and female) (Table 9).

4.7.10 Per cent survivability of *T. absoluta* in different stages

Under ambient laboratory conditions *T. absoluta* registered 58 per cent survivability. In the egg stage 87 per cent of hatching was seen. In the first instar the mortality was 8.04 per cent and in succeeding larval instar 11.25, 1.04 and 6.06 per cent mortality was observed in second, third and fourth instar larva, respectively. Of the 58 per cent adult emergence, 8.06 per cent of pupated larvae failed to emerge (Fig. 24).

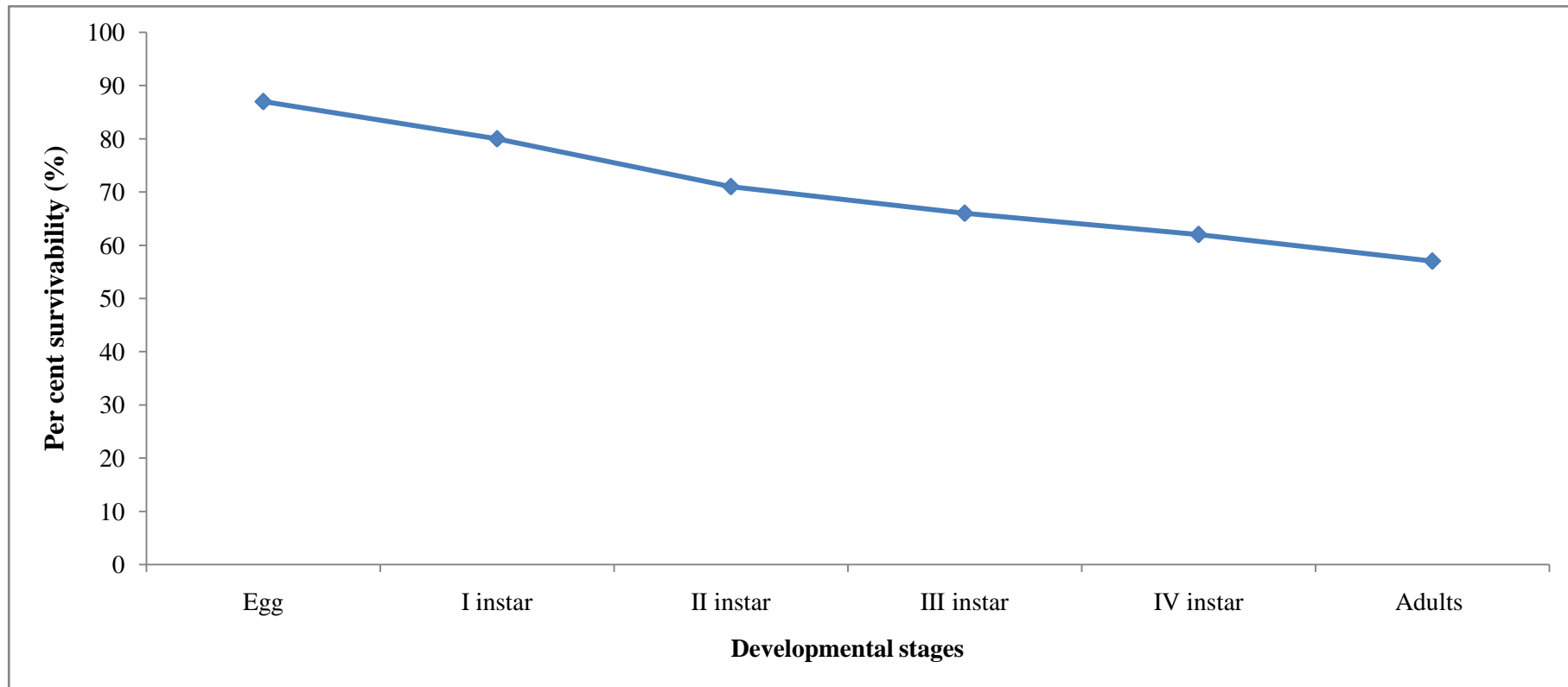


Fig. 24. Per cent survivability of different stages of *Tuta absoluta* from egg to adult on tomato under ambient laboratory condition

V. DISCUSSION

Studies on 'Bio-ecology of South American tomato leaf miner (SATLM), *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)' were carried out to understand the seasonal incidence, natural enemies and collateral host range in selected four districts of southern Karnataka and laboratory biology of SATLM on tomato from July 2015 to April 2016. *Tuta absoluta* is native to South America. This pest was initially reported in eastern Spain in late 2006 (Urbaneja *et al.*, 2007) and has subsequently spread throughout the Mediterranean Basin and Europe (Potting *et al.*, 2009). This pest has taken less than a decade to become a worldwide important pest. During October 2014 it invaded India which gained the importance of ICAR and in Karnataka and Hyderabad it was reported during November 2014 and January 2015 (Sridhar *et al.*, 2014; Kumari *et al.*, 2015). Results of present investigations are discussed here in the light of published knowledge as well as the local situations.

5.1 Seasonal incidence of SATLM

Results on seasonal incidence of SATLM indicated a narrow variation in infestation pattern across different taluks of Bengaluru Rural, Chikkaballapura, Kolar and Mysuru districts. Seasonal pattern of *T. absoluta* infestation in all the surveyed taluks followed a similar trend. Damage ranged from a minimum of 5.92 and 2.50 per cent leaf and fruit infestation respectively during November to a maximum of 24.72 and 13.99 per cent leaf and fruit infestation, respectively during February 2015. This trend remained same across all the ten taluks of study. Infestation reached a maximum (31.9%) on leaf as compared to fruit (17.24%) (Table 4 and 5). Peak infestation was recorded during February month in all the locations except in Srinivaspura taluk which showed high infestation during October 2015. However, SATLM infestation was found to be endemic in certain months and taluks. Out of four selected districts, three districts namely Bengaluru Rural, Chikkaballapura and Kolar had experienced relatively higher incidence of SATLM compared to that in Mysuru. This may be due to prevailing weather conditions, continuous and staggered planting of tomato in these districts throughout the year compared to that in Mysuru district. During November 2015, the pest infestation reduced almost to one third due to heavy and incessant down pour during the months of October and November 2015 due to cyclonic effect (Appendix II). Constant monitoring on pest proliferation and subsequent damage is needed. Spatial variations in the incidence levels are strongly influenced by prevailing abiotic factors in the locality. Similar variations in incidence levels over location were reported worldwide (Cocco *et al.*, 2015; Assaf *et al.*, 2015; Nannini *et al.*, 2011; Sridhar *et al.*, 2014). Population density and per cent infestation of *T. absoluta* on tomato crop under field conditions in three locations at Duhok province of Northern of Iraq showed that average number of mines per leaflet and larvae per leaf and lar fruit during the study season were 2.33, 0.34 and 0.61 respectively (Assaf *et al.*, 2015). Significant difference in per cent infestation and number of male moths per trap among the three locations. The highest percentage of infestation was recorded in September as 74, 72 and 60 for Summel, Shekhan and Zawita respectively. The maximum number of male moths was 1205.40 per trap per week in Summel.

Pest infestation in Bengaluru North taluk of Bengaluru district ranged from a low of 0.08 mines per plant to height of 14.08 mines per plant. At peak damage stage as many as 30 to 40 mines per plant were recorded (Sridhar *et al.*, 2014). It is important to note that this study form the first as this pest is new to India country. A combined view of incidence across space and time suggested SATLM is an importance in every season in one taluk or the other. Field data of infestation levels and weather parameters would go a long way in understanding the reasons for variation in the levels of SATLM and might provide insights into the ways of its management.

5.2 Influence of weather factors on incidence of SATLM in four districts of south Karnataka

Weather parameters *viz.* temperature, relative humidity, wind speed and rainfall have influenced the incidence level of SATLM in tomato (Cocco *et al.*, 2015; Assaf *et al.*, 2015; Nannini *et al.*, 2011). The influence of temperature, relative humidity, wind speed and rainfall

on incidence of SATLM indicated that temperature and rainfall showed both direct and indirect influence on incidence of SATLM. Temperatures showed a rapid reduction in the developmental period (Salmana *et al.*, 2014; Cuthberston *et al.*, 2013).

Results of the present study showed that the maximum temperature had a positive correlation with significant leaf damage in all the taluks (Bengaluru Rural and Kolar) and across different months. Thus, maximum infestation was noticed during February in all the taluks which was hottest month during the study period. Present results barrow the support from the results of Cocco *et al.* (2015). Maximum mines per leaf (6.4) and male moth catches (797.3 per trap per week) was recorded during spring and minimum during winter. All the three locations *viz.*, Summel, Shekhan and Zawita of Northern Iraq showed significant difference with respect to incidence and leaf damage with different temperature range. Of which, Zawita showed minimum infestation as it was located in mountainous location at an elevation of 855 m above sea level with low temperature.

Correlation studies revealed that rainfall had a negative and significant relationship with the incidence pattern of *T. absoluta*. Infestation was minimum in the month of November 2015 which had high rainfall during study period. Similar type of relationship pattern was also observed with wind speed and relative humidity. *Tuta absoluta* is not a very strong flier so that could be reason for having a negative relation with the wind speed. Whenever there is high wind speed the pest failed to establish its population, hence recorded the minimum infestation with the months having high wind speed. The relationship between the wind speed and pest infestation pattern should be investigated further to quantify the relationship which may also help in pest distribution studies. There is also a need to identify the influence of field openness to wind/wind breaks along the edge as the pest infestation to evolve suitable management package for tomato pinworm.

Present studies showed a considerable variation in the relationship and contribution of weather parameters to the leaf and fruit damage by *T. absoluta* in tomato. Inconsistency may due to the fact that the study period was too short which needs to be continued for establishing the clear relationships and quantification of the pest and weather relations, once quantified may be useful in evolving pest forecasting system.

5.3 Influence of mulching and crop stage on leaf and fruit infestation of SATLM in four districts of south Karnataka

Good agricultural practices such as using bio control, trap crops, green manureing, mulching, *etc.*, may also help in reducing the pest and diseases. Many cases have proved that the mulching would help in reducing the pest incidence significantly. In the present study also the same was found true with reduced incidence (Table 7 and 8) of *T. absoluta*. Polythene mulched crop showed less infestation than the non-mulched crops across different crop stages and months. Mean per cent leaf infestation in the polythene mulched crop was 11.26 compared to non-mulched crops (17.03%). Mean per cent fruit infestation in the polythene mulched crop was around (5.12%) which account for 3/5th of damage recorded in non-mulched crop (8.19%).

Less infestation in polythene mulched crop may be due to the fact that larva prefers to pupate in soil (60.56%) rather than on plant (39.34%) (Fig. 23). Polythene mulching will obstruct the larvae to pupate in soil. Studies on impact of mulching with respect to *T. absoluta* infestation and pest build up needs to be studied in depth to explore and advocate it as a pest management tool in general and special to *T. absoluta*.

Literature on the impact of mulching on the incidence and damage by SATLM is lacking. However there are a good number of studies with sucking pest (Csizinszky *et al.*, 1995).

Crop stage has strong influence on the infestation level by *T. absoluta* and there was less infestation up to 30 days crop because the reason might be less availability of foliage and more open canopy. As the crop advanced infestation increased might be due to the availability of foliage and cloud canopy during 30 to 60 days and 60 to 90 days old crops. In

post ninety days old crop, leaf infestation as well as fruit infestation was declined, because of cessation of new growth, yellowing of older leaves, foliar diseases and negligence in crop care which might have pushed away the pest to young crops in the vicinity.

Present study as the crop pest prevalence in the aged crop in agreement with the findings of Leite *et al.* (2001). In *L. esculentum* and *L. hirsutum*, plant ageing increased larval mortality of SATLM. Glandular trichome density in *L. hirsutum* increased with plant age leading to an increase in the levels of tridecan-2-one, which slowed the larval development when compared with insects reared on *L. esculentum*. Commercial varieties of tomato in India having *L. hirsutum* as a parent in the breeding programme (Kalloo and Banerjee, 1990) might have offered production with age during the later stages of the crop.

5.4 Natural enemies recorded on *Tuta absoluta*

Two natural enemies of *T. absoluta* have been recorded in the study area of southern Karnataka. One was a larval parasitoid identified as *Bracon* sp. (Hymenoptera: Braconidae) collected from the Maluru taluk of Kolar district and other was a predator identified as *Nesidiocoris tenuis* Reuter (Hemiptera: Miridae) which is very common throughout the study area with distribution from a low of two to three adults to maximum of five to seven per twig of plant. *Nesidiocoris tenuis* has also been identified as a potential predator on SATLM in tomato ecosystem (Karabuyuk, 2011; Al-Jboory *et al.*, 2012). The finding of *N. tenuis* in India is supported by findings of Ballal (Dr. Chandish R. Ballal, NBAIR, Bengaluru personal communication) where she has recorded a good number of adults and nymphs even in high pesticide pressure areas of Kolar.

Similarly, as many as 13 species of predators (11 confirmed up to species level), 62 species (39 confirmed up to species level) of parasitoids have been recorded on *T. absoluta* on the various stages probably egg and young larvae (Table 2 and 3). Besides five species of nematodes three species of fungi and several isolates of *B. thuringiensis* have been recorded on *T. absoluta* by Colomo *et al.* (2002) and Zappala *et al.* (2012).

Record of less number of natural enemies on *T. absoluta* may be because of its recent invasion to India (During October, 2014) Native natural enemies may need some time to accept this new pest as a host. But, *N. tenuis* which is a facultative predator is abundant in the field conditions in southern Karnataka.

5.5 Host range

Tuta absoluta is an invasive pest introduced to India very. It has been reported on tomato and potato in Gujarat, Maharashtra and Karnataka states. In the present study *T. absoluta* was recorded on potato with 7.66 per cent leaf damage and *S. viarum* with six to eight mines per leaf.

Present findings revealed that three more plant species belonging to family Solanaceae besides tomato *viz.*, *Solanum tuberosum* L. (Potato), *Solanum melongena* L. (Brinjal) and weed plant *Solanum viarum* L. as host plants for *T. absoluta* from Karnataka. On these plants the pest can able to feed and complete its life cycle successfully under laboratory conditions. It forms the first host record for *T. absoluta* from India, on brinjal, bell pepper and *S. viarum*. Pest was seen causing damage to potato crop up to 5.1 per cent in Shivamogga district of Karnataka (Kalleshwaraswamy *et al.*, 2015) besides first record on potato by Sridhar *et al.* (2014).

From Turkey, Bayram *et al.* (2015) recorded *T. absoluta* on 17 species of plants belonging to Solanaceae, Amaranthaceae, Asteraceae and Poaceae which are surviving as host plants for *T. absoluta*. Of these cultivated members of Solanaceae family were tomato, aubergine and *Capsicum annuum* L. (Bell pepper), and rest are uncultivated. Records of *T. absoluta* on *S. woronowii*, *P. angulata*, *X. strumarium*, *A. viridis* and *S. halepense* were the first records as hosts in Turkey (Bayram *et al.*, 2015).

It has been well documented that SATLM has the ability to feed on the other plant species including Solanaceae and plant species belonging to other families (Vargas, 1970;

Galarza, 1984; Portakaldali *et al.*, 2013; Ogur *et al.*, 2014; Rassoul, 2014; Bayram *et al.*, 2015).

5.6 Biology of SATLM

Information available on *T. absoluta* globally revealed that the incubation period ranges from three to eight days, larval period from nine to twelve days, pupal period (8 to 15 days) and the adult longevity from 12 to 25 days with female having a one to five days advantage over male. It has an oviposition period spread over eight to 12 days laying 159-260 eggs and it is polygoites in nature.

Present studies revealed that the freshly laid eggs were oval in shape with fine smooth surface and eggs were creamy white in colour which turned yellow to yellow-orange through age. Upon maturity, eggs turned dark and the outline of the larval head capsule was visible through the chorion. Egg description observed in the present study is in line with observations of Erdogan and Babaroglu (2014) and Silva *et al.* (2015). Incubation period of egg was 4.46 days and is in accordance with the results of previous workers Erdogan and Babaroglu (2014) and Silva *et al.* (2015). The incubation and per cent hatching of eggs are dependent on temperature at which they were placed. Cuthbertson *et al.* (2013) reported that at seven degree temperature, hatching of eggs was absent and with raise in temperature the hatching per cent reached a maximum of 85 per cent at 23°C which declined significantly thereafter.

Neonate larvae were creamy white and had minute setae scattered on all over the larval body. After hatching, the larvae wandered for about five to 20 minutes before mining in to the leaf. Second instar larva was also creamy white upon moulting and was found always with in the leaf mine. Third instar larvae was bright green in colour and fourth instar larvae was larger and longer which became robust pink colour before pupation.

Head capsule width ranged from 0.14 to 0.94 mm in four instars and total larval duration was 9.49 days. Four larval instars were also reported by Salama *et al.* (2014); Durate *et al.* (2015); Erdogan and Babaroglu (2014); Silva *et al.* (2015) on tomato under laboratory controlled conditions. Although the larval period depends on the temperature, longer larval period was also obtained at lower temperature and vice versa.

Full grown larvae pupated on the leaf by silken webbings or dropping down through a silken thread to ground and pupated in a soil cocoon. Initially the pupa appeared green colour and the genital slits were easily seen through at this stage. Larva preferred to pupate in the soil than on the leaf (Fig. 23). Pupal period was 6.15 days, this result is supported by the findings of Salama *et al.* (2014); Attwa *et al.* (2015); Durate *et al.* (2015); Silva *et al.* (2015) for pupation behaviour and duration.

Present study revealed that adult longevity was 12.3 days with the range of 10 to 14 days and is in accordance within the ranges reported (Erdogan and Babaroglu, 2014; Salama *et al.*, 2014; Attwa *et al.*, 2015). Mating periods observed is less compared to the previous reports. Number of mating in the present study was 5.60 times and it is in line with that observed by Lee *et al.* (2014). Female moth had a waiting period of 1.2 days after the first mating. Ovipositional period ranged from 10 to 12 days with a mean of 10.8 days. After the ovipositional period females lived for 1.4 days and it is in close agreement with the previous results (Salama *et al.*, 2014; Durate *et al.*, 2015; Attwa *et al.*, 2015; Silva *et al.*, 2015).

Even though the higher fecundity of 200 eggs has been documented (Durate *et al.*, 2015) but in the present study it was only 159.3 and it is supported by the findings of Silva *et al.* (2015); Attwa *et al.* (2015); Erdogan and Babaroglu (2014); Salama *et al.* (2014) at 30°C temperature.

Study revealed that the adults prefers to lay eggs on the apical portion of the plant (three to four trifoliolate leaves from top) which is in line with the previous study (Torres *et al.*, 2001). Cherif *et al.* (2013) reported that the adults prefer to lay the eggs on the apical portion of plant which might be due to the lower calcium content and the tenderness of part than the

middle and the bottom part of the plant. This suggests that moths select suitable site for the better larval development on this plant part.

Life span of the female appeared to be longer with an average of life span of 32.4 days. These results in support of the previous works (Erdogan and Babaroglu, 2014; Salama *et al.*, 2014 and Attwa *et al.*, 2015) who has reported a life span ranged from 26.08 to 45.4 days at different temperatures.

VI. SUMMARY

Investigations on the 'Bio-ecology of South American tomato leaf miner (SATLM), *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae)' were undertaken at Department of Entomology, College of Horticulture, Bengaluru with field surveys in four districts of southern Karnataka during July 2015 to April 2016 focussing on seasonal incidence, natural enemies, collateral host and laboratory biology. Results of the experimental findings are summarised in this chapter.

Survey carried out in four districts of southern Karnataka viz., Bengaluru Rural, Chikkaballapura, Kolar and Mysuru to know the incidence level of SATLM across taluks at monthly intervals from July 2015 to April 2016 revealed that, the incidence ranged from a minimum of 10.41 per cent leaf infestation and 4.74 per cent fruit infestation in Yelawala taluk of Mysuru to a maximum of 17.45 per cent leaf infestation in Chikkaballapura taluk and 8.76 per cent fruit damage in Shidlaghatta taluk of Chikkaballapura district. With respect to the seasonal pattern, infestation ranged from a low (5.92% leaf infestation) during November 2015 and (1.59 per cent fruit damage) July 2015 to a maximum (24.72% leaf damage and 13.99% fruit damage) during February 2016. *Tuta absoluta* incidence was found to be influenced by the weather parameters viz., temperature, relative humidity, wind speed and rainfall. During the study period, months with high temperature recorded the highest incidence level (February) had positive correlation. During the months of September and November, heavy rainfalls higher than the average of respective taluks lead to minimum infestation of leaf and fruit with significant negative correlations. Influence of temperature, relative humidity, rainfall and wind speed contributed 46 to 72 per cent leaf and fruit damage across four districts of Southern Karnataka.

The stage of the crop influenced the leaf infestation level by *T. absoluta* and it was less in crops less than 30 days old. As the crop advanced leaf infestation also increased up to 60 days which further reduced because of reduction/cessation of new growth. Similar trend was observed in fruit infestation confirming the peak activity of *T. absoluta* in tomato between 30 to 60 days old crop. Polythene mulching (Black and silver colour) has reduced the damage by *T. absoluta* (11.26% and 5.12% leaf and fruit damage, respectively) compared to non-mulched crop (17.03% and 8.19%).

Surveys during July 2015 to April 2016 in four southern districts of Karnataka revealed two natural enemies, a parasitoid, *Bracon* sp. (Hymenoptera: Braconidae) and a predator, *Nesidiocoris tenuis* Reuter (Hemiptera: Miridae). Among these the population of predator was abundant ranging from two to five adults or nymphs per twig.

Eggs were laid either singly or in groups of four to five on the leaves, twigs, flower buds, sepals, etc. Freshly laid eggs are creamy white in colour which turned to yellow colour and each egg measured 0.38 mm long and 0.20 mm wide. Fecundity ranged from 153- 163 with an average of 159.6 eggs. Mean incubation period was 4.46 days which ranged from three to five days during November 2015 to March 2016.

Larval colour varied from creamy white in neonate to green shades in 2nd, 3rd and early 4th instars which turned pink near pupation. Larva spent most of the time in the leaf mine itself or in boring in to twigs and young buds or beneath the fruit skin/peel. Total larval period ranged from eight to ten days with a mean of 9.49 days during November 2015 to March 2016. After completion of fourth instar, larva came out of mine and pupated on leaf in silken webbing (cocoon) or in soil in a soil by forming cocoon. Pupal period ranged from six to eight days with a mean of 6.15 days during November 2015 to March 2016. Length and width of pupa varied from 4.27 to 4.67 mm and 1.23 to 1.37 mm, respectively.

Adult moths are active during dawn (6.30 am to 10.00 am) and dusk (4.00 to 6.00 pm) and mated four to six times in their life time (10 to 14 days). Mating occurs one day after emergence from pupa and egg laying started a day after the mating. Female preferred the apical portion of plant canopy for egg laying rather than the middle or bottom portion of the canopy. The ovipositional period ranged from 10 to 12 days and the females lived relatively longer than the males. Total life cycle of *T. absoluta* recorded during November 2015 to March 2016 was 32.4 days on tomato under ambient laboratory conditions.

Conclusion:

Among the four districts surveyed high incidence of SATLM was recorded in Chikkaballapura. The correlation studies revealed that temperature have a positive influence on pest incidence likewise the rainfall had a significant negative influence also. Polythene mulching has a positive influence in reducing the pest population. One parasitoid and one predator recorded on this pest. Four other plants are serving as host for SATLM. Pest has taken 33.1 days to complete one life cycle and most of the time larvae preferred to pupate in soil

Future line of work

1. Surveillance has to be continued to confirm the relationship of SATLM with the weather parameters and evolve forecasting modules.
2. Biology has to be studied on the other host plants and their role in pest build up especially on common weed host.
3. Exploring the mulching practice as a component in IPM of *T. absoluta*
4. Development and evaluation of exiting IPM.

VII. REFERENCES

- ABBES, K., BIONDI, A., ZAPPALA, L., CHERMITI, B., 2013, Fortuitous parasitoids of the invasive tomato leaf miner *Tuta absoluta* in Tunisia. *Phytoparasitica*. doi:10.1007/s12600-013-0341-x
- AL-JBOORY, I. J., KATBEH-BADER, A. AND AL-ZAIDI, S., 2012, First observation and identification of some natural enemies collected from heavily infested tomato by *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Jordan. *Middle East J. Sci. Res.*, **11**: 435-438.
- ANONYMOUS, 2015, National Horticulture Board. <http://nhb.gov.in/PDFViwer.aspx?enc=3ZOO8K5CzcdC/Yq6HcdIxCOU1kZZenFuNVXacDLxz28=>.
- ASSAF, L. H., HASSAN, F. R., RASHEED, H. I., SADIQ, M. A., ISMAEL, R. M., AHMED, M. S., SAEED, S. A. AND TAHER SALIH, F. M., 2015, Occurrence of tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) in Duhok region (A). *J. Univer. Zakho*, **3**(1): 79-87.
- ATTWA, W. A., NEAMA, A. O., EBADAH, I. M. A., EL -WAHAB, A., MOAWAD, S. M. AND SADEK, H. E., 2015, Life table parameters of the tomato leaf miner, *Tuta absoluta* (Meyrick) and potato tuber moth *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae) on tomato. *Agri. Sci. Res. J.*, **5**(1): 1-5.
- *BALDWIN, I. T., 2007, Induced responses to herbivory. *University of Chicago Press*, 319.
- *BARRIENTOS, Z. R., APABLAZA, H. J., NORERO, S. A. AND ESTAY, P. P., 1998, Temperatura basica y constante termica de desarrollo de la Polilla del tomate *Tuta absoluta* (Lepidoptera: Gelechiidae). *Ciencia e Investigacion Agraria.*, **25**(1): 33-137.
- BAYRAM, Y., BUYUK, M., OZASLAN, C., BEKTAS, O., BAYRAM, N., MUTLU, C., ATES, E. AND BUKUN, B., 2015, New host plants of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Turkey. *J. Tekirdag Agri. Faculty Bayram*, **12**(2): 43-46.
- *BIONDI, A., DESNEUX, N., SISCARO, G. AND ZAPPALA, L., 2012, Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. *Chemosphere*, **87**: 803-812.
- BIONDI, A., CHAILLEUX, A., LAMBION, J., ZAPPALA, L., DESNEUX, N., 2013, Indigenous natural enemies attacking *Tuta absoluta* (Lepidoptera: Gelechiidae) in Southern France. *Egypt J. Biol. P. Control*, **23**:117-121.
- *BOTTO, E. N., 1999, Control Biologico de plagas en ambientes protegidos. ACTAS IV Congreso Argentino De Entomologia, Mar Del Plata, Marzo, 1998. *Rev. Soc. Entomol. Argent.*, **58**(1-2): 58-64.
- *BOUALEM, M., ALLAOUJ, H., HAMADI, R. AND MEDJAHED, M., 2012, Biologie et complexe des ennemis naturels de *Tuta absoluta* a Mostaganem (Algerie). *EPPO Bull.*, **42**: 268-274.
- BUENO, V. H. P., VAN LENTEREN, J. C., LINS, J. C., CALIXTO, A. M., MONTES, F. C., SILVA, D. B., SANTIAGO, L. D. AND PE REZ, L. M., 2013, New records of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) predation by Brazilian Hemipteran predatory bugs. *J. Appl. Entomol.*, **137**: 29-34.

- CABELLO, T., GALLEGO, J. R., VILA, SOLE, A., CAMEROL, A., HEMANDEZSUAREI, E. AND POLASZEK, A., 2009, Biological control of the South American Tomato Pinworm, *Tuta absoluta* (Lepidoptera: Gelechiidae), with releases of *Trichogramma achaeae* (Hymenoptera: Trichogrammatidae) in tomato greenhouses of Spain. *IOBC/wprs Bull.*, **49**: 225-230.
- CACERES, S., AGUIRRE, A., MINO, V. AND ALMONACID, R., 2011, Líneas de trabajo para el manejo integrado de la polilla del tomate en Corrientes. Libro de Resúmenes del Taller: La polilla del tomate en la Argentina: Estado actual del conocimiento y perspectiva para un manejo integrado de plagas. 7 y 8 de noviembre de 2011, FCNyM, UNLP, p. 7 (in Spanish).
- CARRERA, L. B. AND MORTON, A., 2010, Efficacy of entomopathogenic nematodes against the tomato leaf miner *Tuta absoluta* in laboratory and greenhouse conditions. *Biocontrol.*, **55**: 523-530.
- CAUDAL, T. Y., BAFFERT, V., LEYRE, J. M. AND HULAS, N., 2012, Experimental studies on *Tuta absoluta* (Meyrick) in protected tomato crops in France: biological control and integrated crop protection. *OEPP/EPPO Bull.*, **42**(2): 234-240.
- CHAILLEUX, A., DESNEUX, N., SEGURET, J., KHANH, D. T. H. AND MAIGNET, P., 2012, Assessing European egg parasitoids as a mean of controlling the invasive South American tomato pinworm *Tuta absoluta*. *PLoS One*, **7**(10): 48-68.
- CHERIF, A., MANSOUR, R., LEBDI, K. G., 2013, Biological aspects of tomato leaf miner *Tuta absoluta* (Lepidoptera: Gelechiidae) in conditions of North eastern Tunisia: possible implications for pest management. *Environmental and Experimental Biology*, **11**: 179-184.
- COCCO, A., DELIPERI, S., LENTINI, A., MANNU, R. AND DELRIO, A., 2015, Seasonal phenology of *Tuta absoluta* (Lepidoptera: Gelechiidae) in protected and open-field crops under Mediterranean climatic conditions. *Phytoparasitica*, **43**: 713-724.
- *COLOMO, M. V., BERTA, D. C. AND CHOCOBAR, M. J., 2002, El complejo de himenopteros parasitoides que atacan ala polilla del tomate *Tuta absoluta* (Lepidoptera: Gelechiidae) en la Argentina. *Acta Zool. Lilloana*, **46**: 81-92.
- CSIZINSZKY, SCHUSTER, D. J. AND KRING, J. B., 1995, Color mulches influence yield and insect pest populations in tomatoes. *J. Amer. Soc. Hort. Sci.* **120**(5):778-784.
- CUTHBERTSON, A. G. S., JAMES, J. M., LISA, F. B., ANASTASIA, K., WEIQI, L., ROBERT, J. J. AND PHIL, N., 2013, Population development of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) under simulated UK glasshouse conditions. *Insects*, **4**: 185-197.
- DESNEUX, N., WAJNBERG, E., WYCKHUYS, K. A. G., BURGIO, G., ARPAIA, S. C. A., NARVAEZ- VASQUEZ, S. C. A, LEZ-CABRERA, J. G., RUESCAS, D. C, TABONE, E., FRANDON, J., PIZZOL, J., PONCET, C., CABELLO, T. AND URBANEJA, A., 2010, Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. *J. Pest Sci.*, **83**: 197-215.
- *DESNEUX, N., DECOURTYE, A. AND DELPUECH, J. M., 2007, The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomol.*, **52**: 81-106.
- DESNEUX, N., MARIA, G., LUNA, GUILLEMAUD, T. AND URBANEJA, A., 2011, The invasive South American tomato pinworm, *Tuta absoluta*, continues to spread in Afro-Eurasia and beyond: the new threat to tomato world production. *J. Pest Sci.*, **84**: 403-408.

- DOGANLAR, M. AND YIGIT, A., 2011, Parasitoid complex of the tomato leaf miner, *Tuta absoluta* (Meyrick 1917), (Lepidoptera: Gelechiidae) in Hatay, Turkey. *KSU J. Nat. Sci.*, **14**(4): 28-36.
- DUARTEI, L., MARTINEZI, M. A., BUENOII, V. H. P., 2015, Biology and population parameters of *Tuta absoluta* (Meyrick) under laboratory conditions. *Rev. Protect. Veg.*, **30**(1): 19-29.
- EPPO, 2005, EPPO datasheets on quarantine pests: *Tuta absoluta*. *EPPO Bull.* **35**:434-435. http://www.eppo.org/QUARANTINE/insects/Tuta_absoluta/DS_Tuta_absoluta.pdf
- EPPO, 2009, *Tuta absoluta* found on *Phaseolus vulgaris* in Sicilia (2009/154). EPPO Reporting Services 8(154). http://www.eppo.org/PUBLICATIONS/reporting/reporting_service.htm
- EPPO, 2010, First report of *Tuta absoluta* in Germany (2010/004). EPPO reporting services 10 (004). http://www.eppo.org/PUBLICATIONS/reporting/reporting_service.htm.
- ERDOGAN, P. AND BABAROGLU, N. E., 2014, Life table of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *J. Agri. Faculty Gaziosmanpasa Univer.*, **31**(2): 80-89.
- *FERNANDEZ, S. AND MONTAGNE, A., 1990, Biologica del minador del tomate, *Scrobipalpula absoluta* (Meyrick). *Biol. Entomol. Venez N. S.*, **5**(12): 89-99.
- FERRACINI, C., INGEGNO, B. L., NAVONE, P., FERRARI, E., MOSTI, M., TAVELLA, L. AND ALMA, A., 2012, Adaptation of indigenous larval parasitoids to *Tuta absoluta* (Lepidoptera: Gelechiidae) in Italy. *J. Econ. Entomol.*, **105**: 1311-1319.
- *GABARRA, R. AND ARNO, J., 2010, Resultados de las experiencias de control biologico de la polilla del tomate en cultivo de invernadero y aire libre en Cataluña. *Phytoma-Espana.*, **217**: 66-68.
- GABARRA, R., ARNO, J., LARA, L., VERDU, M. J., RIBES, A., BEITIA, F., URBANEJA, A., TELLEZ, M. M., MOLLA, O. AND RIUDAUVETS, J., 2013, Native parasitoids associated with *Tuta absoluta* in the tomato production areas of the Spanish Mediterranean Coast. *Biocontrol*. doi:10.1007/s10526-013-9545-8.
- *GALARZA, J., 1984, Evaluacion en laboratorio de Algunas Plantas Solanaceas. Posibles Hospederas de la Polilla del Tomate *Scrobipalpula absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *IDIA*, **424**: 30-32.
- *GARCIA, M. F. AND ESPUL, J. C., 1982, Bioecologia de la polilla del tomate (*Scrobipalpula absoluta*) en Mendoza, Republica Argentina. *Revista de Investigaciones Agropecuarlas*, **17**(2): 135-146.
- *GARZIA, G. T. G., SISCARO, A., COLOMBO AND CAMPO, G., 2009, Reappearance of *Tuta absoluta* in Sicily. *Informatore Agrario.*, **65**(4): 71-72.
- *GERMAIN, J. F., LACORDAIRE, A. I., COCQUEMPOT, C., RAMEL, J. M. AND OUDARD, E., 2009, Un nouveau ravageur de la tomate en France: *Tuta absoluta*. *PHM-Revue Horticole.*, **512**: 37-41.
- *GUENAOUI, Y., BENSAD, R., OUEZZANI, K. AND VERCHER, R., 2011, Emerging opportunities to use native entomophagous against *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) infesting tomato in unheated greenhouse in Northwestern Algeria. Between benefits and risks. *9eme Conference Internationale sur les Ravageurs en Agriculture*, Montpellier, France, **42**: 324-334.

- HARIZANOVA, V., STOEVA, A. AND MOHAMEDOVA, M., 2009, Tomato leaf miner, *Tuta absoluta* (Povolny) (Lepidoptera: gelechiidae) – first record in Bulgaria. *Agri. Sci. Technol.*, **1**(3): 95-98.
- *HODGES, R. W. AND BECKER, V. O., 1990, Nomenclature of some Neotropical Gelechiidae (Lepidoptera). *Proc. Entomol. Soc. Washington*, **92**: 76-85.
- *HUEMER, P., AND KARSHOLT, O., 2010, *Gelechiidae II*. Vol.: **6**, Apollo books, stenstrup, Denmarak, 586p.
- KALLESHWARASWAMY, C. M., MURTHY, M. S., VIRAKTAMATH, C. A. AND KUMAR, N. K. K., 2015, Occurrence of *Tuta absoluta* (Lepidoptera: Gelechiidae) in the Malnad and Hyderabad-Karnataka Regions of Karnataka, India. *Florida Entomologist*, **98**(3): 970-971.
- *KALLOO AND BANERJEE, M. K., 1990, Transfer of Tomato leaf curl virus resistance from *Lycopersicon hirsutum* f. *glabratum* to *L. esculentum*. *Plant Breeding*, **105**: 156–159.
- *KARABUYUK, F., 2011, Determination of tomato leaf miner [*Tuta absoluta* (Meyrick)] host, population development with parasitoid and predators in the vegetable fields of the Eastern Mediterranean. *M. Sc. Thesis*, Natural and Applied Sciences, Institute of Cukurova University, Adana-Turkey.
- *KIEFFER, J. J. AND JORGENSEN, P., 1910, Gallen und Gallentiere aus Argentinien Centralblatt für Bakteriologie, Parasitenkunde u. *Infektionskrankheiten*, **27**: 362-444.
- KUMARI, ANITHA, G., ANITHA, V., LAKSHMI, B. K. M., VENNILA, S. AND RAO, N. H. P., 2015, New record of leaf miner, *Tuta absoluta* (Meyrick) in Tomato. *Insect Environ.*, **20**(4): 136-138.
- *LEE, S., HODGES, R. W. AND BROWN, R. L., 2009, Checklist of Gelechiidae (Lepidoptera) in America North of Mexico. *Zootaxa*, **2231**: 1-39.
- LEE, S. M., ALBAJES, R. AND EIZAGUIRRE, M., 2014, Mating behaviour of female *Tuta absoluta* (Lepidoptera: Gelechiidae): polyandry increases reproductive output. *J. Pest Sci.*, DOI 10.1007/s10340-014-0576-4.
- LEITE, G. L. D., PICANCO, M., GUEDES, R.N.C. AND ZANUNCIO, J. C., 2001, Role of plant age in the resistance of *Lycopersicon hirsutum* f. *glabratum* to the tomato leaf miner *Tuta absoluta* (Lepidoptera: Gelechiidae). *Scientia Horticulturae*, **89**: 103-113.
- *LIETTI, M. M., BOTTO, E. AND ALZOGARAY, R. A., 2005, Insecticide resistance in argentine populations of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Neotrop. Entomol.*, **34**: 113-119.
- *LONI, A. E., ROSSI, K., AND ACHTERBERG, K. V., 2011, First report of *Agathis fuscipennis* in Europe as parasitoid of the tomato leafminer *Tuta absoluta*. *Bull. Insectol.*, **64**: 115-117.
- LUNA, M. G., WADA, V. I., SALLE, J. L. AND SANCHEZ, N. E., 2011, *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae), a newly recorded parasitoid of the tomato moth, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), in Argentina. *Neotrop. Entomol.*, **40**(3): 412-414.
- MARCHIORI, C. H., SILVA, C. G. AND LOBO, A. P., 2004, Parasitoids of *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae) collected on tomato plants in lavras, state of minas gerais, Brazil. *Brazil J. Biol.*, **64**(3A): 551-552.
- *MEYRICK, E. 1917. Descriptions of South American Micro-Lepidoptera. *Trans. Ent. Soc. London*, 1-52.

- MIRANDA, M. M. M., PICANCO, M., ZANUNCIO, J. C. AND GUEDES, R. N. C., 1998, Ecological life table of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Biocontrol Sci. Technol.*, **8**: 597-606.
- *MOLLA, O., ALONSO, M., MONTON, H., BEITIA, F., VERDU, M. J., CABRERA, J. AND URBANEJA, A., 2010, Control biológico de *Tuta absoluta*. catalogación de enemigos naturales y potencial de los miridos depredadores como agentes de control. *Phytoma Espana.*, **217**: 42-46.
- MOLLA, O., CABRERA, G. J., URBANEJA, A., 2011, The combined use of *Bacillus thuringiensis* and *Nesidiocoris tenuis* against the tomato borer *Tuta absoluta*. *Biocontrol*, **56**: 883-891.
- MOUSSA, S., SHARMA, A., BAIOMY, F. AND EL-ADL, F. E., 2013, The status of tomato leaf miner; *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Egypt and potential effective pesticides. *Academic J. Entomol.*, **6**(3): 110-115.
- NANNINI, M., ATZORI, F., FODDI, F., PISCI, R. AND SANNA, F., 2011, A survey of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) outbreaks in tomato greenhouses in Southern Sardinia (Italy). *Acta Hort.*, **917**: 39-46.
- OGUR, E., UNLU, L. AND KARACA, M., 2014, *Chenopodium album* L.: A new host plant of *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae). *Turk. Entomol. Bull.*, **4**(1): 61-65.
- OLIVEIRA, C. R. F., CYSNEIROS, C. H. AND HATANO, E., 2007, Occurrence of *Pyemotes* sp. on *Tuta absoluta* (Meyrick). *Brazilian Arch. Biol. Technol.*, **50**(6): 929-932.
- OZTEMIZ, S., 2013, Population of *Tuta absoluta* and natural enemies after releasing on tomato grown greenhouse in Turkey. *African J. Biotechnol.*, **12**(15): 1882-1887.
- PEREYRA, P. C. AND SANCHEZ, N. E., 2006, Effect of two solanaceous plants on developmental and population parameters of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Neotrop. Entomol.*, **35**(5): 671-676.
- PORTAKALDALI, M., OZTEMIZ, S. AND KUTUK, H., 2013, A new host plant for *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Turkey. *J. Entomol. Res. Soc.*, **15**(3): 21-24.
- POTTING, R., VAN DER GAAG, D. J., LOOMANS, A., VAN DER STRATEN, M., ANDERSON, H., MACLEOD, A., CASTRILLON, J. M. G. AND CAMBRA, G. V., 2009, *Tuta absoluta*, Tomato leaf miner moth or South American tomato moth. Ministry of Agriculture, Nature and Food Quality (LVN) Plant Protection Service of the Netherlands. Accessed December 16, 2009. www.minlnv.nl.
- *POVOLNY, D., 1964, Gnorimoschemini trib. nov.-Eine neue tribus der familie Gelechiidae nebst bemerkungen zu ihrer taxonomie (Lepidoptera). *Acta. Soc. Ent. Czechoslov.*, **61**: 330-359.
- *POVOLNY, D., 1987, Gnorimoschemini of southern South America III: the Scrobipalpuloïd genera (Insecta, Lepidoptera: Gelechiidae). *Steenstrupia*, **13**(1): 1-91.
- *POVOLNY, D., 1993, Zur Taxonomie und Nomenklatur der amerikanischen gnorimoschemoiden Gattungen *Tuta* Strand, *Tecia* Strand, *Scrobipalopsis* Povolny and *Keiferia* Busck (Insecta: Lepidoptera: Gelechiidae). *Reichenbachia*, **30**: 85-59.
- *POVOLNY, D., 1994, Gnorimoschemini of South America VI: identification keys checklist of Neotropical taxa and general considerations (Insecta, Lepidoptera, Gelechiidae). *Steenstrupia*, **20**(1): 1-42.

- RASSOUL, M. A. S., 2014, A new host record for tomato leaf miner *Tuta absoluta* (Meyrick, 1917) in Baghdad province, Iraq. *Bull. Iraq Nat. Hist. Mus.*, **13**(1): 15-18.
- *RICIPUTI, C., 2011, Pomodoro, contro la *Tuta* tre nuovi predatori naturali. *Colture Protette*, **40**:32-34.
- *RUSSELL IPM LTD. 2009, *Tuta absoluta* information network-News. Russell IPM Ltd. Accessed May 16, 2011. <http://www.tutaabsoluta.com/agrinenewsfull.php?news=89&lang=en>
- SALAMA, H., FOUADA, M., ISMAIL, A., EBADA, I. AND SHEHATA, I., 2014 Life table parameters and fluctuations in the population density of the moth *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Curr. Sci. Int.*, **3**(3): 252-259.
- SILVA, D. B., BUENO, V. H. P., LINS, J. C., AND LENTEREN, J. C. V., 2015, Life history data and population growth of *Tuta absoluta* at constant and alternating temperatures on two tomato lines. *Bull. Insectol.*, **68**(2): 223-232.
- SILVA, G. A., PICANCO, M. C., BACCI, L., CRESPO, A. L., ROSADO, J. F. AND GUEDES, R. N. C., 2011, Control failure likelihood and spatial dependence of insecticide resistance in the tomato pinworm, *Tuta absoluta*. *Pest Mgmt. Sci.*, **67**: 913-920.
- SNEDECOR, G. W., AND COCHRAN, W. G., 1967. Statistical methods applied to experiments in agriculture and biology. 5th ed. Ames, Iowa: Iowa State University Press, 1956.
- SOHRABI, F., LOTFALIZADEH, H. AND SALEHIPOUR, H. 2014, Report of a larval parasitoid of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) from Iran. *J. Pl. Protect. Res.*, **54**(3): 201-216.
- *SOUZA, J. C. AND REIS, P. R., 1992, Traca do tomateiro, historico, reconhecimento, biologia, prejuizios e controle. *Belo Horizonte: EPAMIG. Bull.*, **32**: 19-25.
- SRIDHAR, V., CHAKRAVARTHY, A. K., ASOKAN, R., VINESH, L. S., REBIJITH, K. B. AND VENNILA, S., 2014, New record of the invasive South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in India. *Pest Mgmt. Hortl. Ecosys.*, **20**(2): 148-154.
- TORRES, J. B., FARIA, C. A., EVANGELISTA Jr, W. S. AND PRATISSOLI, D., 2001, Within-plant distribution of the leaf miner *Tuta absoluta* (Meyrick) immatures in processing tomatoes, with notes on plant phenology. *International Journal of Pest Management*, **47**(3): 173-178.
- UNLU, L., 2012, Potato: A new host plant of *Tuta absoluta* Povolny (Lepidoptera: Gelechiidae) in Turkey. *Pakistan J. Zool.*, **44**(4): 1183-1184.
- URBANEJA, A., GONZALEZ-CABRERA, J., ARNO, J. AND GABARRA, R., 2012, Prospects for the biological control of *Tuta absoluta* in tomatoes of the Mediterranean basin. *Pest Manag. Sci.*, **68**:1215-1222.
- URBANEJA, A., MONTON, H. AND MOLLA, O., 2003, Suitability of the tomato borer *Tuta absoluta* as prey for *Macrolophus pygmaeus* and *Nesidiocoris tenuis*. *J. Appl. Entomol.*, **133**: 292-296.
- *URBANEJA, A., VERCHER, R., NAVARRO, V., GARCIA MARI, F. AND PORCUNA, J. L., 2007, La polilla del tomate, *Tuta absoluta*. *Phytoma. Espana.*, **194**: 16-23.
- *VARGAS, H. 1970. Observaciones sobre la biologia enemigos naturales de las polilla del tomate, *Gnorimoschema absoluta* (Meyrick). *Depto. Agricultura, Universidad del Norte-Arica*, **1**: 75-110.

- YOUSSEF, N. A. AND HASSAN, G. M., 2013, Bioinsecticide activity of *Bacillus thuringiensis* isolates on tomato borer, *Tuta absoluta* (Meyrick) and their molecular identification, *African J. Biotechnol.*, **12**(23): 3699-3709.
- ZAPPALA, L., BERNARDO, U., BIONDI, A., COCCO, A., DELIPERI, S., DELRIO, G. AND GIORGINI, M., 2012, Recruitment of native parasitoids by the exotic pest *Tuta absoluta* in Southern Italy. *Bull. Insectol.*, **65**(1): 51-61.
- ZAPPALA, L., BIONDI, A., ALMA, A., AL-JBOORY, I. J., BAYRAM, J. A. A., CHAILLEUX, A., SISCARO, G., STAVRINIDES, M., TAVELLA, AZNAR, R. Z., URBANEJA, A. AND DESNEUX, N., 2013, Natural enemies of the South American moth, *Tuta absoluta*, in Europe, North Africa and Middle East, and their potential use in pest control strategies. *J. Pest Sci.*, **86**: 635-647.
- ZOUBA, A., CHERMITI, B., KADRI, K. AND FATTOUCH, S., 2013, Molecular characterization of *Trichogramma bourarachae* strains (Hymenoptera: Trichogrammatidae) from open field tomato crops in the South West of Tunisia. *Biomirror*, **4**: 13-19.
-

* Originals not seen

13. Percent fruit damage:

	Total fruits	Damaged fruit	No of pinholes									
Number			1	2	3	4	5	6	7	8	9	10
Weight												

(Harvested /Intact)

Twig	1	2	3	4	5	6	7	8	9	10
1	T									
	D									

14. Natural enemies recorded per plant:

15. Plant protection: (Organic/High Input (Intensive)/Low Input/ Average)

Date/Age	Pest/disease	Management

APPENDIX II

Metrological observation recorded during the survey period (July 2015-
April 2016) in the respective places.

Devanahalli, Bengaluru Rural						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	20.63	31.01	44.40	90.07	1.88	89.80
Aug-15	20.14	29.84	51.02	95.54	1.94	80.8
Sep-15	20	29.74	53.04	91.2	1.56	349.3
Oct-15	23.22	34.4	35.38	78.24	0.56	86.0
Nov-15	22.42	31	47.08	75.64	0.34	183.0
Dec-15	23.42	34.46	33.64	64.26	0.34	6.6
Jan-16	21.58	35.38	21.76	58.62	0.34	2.2
Feb-16	22.2	39.16	15.04	60.42	0.18	0.0
Mar-16	24.5	37.2	23.88	62.14	0.52	12.5
Apr-16	24.6	38.01	24.56	65.02	0.89	4.7

Doddaballapura, Bengaluru Rural						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	20.41	31.23	45.55	91.54	1.63	65.00
Aug-15	20.46	29.54	52.16	92.86	1.82	68.0
Sep-15	20.64	30.46	49.12	85.02	1.74	279.0
Oct-15	18.9	30.46	47.08	100	1	96.9
Nov-15	20.96	24.08	81.36	94	0.92	254.0
Dec-15	16.98	28.58	53.1	100	0.14	3.4
Jan-16	15.14	28.56	36.06	100	0.14	2.5
Feb-16	14.82	32.86	21.28	100	1.14	0.1
Mar-16	18.86	34.9	21.44	97.12	1.42	0.6
Apr-16	19.35	35.62	21.98	98.02	1.62	0.2

Hosakote, Bengaluru Rural						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.03	30.94	44.91	90.05	3.09	47.30
Aug-15	20.46	29.96	50.2	95.28	3.04	96.4
Sep-15	21.02	30.3	50.3	88.36	3.26	146.1
Oct-15	20.48	32.1	40.34	95.48	1.46	81.8
Nov-15	20.04	28.2	55.36	91.72	1.7	177.2
Dec-15	18.52	28.14	54.06	96.86	1.44	4.9
Jan-16	16.72	27.18	41.2	89.04	1.6	6.6
Feb-16	17.32	33.7	23.44	90.48	0.98	0.0
Mar-16	19.74	34.72	21.52	92.74	1.68	21.7
Apr-16	22.6	36.01	24.56	89.02	1.89	4.4

Chikkaballapura, Chikkaballapura						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.16	31.40	39.83	85.19	2.97	62.10
Aug-15	21.2	30.56	49.38	86.72	3.82	137.4
Sep-15	21.06	29.32	56.04	84.14	2.92	164.8
Oct-15	20.5	31.4	48.72	90.02	1.24	123.4
Nov-15	18.64	26.76	68.64	91.98	1.36	283.8
Dec-15	18.2	28.86	55.16	89.46	1.38	7.3
Jan-16	16	29.12	35.72	83.1	1.94	2.9
Feb-16	17.3	33.4	21.68	83.38	1.46	0.2
Mar-16	20.76	35.84	22	77.46	3.5	1.6
Apr-16	21.36	36.21	24.65	80.1	3.32	0.0

Chintamani, Chikkaballapura						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.73	34.04	34.32	80.75	1.85	52.17
Aug-15	20.66	31.42	43.22	91.76	2.04	132.3
Sep-15	19.64	29.5	50.8	94.52	2.28	180.3
Oct-15	19.36	31.04	42.84	100	1.46	84.0
Nov-15	17.82	25.62	66.3	99.98	1.46	334.3
Dec-15	17.38	27.58	55.66	99.72	1.34	5.5
Jan-16	15.28	28.02	34.44	93.7	1.68	7.2
Feb-16	15.52	33.54	23.28	97.84	1.74	0.0
Mar-16	18.92	35.28	20.28	92.1	2.58	3.5
Apr-16	18.99	36.2	24.12	93.65	3.98	1.7

Shidlaghatta, Chikkaballapura						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.16	32.15	39.29	89.34	2.57	67.58
Aug-15	21.42	31.24	44.92	92.32	2.4	121.7
Sep-15	21.08	30.48	50.88	91.46	2.48	240.3
Oct-15	22.06	33.16	40.56	90.06	0.72	131.8
Nov-15	19.34	26.78	66.92	94.96	0.72	271.7
Dec-15	18.84	28.7	51.04	91.68	1.3	6.8
Jan-16	15.26	28.44	33.02	87.46	1.58	3.8
Feb-16	17.22	33.62	22.04	85.5	1.74	0.0
Mar-16	20.64	35.68	20.94	88.74	1.34	8.9
Apr-16	23.12	36.5	25.01	89.21	1.95	0.0

Kolar, Kolar						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.58	32.54	38.32	85.72	2.30	38.33
Aug-15	20.46	30.12	50.16	97.32	1.08	76.8
Sep-15	19.58	30.2	53.42	96.42	1.74	119.1
Oct-15	19.5	30.22	47.88	100	1.42	41.5
Nov-15	18.16	24.12	77.98	100	1.84	333.2
Dec-15	17.7	26.14	67.2	100	1.74	11.1
Jan-16	16.04	28.22	35.08	91.48	1.74	20.3
Feb-16	16.54	31.92	26.14	95.44	1.4	0.2
Mar-16	19.82	34.02	23.66	92.22	1.78	6.4
Apr-16	20.36	34.03	25.89	93.81	1.92	3.8

Maluru, Kolar						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.28	32.38	39.60	85.72	2.10	48.67
Aug-15	21.24	30.34	49.56	96.12	2.88	84.4
Sep-15	21.2	30.74	53.32	90.8	1.9	174.9
Oct-15	22.2	32.64	43.1	86.56	1.32	103.3
Nov-15	21.58	29.34	52.46	78.34	1.06	212.7
Dec-15	21.9	31.02	46.48	76.82	1.2	9.7
Jan-16	15.04	28.74	35.68	91.52	1.44	7.1
Feb-16	15	33.42	24.38	95.3	1.48	0.0
Mar-16	19.44	36.22	21.32	92.68	1.44	6.3
Apr-16	20.35	36.54	22.36	93.65	1.56	6.9

Srinivaspura, Kolar						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.88	30.80	47.84	85.31	3.21	50.25
Aug-15	20.68	31.64	41.78	94.24	1.46	135.9
Sep-15	20.22	30.32	49.6	92.56	1.32	149.8
Oct-15	19.22	30.82	44.3	99.88	0.98	107.3
Nov-15	18.14	25.02	69.74	100	1.28	356.1
Dec-15	17.08	26.8	58.54	99.98	1.22	6.5
Jan-16	13.88	27.72	35	99.2	1.22	12.3
Feb-16	15.02	31.72	27.4	97.36	1.6	0.0
Mar-16	19.1	34.02	22.5	97.76	1.92	0.6
Apr-16	20.35	34.21	23.02	98.03	1.86	0.9

Mysuru						
Study period	Temperature (°C)		Relative humidity (%)		Wind Speed (km/hr)	Rainfall (mm)
	Min	Max	Min	Max		
Jul-15	21.52	32.45	35.37	75.72	3.28	32.21
Aug-15	21.68	32.68	36.52	71.72	1.82	59.9
Sep-15	21.56	32.66	43.06	91.34	1.54	56.1
Oct-15	21.74	31.94	45.24	95.6	1.60	71.6
Nov-15	20.7	28.28	61.6	96.26	1.80	149.6
Dec-15	19.52	29.04	52.58	92.72	1.98	0.6
Jan-16	18.36	28.9	35.52	85.76	1.71	3.2
Feb-16	20.64	33.6	22.46	73.22	1.60	0.0
Mar-16	22.98	36.5	23	85.5	2.30	1.4
Apr-16	23.65	37.58	25.16	86.32	2.18	0.1

APPENDIX III

Temperature and relative humidity recorded in the Entomology laboratory, COH, Bengaluru during the experimental period

Months	Temperature (°C)		Relative Humidity (%)	
	Max.	Min.	07.00 hrs	14.00 hrs
November – 2015	25.3	17.9	94	65
December – 2015	27.6	19.9	91	52
January -2016	27.5	14.7	90	47
February -2016	34.1	19.9	86	37
March – 2016	34.2	21	86	40