STUDIES ON MORPHOLOGICAL AND BIOCHEMICAL FACTORS IMPARTING RESISTANCE AGAINST AMERICAN PINWORM, *Tuta absoluta* (MEYRICK) (LEPIDOPTERA: GELECHIIDAE) AND THRIPS SPECIES IN TOMATO

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BANGALORE - 560 065

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Thesis submitted to the

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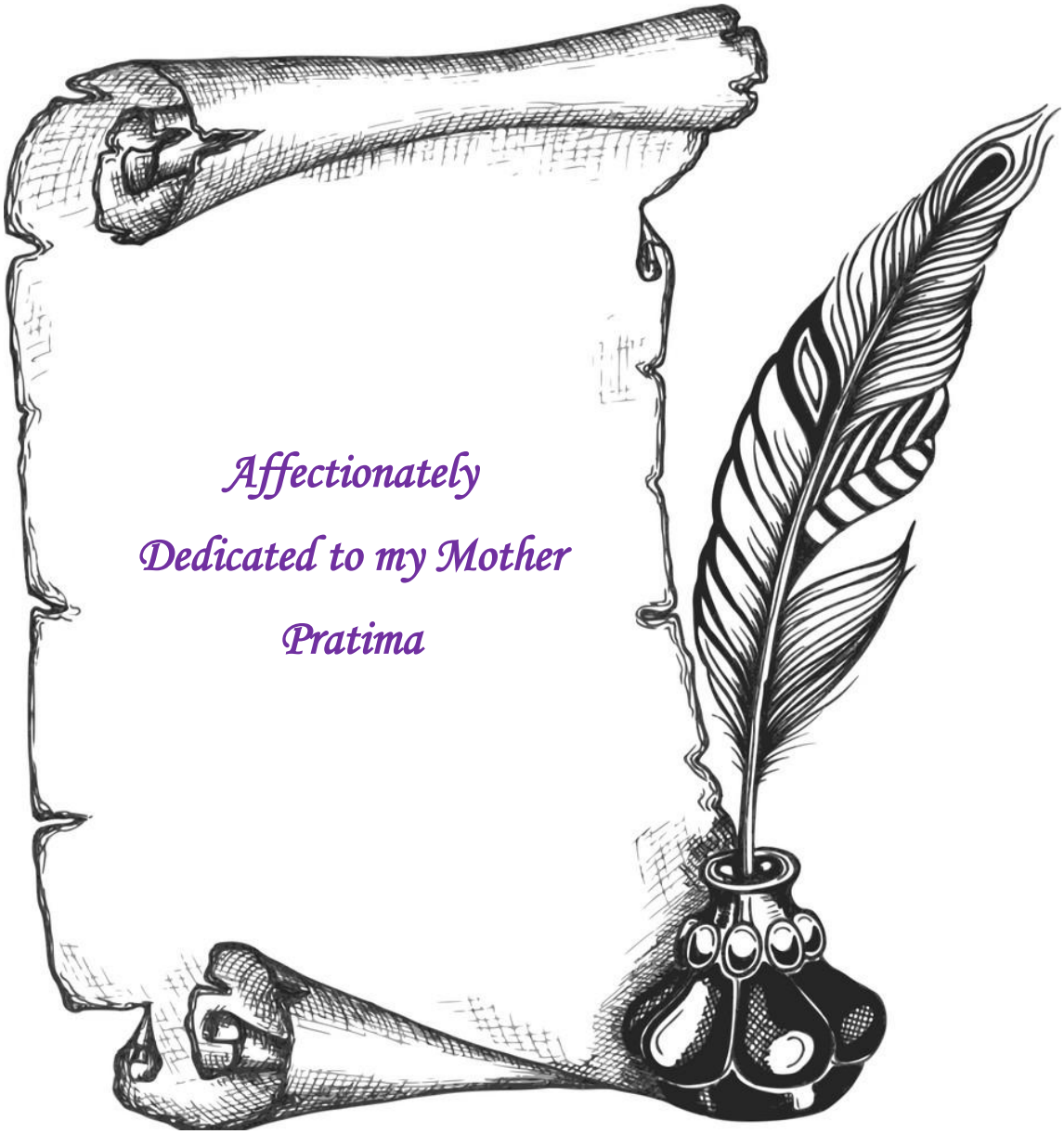
Affectionately
Dedicated to my Mother
Pratima

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE – 560 065

C E R T I F I C A T E

This is to certify that the thesis entitled **"STUDIES ON MORPHOLOGICAL AND BIOCHEMICAL FACTORS IMPARTING RESISTANCE AGAINST AMERICAN PINWORM, *Tuta absoluta* (MEYRICK) (LEPIDOPTERA: GELECHIIDAE) AND THRIPS SPECIES IN TOMATO"** submitted by **Ms. PRITHA GHOSH., ID No. PALB 6017** in partial fulfillment of the requirement for the degree of **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENTOMOLOGY** of the University of Agricultural Sciences, Bangalore is a record of *bona-fide* research work done by her during the period of her study in this University, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar titles.

Bengaluru

December, 2019

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STUDIES ON MORPHOLOGICAL AND BIOCHEMICAL FACTORS IMPARTING RESISTANCE AGAINST AMERICAN PINWORM, *Tuta absoluta* (MEYRICK) (LEPIDOPTERA: GELECHIIDAE) AND THRIPS SPECIES IN TOMATO

ABSTRACT

Investigations on morphological and biochemical factors imparting resistance against *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) and thrips species in tomato revealed that egg and larval load of *T. absoluta* were found to be significantly higher during summer 2018-19, followed by *rabi* 2017-18 and *kharif* 2018-19. Four thrips species were recorded namely *Gynaikothrips uzeli* Zimmermann, *Scirtothrips dorsalis* Hood, *Thrips palmi* Karny and *Thrips hawaiiensis* Morgan from the field screening. Pheromone trap catches of *T. absoluta* had significant negative correlation with rainfall (r = -0.35*) and relative humidity (r = -0.61*) and significant positive correlation with temperature (r =0.76*). Laboratory bioassays confirmed the resistances of wild accessions of tomato against *T. absoluta* and TOSPO vector, *S. dorsalis* by recording significantly lower egg load and higher larval mortality as compared to the susceptible check. Higher acylsugar content had a negative impact on *T. absoluta* larvae and resulted in reduced pupal weight. Dense glandular trichomes showed highly significant positive correlation (R^2=0.94*) with acyl sugar content. Total glandular trichomes showed significant negative correlation with egg load (R^2= 0.89*). Wild accessions showed contrasting differences in their green leaf volatile profile as compared to susceptible genotypes. Among biochemical parameters, acyl sugar, tannin, phenol, monoterpene and sesquiterpene contents were found at significantly higher quantity in resistant wild accessions as compared to susceptible genotype.

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ಟೊಮೆಟೊದಲ್ಲಿ ಅಮೇರಿಕನ್ ಪಿನ್‌ವರ್ಮ್ *ಟ್ಯೂಟ ಅಬ್ಸೊಲ್ಯೂಟಾ* ಮತ್ತು ಥ್ರಿಪ್ಸ್ ವಿರುದ್ಧ ಕೀಟ ನಿರೋಧಕತೆಯನ್ನು ನೀಡುವ ಬಾಹ್ಯಗುಣಗಳು ಮತ್ತು ಜೀವರಾಸಾಯಿನಿಕ ಅಂಶಗಳ ಕುರಿತು ಅಧ್ಯಯನ

ಸಾರಾಂಶ

ಈ ಅಧ್ಯಯನದಲ್ಲಿ *ಟ್ಯೂಟ* ಮತ್ತು ಥ್ರಿಪ್ಸ್‌ಗಳ ಮೊಟ್ಟೆ ಮತ್ತು ಮರಿಹುಳುಗಳ ಸಂಖ್ಯೆ ೨೦೧೭–೧೮ರ ಚಳಿಗಾಲ ಹಾಗೂ ೨೦೧೮–೧೯ರ ಬೇಸಿಗೆ ಮತ್ತು ಮುಂಗಾರಿನಲ್ಲಿ ಗಣನೀಯವಾಗಿ ಕಂಡುಬಂದಿತ್ತು. ಕ್ಷೇತ್ರ ಪರೀಕ್ಷಿಸಿದಾಗ ಥ್ರಿಪ್ಸ್‌ನಲ್ಲಿ *ಗೈನಕೊಥ್ರಿಪ್ಸ್ ಉಝೆಲಿ, ಸಿಟ್ರೊಥ್ರಿಪ್ಸ್ ಡಾರ್ಸಾಲಿಸ್, ಥ್ರಿಪ್ಸ್ ಪಾಮಿ* ಮತ್ತು *ಥ್ರಿಪ್ಸ್ ಹವಾಯನ್ಸಿಸ್* ಎಂಬ ನಾಲ್ಕು ಪ್ರಬೇಧಗಳು ಕಂಡುಬಂದವು. ಟೂಟಾದ ಮೋಹಕ ಬಲೆಯ ಅಂಶಗಳು ಗಮನಾರ್ಹವಾಗಿ ಮಳೆಯ ಮತ್ತು ಆರ್ದ್ರತೆಗಳಿಗೆ ಋಣಾತ್ಮಕವಾದ ಮತ್ತು ಉಷ್ಣಾಂಶದಲ್ಲಿ ಧನಾತ್ಮಕವಾದ ಸಂಬಂಧವನ್ನು ಕಂಡುಕೊಳ್ಳಲಾಯಿತು. ನಿಸರ್ಗಸಹಜವಾದ ನಮೂನೆಗಳು *ಟ್ಯೂಟ* ಮತ್ತು ಟಾಸ್ಪೋ ವಾಹಕ *ಸಿ. ಡಾರ್ಸಾಲಿಸ್*‌ಗಳಲ್ಲಿ ಮೊಟ್ಟೆಯ ಹೊರೆ ಗಣನೀಯವಾಗಿ ಕಂಡುಬಂದಿದ್ದು ಹಾಗು ಮರಿಹುಳುಗಳ ಸಾವಿನ ಮಟ್ಟ ಹೆಚ್ಚಾಗಿ ಕಂಡು ಬಂದಿತು. ಹೆಚ್ಚಿನ ಅಸೈಲ್ ಸುಗರ್ ಪ್ರಮಾಣವು *ಟ್ಯೂಟ* ಮರಿಹುಳುಗಳ ಮೇಲೆ ನಕರಾತ್ಮಕ ಪರಿಣಾಮ ಹೊಂದಿರುವ ಕಾರಣ ಕೋಶಗಳ ತೂಕ ಕಡಿಮೆಯಾಯಿತು. ನಿಬಿಡಾದ ಗ್ರಂಥಿ ಕೂದಲುಗಳು ಅಸೈಲ್ ಸುಗರ್ ನೊಂದಿಗೆ ಗಮನಾರ್ಹವಾಗಿ ಧನಾತ್ಮಕ ಸಂಬಂಧವನ್ನು ಹೊಂದಿರುವುದು ಹಾಗೂ ಮೊಟ್ಟೆಯೊಂದಿಗೆ ಋಣಾತ್ಮಕ ಸಂಬಂಧವನ್ನು ಹೊಂದಿರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ. ನಿಸರ್ಗಸಹಬಾವದ ಮತ್ತು ಸಂವೇಧನೆಗೆ ಕಾರಣವಾದ ನಮೂನೆಗಳಲ್ಲಿ ಹಸಿರು ಎಲೆಗಳಲ್ಲಿನ ಬಾಷ್ಪಶೀಲ ಪ್ರೋಫೈಲ್‌ನಲ್ಲಿ ವ್ಯತಿರಿಕ್ತ ವ್ಯತ್ಯಸವಿರುವುದು ಕಂಡುಬಂದಿದೆ. ಸಂವೇಧನೆಗೆ ಒಳಗಾಗುವ ನಮೂನೆಗಳನ್ನು ಹೋಲಿಸಿದರೆ ನಿಸರ್ಗದಾಯಕಗಳಾದ ನಮೂನೆಗಳಲ್ಲಿ ಅಸೈಲ್ ಸುಗರ್, ಟ್ಯಾನಿನ್, ಫಿನಾಲ್, ಮೋನೊಟರ್ಪಿನ್ ಮತ್ತು ಸೆಸ್ಕ್ವಿಟರ್ಪಿನ್‌ಗಳ ಧಾತುಗಳು ಹೆಚ್ಚಾಗಿ ಇರುವುದು ಕಂಡುಬಂದಿರುತ್ತದೆ.

ಡಿಸೆಂಬರ್, ೨೦೧೯
ಕೃಷಿ ಕೀಟಶಾಸ್ತ್ರ ವಿಭಾಗ
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(ಕೆ. ಎಸ್. ಜಗದೀಶ್)
ಪ್ರಮುಖ ಸಲಹೆಗಾರರು

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I INTRODUCTION

Tomato *Solanum lycopersicum* L., is one of the important vegetable crops of India. It is grown in 0.760 M ha area, with an annual production of 18399 mt (2015-16). The major tomato producing states are Bihar, Karnataka, Uttar Pradesh, Orissa, Andhra Pradesh, Maharashtra, Madhya Pradesh and West Bengal and this crop is menaced by multiple pests.

Among wide range of pests, the tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is one of the major pests of tomatoes, *Solanum lycopersicum* L., in South America. It was introduced to Europe via Spain and now it has spread all over the continent. Recently, it has been found in Africa and Asia, where heavy damage occurred due to this pest. Larvae of *T. absoluta* can injure both the leaves and fruits of tomatoes, ultimately leading to reduction in yield (Galdino *et al.*, 2015). Inspite of our country's strong quarantine measures, *T. absoluta* has invaded the country through wind and trade. It was first reported in Maharashtra during 2014. It can cause upto 90 per cent loss in yield and fruit quality under greenhouse and open conditions. Apart from the major host tomato, pest also attacks potato (*Solanum tuberosum*), eggplant (*Solanum melongena*), Jimson weed (*Datura stramonium*) broad bean (*Vicia faba*) and alfalfa (*Medicago sativa*) of the family Fabaceae and members of Cucurbitaceae, Euphorbiaceae, Asteraceae *etc.*, (Mohamed *et al*., 2015).

The current status of *Tuta absoluta* is alarming as it can feed and attack several solanaceous host plants and the effective control measures are also not known. The production loss of USD 59.3 and 8.5 million was reported in Kenya and Zambia, respectively (CABI 2019). It is a threat to the tomato industry of our country as tomato is the second most important vegetable crop grown in our country. Taking this factor into consideration, it is utmost essential to manage this pest in an eco-friendly manner, before it turns into a major bottleneck for successful tomato production.

Species of Thrips such as *Thrips palmi* Karny and *Scirtothrips dorsalis* Hood form another major group that act as vectors of virus diseases of tomato. These pests

destroy seedlings before they have a chance to become hardy. They can thrive on expanding plant tissue - the flower buds, tomato fruits, as well as growing stems and leaves. In addition, thrips carry tomato spotted wilt (TOSPO) virus, to cause severe yield losses. TOSPO virus infection is known to induce a wide array of symptoms on its host plants, including leaf speckling, chlorotic, and necrotic lesions of various shapes, sunken spots, etches, ring spots, stunting, yellowing, and wilting (David *et al.*,2011).

Thrips are known to transmit TOSPO viruses in a persistent propagative manner (Ullman *et al*,. 1997). Both larval and adult stages of thrips vectors can actively feed on virus infected host plants, but only early larval instars can acquire the virus and later instar larvae and adults can transmit the virus after a latent period (Ullman *et al*., 1997 and Persley *et al.*, 2006). As a vector, thrips are very important because they contribute to significant yield loss due to TOSPO disease. It has been reported that due to TSWV, 58 counties got affected and huge losses have been identified since 1993 to 2007 (Mila, 2011).

To control pests, host plant resistance can be an important component of IPM programme. Resistant plants can help maintain pest populations below economic injury levels and are usually compatible with other control methods, in addition being eco-friendly.

Plants have evolved different kinds of adaptations to combat insect attacks. Their defense mechanisms interfere with the physiology and/or behaviour of the insect. Plant possesses different biophysical traits or biochemical parameters to act against insect attack. Biophysical traits such as the presence of glandular trichomes, wax layers, defensive metabolites or proteins have been identified (Fan *et al*., 2016; Schilmiller *et al*., 2012 and 2015). Among different allelochemicals or secondary metabolites, acyl sugars play a major role, which may be directly toxic to insects (Luu *et al*., 2017), or because of their sticky nature, causes death of the insect by immobilizing them on the leaf (Schilmiller *et al*., 2008; Rakha *et al*., 2017a). There are many different acyl sugars produced in a tomato plant and its wild relatives (Lucatti *et al*., 2013; McDowell *et al*., 2011) which may have different effects on different insects' species. It has been

identified that some specific plant compounds present in the glandular trichomes, including acyl sugars, terpenes, methyl ketones and flavonoids (Glas *et al.*, 2012) have a role in resistance mechanisms against mite and insect species (Lucini *et al*., 2015) . Thus host plant resistance can play a pivotal role in resistance to insect pests and should be one of the major criteria in the development of newer crop cultivars, in order to ensure prolonged cultivar life and cost effective production.

Information on insect resistance levels among a large number of accessions and their underlying resistance mechanisms would be very useful for tomato breeders worldwide. The main focus of this study was to characterize the available wild accessions *viz., S. galapagense, S. cheesmaniae, S. habrochaites and S. habrochaites. var. glabratum* of The World Vegetable Center (AVRDC),Taiwan's genebank for trichome types and to evaluate them for their reaction to *Tuta absoluta* and thrips species.

In view of significant status of American pinworm, *Tuta absoluta* and TOSPO vector thrips species as two major biotic constraints in successful tomato cultivation, and to avoid our over reliance on synthetic chemicals the investigations on resistance against these pests were carried out with the following objectives:

1. Screening of tomato accessions for their reaction to *T. absoluta* and thrips species.
2. Evaluation of morphological traits imparting resistance to *T.absoluta* and thrips species in tomato.
3. Evaluation of biochemical factors imparting resistance to *T. absoluta* and thrips species in tomato.

II REVIEW OF LITERATURE

The literature pertaining to population dynamics of invasive *Tuta absoluta* and TOSPO vector *Thrips* sp. with changing weather parameters, assessment of the reaction of *T. absoluta* and *Thrips* sp. towards elite genotypes, mechanism of resistance, variation in resistance parameters are reviewed hereunder.

Tomato (*Solanum lycopersicum* L.), belonging to family Solanaceae is an important vegetable crop around the world and also as a popular garden vegetable and commercially grown in 159 countries. There are more than 700 varieties of tomatoes all over the world. Different insects attack tomato from nursery stage to the harvesting stage. Insects can cause the death of the tomato plant and damage to fruits. The major insect pests play a most important role in the economic loss.

2.1 Insect pests of tomato

Tomato cultivation is threated by multiple pest attacks. Scientists have reported different insect pests in tomato starting from nursery stage to harvesting stage. Pest incidence and their occurrence vary with seasons. Among various pests, tomato fruit borer, *Helicoverpa armigera,* an important economic pest which causes considerable losses in yield of tomato fruits of about 40 per cent according to Tewari and Moorthy, (1984).

Oscar *et al*. (1999) reported the two species of leaf miner, *Liriomyza trifolii* and *Liriomyza bryoniae* as important pests of ornamentals and vegetables including tomato.

Arnal *et al.* (1998) recorded the presence of adult whiteflies (*Bemisia tabaci*) during the plant growth and increased by the end of the rainy season.

Gravena (1999) noted that three significant tomato pests were *Bemisia tabaci, Helicoverpa armigera* and *Liriomyza trifolii*, whereas Chaudhuri *et al*., (2001) observed aphid (*Aphis gossypii*), whitefly (*Bemisia tabaci*), leaf miner (*Liriomyza trifolii*), tingid bug (*Urentius hystricellus*) and fruit borer (*Helicoverpa armigera*) as significant tomato pests.

Helicoverpa armigera was reported by Rudenko *et al.* (2001) as the main insect pest of tomato fruit and caused significant damage.

Umeh and Onukwu (2005) performed a study of some Nigerian tomato-producing fields and reported that the fruit borer, *Helicoverpa armigera*; whitefly, *Bemisia tabaci* and multiple aphid species, mostly *Aphis gossypii*, were the main insects attacking tomatoes.

Reddy and Kumar (2004) have recorded a total of 41 species of insects belonging to 21 families, including the defoliators *Spodoptera litura*, *Monolepta andrawesi*, *Poekilocerus pictus* and *Atractomorpha crenulata*, *Liriomyza trifolii*, *Bemisia tabaci*, *Aphis gossypii*, *Myzus persicae* and *Nezara viridula*, stem feeders *Euzophera perticella* and *Leucinodes orbonalis*.

Mandal (2012) reported that the fruit borer, *Helicoverpa armigera* Hubn, aphid (*Aphis gossypii* Glov.) and white fly (*Bemisia tabaci*) had been major insect pest of tomato.

Oda *et al*., (2012) recorded the incidence of numerous insect pests such as aphids, thrips, whitefly and leaf miners; insects belonging to the Coccidae and Miridae families and cotton bollworms in tomato crops were more. Besides these significant insect pests, there are some invasive pests that are becoming a danger to growers of tomatoes.

Tomato pinworm is a severe danger to the tomato sector as an invasive pest by causing harm to the quality of fruits. Shiberu and Getu (2017) reported that the amount of larvae per crop decreased the yield from 10.51 to 75.62 percent in 2015 and from 11.87 to 80.22 percent in 2016.

Few of the *Thrips sp*., aphids and whiteflies are essential among significant sucking pests. Kagezi *et al*. (2001) reported that thrips causing 23.7% reduction in tomato yield. They can also function as a vector to spread various virus diseases. They cause harm both directly and indirectly. Thrips feed on plant tissue by scratching and sucking sap, leading to tissue scarification and crop resource depletion. Various approaches for

insect pest management in tomato are chemicals, botanicals, use of resistant cultivars. Chemical insecticide leaves a film of persistent poison over the foliage and fruits which is hazardous.

2.1.1 Invasive insect pest *T. absoluta* and assessment of crop loss by *T. absoluta* in tomato

Large-scale movement of planting materials often involves the risk of accidental introduction of insect pests through trade between nations. The issues caused by such invasions are countless and can cause havoc in the lack of natural enemies as the introduced pests exploit the conducive nature of the breeding and establishment setting.

Chandrashekar and Shashank (2014) reported that on tomato crops which were cultivated in polyhouse and open areas get affected by *T. absoluta*. Its occurrence then spread over 50% of the crops in various parts of Maharashtra viz., Pune, Ahmadnagar, Dhule, Jalgaon, Nashik, and Satara.

Sridhar *et al*. (2015) recorded the incidence of Tomato Leafminer introduced from South America, *T. absoluta* (Meyrick) was observed during regular surveillance on tomato at Indian Institute of Horticultural Research (IIHR) and adjoining farmers' fields in Bengaluru, Karnataka including six districts of Karnataka State viz., Bengaluru Rural and Urban, Kolar, Chikkaballapur, Ramanagar and Tumkur. The infestation of *T. absoluta* ranged from low to high (upto15 mines per plant) in different tomato fields surveyed and in some of the fields up to 87% of the tomato plants were found infested by *T. absoluta*.

Kalleshwaraswamy *et al.* (2015) reported that in January and February 2015, the tomato leafminer, *T. absoluta*, entered and established in the Malnad and Hyderabad-Karnataka Regions of Karnataka, India, where it infested tomato and potato crops. This was the first record of *T. absoluta* in these regions of India.

Ballal *et al*., (2016) investigated occurrence in three Indian states and reported fruit harm by *T. absoluta* in Tamil Nadu. Absolutes ranged from 0.5 to 13.5 per cent; 2.0

to 100 per cent in Karnataka and 5 per cent to 12 per cent in Gujarat. Slight damage has also been reported on Kolar district potato leaves. The incidence of this pest in tomato areas at distinct development phases, reported at distinct rates of infestation in four countries, shows that from the nursery level to the harvesting stage this pest is a major danger to tomato crop.

Santana *et al*. (2018) presented model which showed large suitable areas for the tomato pinworm in the North and Central Americas, Africa, Europe, Asia and Oceania for the current and future times. Important tomato producers such as China, Mexico and the USA should be concerned about the risk of an eventual invasion of *T. absoluta* due to their climatic suitability for this pest. They predicted that climate changes will affect *T. absoluta* negatively around the equator and positively near the poles. Regions with high latitude, for example the USA and northern Europe, will become more suitable for the tomato pinworm due to the increase in temperature due to climate change.

2.1.3 Host range of *T. absoluta*

In a laboratory research in Venezuela, *T. absoluta* was found to prefer tomato cultivar ―Rome Gigante as an oviposition host compared to potato, tobacco, eggplant, *Physalis angulata, Solanum hirsutum, Solanum americanum,* and tomato variety Cerasiforme (Fernandez and Montagne, 1990).

Although *T. absoluta* prefers tomato as its host (EPPO 2005), it also attacks a number of other of solanaceous crops including eggplant (*Solanum melongena* L., also called aubergine), potato (*Solanum tuberosum* L.), tobacco (*Nicotiana tabacum* L.), and African eggplant (*Solanum aethiopicum* L.) (EPPO, 2005; Mohamed *et al*., 2015).

Tuta absoluta also has been found on a range of wild solanaceous plants (e.g., *Solanum* spp. and *Datura* spp.). Besides Solanaceae, it has been reported to feed on plants from the families Amaranthaceae, Asteraceae, Brassicaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Fabaceae, and Poaceae (Mohamed *et al*., 2015; CABI, 2017).

2.1.4 Host plant resistance

Because of domestication and intended focus on yield aspects, most of the tomato cultivars are susceptible to a wide range of arthropod pests, which can cause significant losses, including complete destruction of the crop. The use of chemicals has had a negative impact on the environment, which has led the scientific community to assess the genetic resistance as a key element in the Integrated Pest Management (IPM) as a more durable and safe way of control (Reseña 2015). On the other hand wild species has diverse traits and are capable to fight against insect-pests. Based on geographical distribution the *Solanum* sp. varies (Table 1) and based on origin their traits also differs.

T. absoluta already showed resistance to various groups of insecticides under laboratory conditions (Silva *et al.,* 2011). Improving resistance to pests in tomato has had lots of difficulties; however, results of new technology application to the study of mechanisms and heritage provide elements that increase introgression effectiveness; as identifying of markers associated with resistance to enable assisting the selection during production of tomato cultivars resistant to insect pests. Biological control measures with less chemical damage to the environment gained importance because it uses pathogen or insect predators. Besides, natural insecticides extracted from plants, are also good examples of effective control. Another strategy to control pests would be the use of resistant cultivars for its durability and safety. It has been limited as most cultivars do not have a high level of resistance to allow a significant reduction in insect damage (Foolad 2007).

Controlling *T. absoluta* is challenging for its biology and behaviour. Chemical control techniques have been trusted to manage this insect, but because of the larvae's feeding habits, the growing amount of this pest's resistant strains and the adverse effect of the chemical on the surroundings make the chemical control technique unsustainable (Moreno *et al*., 2011; Deliperi and Delrio, 2012).

Resistance has been reported for so many herbivores in wild relatives of tomato. *Bemisia tabaci* and *Trialeurodes vaporariorum* resistance have been defined in *S. galapagense.* Insect resistance was connected with the appearance of glandular trichomes

and secondary metabolites in wild relatives of tomatoes. In Integrated Pest Management (IPM) programs, host plant resistance is an economically and environmentally friendly approach (Pedigo, 2002; Sharma and Ortiz, 2002).

Table 1: *Solanum* tomato species and their geographical distribution Peralta *et al.* (2008)

Section	Group	Species	Geographical distribution
Lycopersicum	Lycopersicon	*S. lycopersicum*	Cultivated worldwide
		S. pimpenellifolium	Coast of Ecuador of Chile
		S. cheesmaniae	Galapagos Island
		S. galapagense	Galapagos Island
	Neolycopersicon	*S. pennelli*	Western Andean slopes from Peru to Chile
	Eriopersicon	*S. habrochaites*	Mountains of Ecuador and Peru
		S. huaylasense	Callejon de Huaylas.Peru
		S. corneliomulleri	Western Andean slopes of southern Peru
		S. peruvianum	Coast of Peru to the north of Chile
		S. chilensis	Chilean coast and southern Peru
	Arcanum	*S. Arcanum*	Northern peru inter-Andean and coastal valleys
		S. chmielewskii	South of Peru
		S. neorickii	Ecuador to Peru, inter-Andean valleys
Lycopersicoids		*S. lycopersicoids*	Southern Peru and northern Chile
		S. sitiens	Southern Peru and northern Chile
Juglandifola		*S. juglandifolium*	Colombia, Ecuador and Peru andes
		S. ochranthum	Ecuador and Peru andes

Resistant cultivar may cause significant reduction in the use of chemical insecticides, which results in the increase of the activity of beneficial organisms and decrease in residues of pesticides in human food and also in the environment (Sharma and Ortiz, 2002). The use of resistant host plant is consistent with other control strategies in IPM programs in many instances nearby (Pedigo, 2002). The main stage in using host crop resistance in IPM programs is to find pest-resistant cultivars (Panda and Khush, 1995).

Moreira *et al.* (2013) reported that, due to relatively low costs, insect and arachnid plant resistance developed by breeding programs was considered ideal, allowing pests to be kept below the level of economic damage and in balance with their natural enemies without polluting the environment and human health.

Dias *et al.,* (2016) researched wildlife species and interspecific crosses and recorded the effectiveness of these species in transmitting genes expressing certain desirable features, such as the manufacturing of glandular trichomes, which in most instances exude chemical compounds, called alllochemicals.

2.1.5 Screening of tomato accessions for their reaction to *T. absoluta* and thrip species

2.1.5.1 Field screening and laboratory screening

Bitew (2018) tested sixteen accessions of wild genotypes and correlated with parameters like damaged leaf area, oviposition rate, emerged larvae, adult and larvae survival, larvae and adult preference. Those parameters were correlated with the density of each trichome type and with LC-MS data. From no-choice test parameters accession LA1777, LA1718 and LA716 were the most resistant and LA1401 and LA1139 were the most susceptible, and all *S. lycopersicum* accessions were susceptible. From choice test, they found that the accessions G1.1561, LA1718, LA716, LA1645, LA0483 and LA1408 were not preferred by the larvae, and the accessions LA1777 and G1.1561 were the least preferred by the adults. The accession LA1777 and LA716 were out of the most

resistance. The resistance of this genotype tested by him was related to the presence of trichome Type I and IV.

Liliana *et al*. (2010) carried out studies in order to determine the effect of infestations with *Tuta absoluta* on the growth and development of tomato plants under greenhouse conditions with six densities of the pest (0, 2, 4, 6, 8, and 10 females/plant). The plants exposed at infestation levels between 6 and 10 females presented the highest percentages of leaf area consumed (between 27 and 43%), damage on fruits (between 45 and 100%), and loss of apical leaves in comparison with the treatments with two and four females/plants. The height, number of internodes, number of leaves and leaflets, number and biomass of fruits were differentially affected by the densities of *T. absoluta* infestation ($P \leq 0.05$). The leaf area and the biomass of stems and leaves did not vary with the infestation levels evaluated. On the damage curve, they observed that with more than two females per plant, the variables biomass, quality and number of fruits, result affected in an important way.

Glandular trichomes, especially type I and type IV are known to be important as they secrete secondary metabolites that can be toxic, repellent, trap insects or act as a physical barrier and interfere with insect feeding and oviposition (Dimock and Kennedy 1983; Channarayappa *et al*., 1992; Sharma *et al.*, 2009).

Plant trichomes are considered the most important factor conferring pest resistance. Trichome type and density confers resistance to a variety of insect pests. The glandular trichomes can produce a plethora of biochemical components (Hawthhorn *et al.*, 1992).

Sarkar *et al.* (2018) tested six major tomato genotypes for resistance / tolerance under West Bengal conditions against major sucking pests and their natural enemies. In the third week of January and the second week of February respectively, Aphid *(Aphis gossypii* Glover) and whitefly *(Bemisia tabaci* Genn.) appeared first on the plant. Both the pests peak population were reported in February's third to fourth week. The peak populations of both the pests were recorded in the third to fourth week of February. The

maximum (r= -0.027 and -0.210) and minimum temperatures (r= -0.138 and -0.283) and minimum relative humidity (r= -0.191 and -0.031) were found to exert unfavorable influence on population development of whitefly and aphid species and showed negative correlation whereas maximum relative humidity (r=0.225 and 0.428) and sunshine hour (r=0.547 and 0.387) favoured the population build up. Their findings showed that none of tested tomato genotypes were found either tolerant or resistant against aphid and whitefly.

Ghulam, (2016) studied the varietal preference of insect pests in tomato and their result revealed that the highest population mean of whitefly *Bemisia tabaci*, followed by the leaf hopper *Amrasca bigutella bigutella*, Thrips *Scirtothrips dorsalis*, Aphid *Aphis gossipii* Glover and American bollworm *Helicorverpa armigera*. Their general peak population mean for the Hybird-1000 variation was 4.45 to 3.02, 2.27, 0.70 and 0.47, while for the Zatooni variation it was 5.30 to 4.28, 2.47, 0.70 and 0.47 Moon Star was 5.18, 3.91, 2.32, 0.35 and 0.38 respectively. The highest whitefly population was reported, followed respectively by Jassid, Thrips, Aphid, and American bollworm. However, Whitefly's infestation on the Zatooni variety was more than the pests of other insects followed by Moon star. The Hybrid-1000 variety discovered to be more resistant to insect pest and from their investigation suggested batter production.

Solangi *et al.* (2017) studied population dynamics on six genotypes of tomatoes, i.e., Rutgar, Eden Oblong, Rio Granade, Nagina, Pakit and Roma sucking pests, aphids, thrips, whiteflies, jassids and mites, since the early development of multiple tomato genotypes was recorded. They discovered that the genotype of Nagina was more likely to attack all recorded sucking pests, whereas the genotypes of Rutgar and Eden Oblong were the least prone to different sucking pests (Bhai *et al*., 2017).

2.1.2 Seasonal incidence of insect pests in tomato

Bagmare *et al.* (1995) analyzed that the mean temperature of a sunshine hour had a positive correlation with the tomato population of *Liriomyza trifolii*, where it had a negative correlation with the leaf miner population as rainfall and relative humidity. In

surveillance research, they found that tomato is a significant nursery host plant for *Liriomyza trifolii*.

Arnal *et al.* (1998) observed that the adult whiteflies (*B. tabaci*) were present throughout the growing age in the tomato field research and discovered their population to be larger at the end of the rainy season. They noted that the adult whiteflies (*B. tabaci*) were present in the tomato field research throughout the increasing era and found that at the end of the rainy season their population was greater.

Kharpuse and Bajpai (2006) studied the seasonal incidence of major insect pests of tomato. The tomato plant was infested with leaf miner (*Liriomyza trifolii* Burgess), yellow fly (*Bemisia tabaci* Genn.) and fruit borer (*Helicoverpa armigera* Hub). Leaf miner appeared in December's last week, whitefly and fruit borer appeared in January's second week and February's third week respectively. The maximum activity reported by them in the second and last week of March was the leaf miner, white fly and fruit borer.

2.2 Evaluation of morphological trait imparting resistance to *T.absoluta* and thrips species in tomato

The reviews pertaining to resistance factors or mechanism against *T. absoluta* and TOSPO vector *Thrips sp*. are scanty. However, pertinent literature on mechanisms of host plant resistance of other miners, borers and sucking pests are presented here under.

Many structural differences in plant varieties have been reported to be concerned with resistance (Amin *et al*., 2016). The morphological factors are known to interfere physically with insect locomotion and especially with the mechanism of host selection, feeding, ingestion, mating and oviposition (Norris and Kogan, 1980).

In the context of insect pests, mechanical stimulation is considered mainly due to the impact on many aspects of the insect or pest body of articulated spines and hairs. The antennae, mouth sections and ovipositor or ovipositor-related structures generally carry significant amount and range of these hairs and setae. The continuous palpitation of the antennae or mouth parts of many insect or pest species appears to be part of the way they

learn about their habitat (Painter, 1951). Thus morphological traits have a great role in insect host selection.

Khanam *et al*. (2003) performed a field experiment to screen thirty tomato varieties/ lines against tomato fruit borer, *Helicoverpa armigera* (Hub.) in relation to their morphological features. The infestation of tomato fruit borer varied considerably between the varieties/ lines and also with the age of tomato crops. Among the varieties/ lines they tested, V-29 and V-282 were discovered to be mildly resistant and prone to attack, respectively where morphological traits like plant height, stem diameter, total number of branches/plant, total number of leaves/plant, 2nd leaf area, total leaf chlorophyll, number of leaf hair, number of fruits/plant of V- 29 line were 81.74, 1.45 cm, 14, 14,453, 19.58 sq. cm, 1.13 mg g-1, 12 and 48, respectively whereas aforementioned characters for V-282 line were 80.74 cm, 1.18 cm, 9, 396, 21.57 sq. cm, 1.24 mg g-1, 17 and 30, respectively.

2.2.1 Mechanism of resistance in elite genotypes against *T. absoluta* and *Thrips.* species

Morphological and biochemical defences in plants are important to withstand insect attack. Although morphological defence is primarily used by plants against insect pests, the biochemical-based defence is considered more effective as it directly affects insect growth and development (Kariyat *et al*., 2013).

Host plant defence may be associated with morphological, biochemical and molecular characteristics in resistant cultivars to counter/ offset herbivore attacks (War *et al.*, 2012).

Trichomes are hair-like appendages that grow from aerial epidermis cells and are formed by most plant species and contribute to host plant resistance to herbivorous insects (Dalin *et al.,* 2008).

It is known that plant morphology imparts a significant role in giving a cultivar resistance or susceptibility. The physical appearance of the plant, such as colour,

hairiness, hardness, trichomes, surface waxes, mineral incrustation in cuticles and anatomical adjustment of organs, may influence the preference or non-preference for egg laying, feeding and insect growth (Dhankhar, 1997).

2.2.2 Leaf thickness and leaf area

Afzal and Abbas (1943) observed that in their selection work, the moisture percentage of the leaves, the pH value of their cell sap or the toughness of the cuticle of the leaf vein could not be used by the plant breeders as criteria, because the character associated with resistance should be an easily identifiable morphological character.

Singh and Agarwal (1988) discussed physical and biochemical factors including leaf thickness and hairiness to resistance against insect pests. According to them, hairiness is the characteristic of resistance against leafhoppers.

Ambekar and Kalbhor (1981) also found that length of hair and hair density on midrib and leaf lamina of cotton were found to contribute towards resistance against leafhoppers.

Bhatti *et al.* (1976) noted differences in *Bt* cotton resistant and prone genotypes owing to plant height, hair density, leaf lamina thickness, leaf region, hair length, moisture proportion and complete minerals. The findings revealed that there was an adverse and substantial correlation between hair density on midrib, vein and lamina; hair length on midrib and vein was not significantly correlated. While there was a favourable and substantial correlation between the densities of the leaf lamina and the leafhopper population per leaf were observed.

Gossypol glands on the midrib and vein showed favourable and substantial correlation while adverse and substantial effects were observed on the lamina. Total minerals had a favourable and substantial impact, while the reduction of sugar, calcium and manganese had an adverse and substantial connection with the density of the leafhopper. Leaf area and its succulency play a part in leafhopper resistance. More the area of a leaf supports more population of nymphs. Similarly, other scientists also noted

that resistance to cotton leafhopper in cotton (Tidke and Sane 1962, Sikka *et al.*, 1966, Ambekar and Kalbhor 1981) and in okra (Mahal 1973, Bindra and Mahal 1979, Mahal and Singh 1982) in terms of either leafhopper population or the extent of injury inflicted by it.

Leaf toughness serves as a limiting factor in the growth of certain pests in the population (Kadapa *et al.,* 1989). Leaves of resistant genotypes of cotton were found to be thinner than genotypes susceptible to insect pests. In resistant genotypes, the thinner leaves coupled with the higher density of upper and lower epidermal cells and mesophyll cells make the lamina of these genotypes very compact. Thick leaf lamina with loosely arranged epidermal and mesophyll cells characterize the susceptible genotypes, making the leaves succulent and prone to insect pests attack (Thimmaiah, 1997: Chandrashekara, 1994).

Mehetre and Patil (2004) studied the anatomical basis of resistance in cotton for sucking pest complex. They described that specific leaf anatomical structures control resistance or susceptibility to various sucking pests. Hence, to breed a genotype resistant to sucking pests, modification in cellular structure of leaf at genic level was required. Asian cotton species have a comparatively longer phloem distance from the reduced epidermis, compact cell arrangement of parenchyma tissue, and longer palisade tissue, while wild species have very compact palisade tissue and genetic resistance to pest.

Attempt to improve the *G. arboreum* lines with genic resistance of wild species through introgression breeding approach were effective. Hybrid crosses between *G. arboreum* x *G. hirsutum* are difficult to obtain. Successful hybridization between haploid *G. hirsutum* x *G. arboreum* var. G- 27 has been reported by More *et al*., (2007). In their anatomical studies in apomictic lines IS-244/4/1 and IS-181/7/1 revealed that distance to phloem from lower epidermis was 31 and 33.2 mm respectively, which was on par with *Gossypium arboreum* check PA-183 (36.4 mm) whereas *G. hirsutum* check (NH-545) had significantly less (23.6 mm) distance to phloem from lower epidermis compared to other genotypes. Parenchymatous cells were more compact in *G. arboreum* check PA-183 and apomictic lines (IS-244/4/1 and IS-181/7/1) than *G.hirsutum* check NH-545.

Palisade compactness, parenchyma tissue width of apomictic lines IS-244/4/1 and IS-181/7/1 were similar to that of *G. arboreum* check but were less in *G. hirsutum* check. Similarly, in interspecific hybrid derivatives with PA-183, the phloem distance from upper epidermis confirmed the resistance of these lines to sucking pest complex.

Uthamasamy (1980) recorded a lower preference for *A. devastans* oviposition for the okra variety AE 22 on its leaf lamina and midrib because of its hairiness. It has been noted that the midrib thickness of okra and cotton has a favourable connection with leafhoppers ' oviposition (Ambekar and Kalbhor 1981, Sharma and Sharma 1997). Similar trials have been performed in Delhi on 12 cotton genotypes and the mean leafhopper population has been discovered to be negatively correlated with leaf hairiness (Sharma and Agarwal, 1983).

In brinjal, lamina and midrib thickness were discovered to be strongly correlated with leafhopper infestation, while lateral vein thickness, midrib hair density, and midrib hair length were not significantly associated with leafhopper infestation (Subbaratnam and Butani, 1981).

Increased populations of thrips are often associated with enhanced incidence of viruses (Garcia *et al*., 2000; Culbreath *et al.*, 2003).

2.2.3 Trichomes type and density

Luckwill (1943) recorded seven kinds of trichomes in the Solanum genus. Their classification is based on trichome length, the presence or lack of the nucleus at the apical end, and when present, the amount of neurons that make up the organ. Trichomes are classified into two types, nonglandular trichomes (II, III, V), which are quite similar to each other, differing in length only, and glandular trichomes (I, IV, VI, VII), capitated, with the head, mostly acting as the region of alllochemical secretory (Gonçalves *et al*., 1998, Gonzale *et al*., 2012)

Rakha *et al.,* 2015 tested the abundance of Type I, IV and VI trichomes in wild tomato accessions. In comparison, mostly type V trichomes of cultivated tomato display,

with the unusual appearance of type I and type VI. Trichomes of type I, IV and VI, owing to the existence of alllochemicals, are deemed to be of major significance in pest resistance.

Aragão *et al.,* (2000) reported trichomes, act as physical barriers besides acting as chemical barriers, which can help in limiting pest insect and arachnid access to the plant surface, due to trichome density and length. Morphological characteristics and chemical composition of tomato leaves (*Lycopersicon esculentum* Miller) were evaluated and compared between nine types of tomatoes (Roma VFN, NARC-1, Fs-8802, Tommy, Pant Babr, Rio Grande, Nova Mecb, Pakit and Sahil) with differing concentrations of host plant resistance to *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) as a result of fruit infestation. The variety Sahil, was resistant, while the vulnerable variety was Roma VFN. Hair length and hair density on the reduced surface of the leaf, as well as leaf lamina thickness considerably correlated with larval population and infestation of the fruit. 92.0 percent of the variability in fruit infestation and leaf hair density. Hair length and hair density on abaxial leaf surface, as well as leaf lamina thickness considerably correlated with larval population and fruit infestation. Leaf hair density accounted for 92.0% of fruit infestation variation and 77.0% of larval population variation in their findings (Amzad *et al*., 2015).

2.3 Evaluation of biochemical factors imparting resistance to *T. absoluta* and thrips species in tomato

Plant tissues consist mainly of water, proteins, carbohydrates, minerals and lipids. This provides a potential source of water and nutrients through which insect pests obtain the energy, nitrogen, proteins and carbohydrates needed. For each unit of insect pest development, the infesting pests must consume proportionately large amounts of plant leaf. At the same moment, crops have developed a number of defense mechanisms that can withstand the harm caused by pests or feeding insects. The plant-evolved resistance mechanism involves biochemical factors that act as repellent, poisonous or otherwise and render the plant unfit for use.

2.3.1 Total sugar and Total protein

Nagrare *et al.,* (2017) first indicated that *Phenacoccus solenopsis* Tinsley (Hemiptera: pseudococcidae) causes alterations in cotton plant biochemistry. Total protein content estimated from healthy plant shoots (4.29 mg / g) showed a rise of 50.5% over healthy crops (2.85 mg / g). It was discovered that total sugar reduction was not affected by the mealybug infestation.

Lakra *et al.,* (2018) experimented to study biochemical composition of different genotypes of tomato which varied significantly. The highest TSS percent (%) recorded in genotype 2015/TOCVAR-5 on the other hand genotype 2015/TOINDVAR-5 gave highest total sugar (%) and reducing sugar (%), and 2015/TOINDVAR-4 gave highest non-reducing sugar (%).

Rath and Nayak (2007) evaluated distinct biochemical components, i.e., complete N, P, K, crude protein, sugar, complete soluble solid (TSS) and pH, of fruit juice of six distinct chosen tomato genotypes (BT10, BT12, Rishi 7, T35, H Cross 17 and Century 12), which revealed that lower levels of N, protein, sugar and TSS and higher levels of potash and pulp acidity were the chemical factors responsible for the low susceptibility of tomato varieties to fruit borer *(Helicoverpa armigera*) especially in BT10 and BT12 tomato varieties.

A positive correlation between the protein contents and survival of leafhopper were reported by Singh and Taneja (1989). They also found oviposition of the leafhopper which was correlated positively with protein content.

Whereas, Ali *et al.* (1995) did not observe any role of proteins against the leafhopper attack and reported that reducing sugars had positive and significant correlation with the leafhopper density.

Comparatively reduced proteins, humidity and sugar content in Arka Anamika and Varsha Uphar leaves were assessed for their resistance and more proteins, moisture

and sugars in Parbhani Kranti, P-8, Pusa Sawani and Shagun leaves are responsible for their susceptibility (Chavan *et al.* 1991, Bhat, 1999).

Comparison of relative variations between susceptible and resistant cotton genotypes with respect to the distribution of protein in leaves, petioles, stem tips and boll rinds showed greater protein content in susceptible genotypes compared to resistant genotypes (Thimmaiah *et al.,* 1997).

Kabre and Ghorpade (1999) reported significantly low protein content (13.21%) in least susceptible genotype (X2(Y) 5089) of maize as compared to highly susceptible CM-202 (16.42%) ones.

The protein content correlated favourably with the susceptibility of stem borer. The leafhopper's differential survival was noted on resistant and vulnerable cotton varieties. The protein content influenced the growth, development and harm caused by leafhopper (Mohan Kumar and Venugopal, 1999).

Sahoo and Patnaik (2003) discovered reduced protein levels in resistant entries compared to susceptible entries *i.e.,* (18% in plants and 11.6% in pod coats), (18.2 and 11.6% in plants and pod coats, respectively). They concluded that low protein content could provide resistance in pigeonpea to most of the pod borer species and form a foundation for variety choice.

2.3.2 Phenols and tannin content

Nagrare *et al.,* (2017) studied that total phenol content increased by 185.7% in the mealybug infested plants (0.20µg/g) over the healthy plants (0.07µg/g) although insignificant difference in the level of total soluble sugar was observed in mealybug infested plants (1.00µg/g) as compared to healthy plants (0.90µg/g).

Vaishali *et al.* (2012) observed that the amount of total phenolics were relatively low in susceptible varieties than the resistant varieties and hybrids. Cotton plants with high phenolic content showed low incidence of leafhoppers.

Simmonds (2003) studied the flavonoid-insect interactions and observed that the phenols act as antifeedant to insect herbivores. Massey *et al.,* (2006) reported that silica may act as an anti-herbivore defence by increasing the abrasiveness and reducing the digestibility of grass leaves.

Experiment was conducted under field circumstances on the impact of different biochemical variables on the incidence of *Helicoverpa armigera* in tomato. Multiple linear regression models showed resistance, rather than a single factor, to be affected by combining different variables. Tomato genotypes with elevated ascorbic acid and phenols, as well as acidity, could be used as strength markers against *H. armigera.*

Rathi *et al.* (1986) found that upon inoculation, phenolic content raised in both resistant and susceptible varieties. However, the magnitude of increase was greater in the resistant variety than in the susceptible one particularly during initial intervals i.e. 7 and 14 days after inoculation.

In the resistant cell line, total phenols were more than in the vulnerable cultivars. However, increase in phenolics in the resistant cell line were greater than in susceptible cultivars after cultural filtrate therapy, suggesting that phenols in the resistant cell line achieve an inhibitory level to the fungus (Singh *et al.* 2003).

Increased levels of reducing sugars and non- fermentable reducing substances were observed in diseased leaves over healthy leaves of Pigeon pea infected by Pigeon pea sterility mosaic virus (Nambiar and Ramakrishnan, 1968).

Senthil *et al*., (2010) conducted an experiment to see some phytochemical properties on *Cucumis sativa* (Linn.) affected by leaf spot disease caused by *Penicillum notatum*. The results revealed that in both healthy and infected leaves, terpenoids, Steroids, Saponins, Phenols were found to be present. But in infected leaves the quantities of phenols was found to be higher compared with healthy ones. Phenol content was found to be increased simultaneously in diseased leaf tissues in comparison to the healthy one with the increase in the period of infection.

Sugars function as a precursor to phenolic, phytoalexin, lignin, and cellulose synthesis that plays a significant role in plant protection against invading pathogens. It is indicated that generally elevated concentrations of complete sugars are accountable for disease resistance in the host plant. During development, the resistant wheat genotypes (NIDW 295 and DWR 185) showed more mean complete sugar than prone genotypes, i.e. 60 and 90 DAS. Observations also disclosed that complete sugars were reduced owing to infection. Further, observations revealed that there was reduction in total sugars due to infection (Patil *et al.* 2011).

Sharma *et al.,* (2009) and Barbehenn and Peter (2011) observed that tannins have a strong astringent taste and deleterious effect on phytophagous insects and affect the insect growth and development by binding to the proteins, reduce nutrient absorption efficiency and cause midgut lesions.

2.3.3 Chlorophyll content and others

Most of the yellows type of diseases caused by viruses and MLO's induce reduction in chlorophyll content. Mall and Seikh (1977) reported quantitative reduction of chlorophyll 'a' and 'b' in little leaf infected brinjal plants.

Lakra *et al.,* (2018) analysed 22 genotypes, where genotype 2014/TODVAR-3 showed highest β-carotene (mg/100 ml) and lycopene content (mg/100 ml), whereas genotype 2015/TOCVAR-3, showed highest chlorophyll a (mg/100 ml) and b. Genotype 2015/TOINDVAR-5 showed highest total carotenoid (mg/100 g). Highest Ascorbic acid (mg/100 g), titrable acidity (%) and pH observed in the genotype 2014/TODVAR-5, 2015/TOCVAR-5 and 2015/TOCVAR-3, respectively.

Shukla *et al*., (1984) have also reported significant reduction in chlorophyll 'a' and 'b' content in grassy shoot infected sugarcane leaves. Gupta and Chawla (1987) found a lower chlorophyll content in inoculated plants than in healthy ones in Phaseolus vulgaris infected with bean common mosaic virus.

Nagare *et al.,* (2017) reported from their studies in mealybug infestation in cotton where there was depletion in all the photosynthetic pigments *viz.*, chlorophyll a (19.1%), chlorophyll b (23.7%), total chlorophyll (21.2%) and carotenoids (20.8%) due to the mealybug infestation, these values were not statistically different in the healthy plants.

Purohit *et al*., (1978) have reported that chlorophyll content (total, a and b) of leaf tissue decreased with increasing disease severity although the ratio between chlorophylls 'a' and 'b' remained constant while Purohit *et al.* (1983) have also observed in diseased tissues that ascorbic acid content increased and availability of sugars in diseased tissues may enhance ascorbic acid synthesis, these factors leading to proliferation of the tissues.

Development of disease causes impairment in photosynthetic pigments that impacts the plants ' use of light energy. This interferes with the diseased tissue's biochemical occurrences and culminates in decreased photosynthesis and yield (Mahadevan and Sridhar, 1982).

Kandakoor *et al.* (2013) reported that phenol and tannin content showed negative relationship with number and damage by thrips. Total sugar, reducing sugar and amino acids showed positive correlation with thrips and their per cent damage. In their study they concluded higher tannin and phenol content contributed for thrips resistance in groundnut.

2.3.4 Allelochemicals

Allelochemicals are mainly present in higher plants as natural chemicals that act as dietary, antinutritional, herbal, medicinal, pest-and disease-resistance factors. The chemical substances responsible for plant resistance to insects and arachnids can be categorized into three types: substances acting on pest conduct (glycosides, alkaloids, terpenes, phenols and essential oils); those acting on pest metabolism, such as secondary metabolites (including some alkaloids and quinones, among others); and antimetabolites making essential nutritional imbalances. The most important allelochemicals found in wild tomato species are acyl sugars, sesquiterpenes and methyl ketones. Acyl sugars

(AA), such as acylglycosis and acylsucrose, are found in *S. pennellii* and *S. galapagense* accession leaf trichomes.

Secondary metabolites are multiple compounds found in species of terrestrial and marine plants. Plants generate secondary metabolites under biotic or abiotic stress due to antimicrobial, anti-herbivorous and allopathic impacts of the compounds (Dixon, 2001).

2.3.5 Acyl sugar content

Research has demonstrated the efficiency of these species in the transmission of genes that express certain desirable characteristics, such as the production of glandular trichomes that, in most cases, exude chemical compounds, called allelochemicals.

The most important allelochemicals found in wild tomato species are acyl sugars, sesquiterpenes and methyl ketones. Acyl sugars (AA), such as acylglycosis and acylsucrose, are the most considerable allelochemicals in *S. pennellii* and *S. galapagense* accession leaf trichomes (Silva, *et al.* 2016)

Acylsugars are one of the most promising classes of plant-derived control agents associated with insect resistance and are produced by a diversity of taxa in the Solanaceae; including some species in the *Nicotiana*, *Solanum*, *Petunia*, and *Datura* genera (Buta *et al.*1993).

A cross between *S. pennellii* LA716 with cultivated tomato was used in breeding lines with acylsugar-mediated insect resistance. The benchmark acylsugar breeding line, CU071026, produces ~15% of the acylsugar levels of LA716 but with a different composition (Leckie *et al*. 2012). An introgressed line showed effective control of *B. tabaci* in field cage trials under heavy infestation (Leckie *et al*. 2012). Multiple QTL underlying sugar moiety as well as fatty acid profile have been identified from a BC_1F_1 population (*S. pennellii* LA716 x CU071026) x CU071026) and from a intraspecific *S. pennellii* BC_1F_1 population allowing manipulation of the acylsugar component parts.

Acylsugars (AA) are glucose or sucrose esters containing acyl groups present in type IV glandular trichomes reported by Silva *et al*., (2008). In *S. pennellii* accession ‘LA

716', the main AA is 2, 3, 4 -tri-O-acyl-glucose. Its resistance character is presumably due to the fact that it confers a sticky appearance to leaf surfaces, which acts as a natural trap, avoiding pest insect oviposition, feeding or even causing deleterious effects on their development reported by Goffreda *et al*., (1989).

Acylsugars are polyesters of short- to medium-length acyl chains on sucrose or glucose backbones that are produced in secretory glandular trichomes of many solanaceous plants, including cultivated tomato (*Solanum lycopersicum*). Despite their roles in biotic stress adaptation and their wide taxonomic distribution, there is relatively little information about the diversity of these compounds and the genes responsible for their biosynthesis. In this study, acylsugar diversity was assessed for 80 accessions of the wild tomato species *Solanum habrochaites* from throughout the Andes Mountains.

Trichome metabolites analysis revealed the presence of at least 34 structurally diverse acylsucroses and two acylglucoses. Distinct phenotypic classes were discovered that varied based on the presence of glucose or sucrose, the numbers and lengths of acyl chains, and the relative total amounts of acylsugars. The presence or absence of an acetyl chain on the acylsucrose hexose ring caused clustering of the accessions into two main groups (Kim *et al*. 2012).

Trichome secreted acylsugars are very important in pest resistance (Buta, 1993). Acyl-sugar synthesized in the glandular trichomes of the Solanaceae family is implicated in protection against abiotic and biotic stresses.

Acylsugars are composed of either sucrose or glucose, esterified with varying numbers of acyl chains of differing length. But acylsugar and its chemotypes can vary based on the weather parameters and geographical area (Lekie *et al.*, 2012).

Rakha *et al.* (2017a, 2017b) screened wild tomato accessions against *T.absoluta*, *Tetranychus urticae* and whiteflies (*B.tabaci*) where they found high acylsugar content have significant negative correlation with all the three insect damage in tomato.

2.3.6 Green leaf volatiles

Plants produce volatile chemical compounds that can negatively affect the preference (antixenosis) or the performance (antibiosis) of herbivorous insects. It is thought that these volatile compounds are used as cues by herbivorous insects to determine the suitability of the plant for egg deposition and, hence, offspring performance.

Volatile organic compounds in tomato plants affect the behaviors of pests and pollinators of tomato. Glycoalkaloids are of interest because of their implication in host-plant resistance (Buttery *et al*., 1987).

Naturally occurring biogenic volatile organic compounds (BVOCs), released by plants, have important atmospheric and ecological consequences (Ormeño *et al.,* 2011). They contain air borne semiochemicals that promote or deter interactions between plants and herbivorous insects (Bawin *et al.,* 2014).

Some varieties of cultivated tomatoes have shown that 26referred2626g26ographic (EAG) responses for monoterpenes, in particular β–phellandrene, limonene, and 2–careen, and the sesquiterpene I–β–caryophyllene, were relatively high, suggesting that they could be playing a major role in attraction and oviposition of *T. absoluta* females (Zhang *et al.,* 2008; Proffit *et al.,* 2011; Bawin *et al.,* 2014). BVOCs released to the atmosphere by plants accounts for about 30% of the photosynthetically fixed carbon. These metabolites may act as plant 26referre against herbivores and facilitate the foraging 26referred of natural enemies of herbivores, and protect leaf cells from a variety of abiotic stress.

Livia *et al*. (2017) discovered that when flying to resistant or vulnerable tomato genotypes, the behavioural steps shown by mated *T. absoluta* females did not vary, but reached the vulnerable genotypes quicker than the resistant ones. Moreover, females landed more often and laid more eggs on the most susceptible genotype, the Santa Clara variety. Because this variety is known to be of high quality for the development of *T.*

absoluta larvae, the female's decision to land and lay more eggs on this genotype seems to be mainly to maximize offspring performance.

Bleeker *et al*. (2009) studied *Bemisia tabaci* (whitefly) infestations and the subsequent transfer of viruses as the cause of severe losses in crop production and horticultural practice. They investigated repellent properties of plant-produced semiochemicals. The mix of headspace volatiles, collected from naturally repellent wild tomato accessions, influenced *B. tabaci* initial choice 27referred, indicating a role for plant semiochemicals in locating host plants. A collection of wild tomato accessions and introgression lines (*Solanum pennellii* LA716 × *Solanum lycopersicum* 'Moneyberg') were extensively screened for attractiveness to *B. tabaci*, and their headspace profiles were determined by means of gas chromatography-mass spectrometry. Correlation analysis revealed that several terpenoids were putatively involved in tomato-whitefly interactions. Several of these candidate compounds conferred repellence to otherwise attractive tomato plants when applied to the plant's branches on paper cards. The sesquiterpenes zingiberene and curcumene and the monoterpenes p-cymene, α-terpinene, and α-phellandrene had the strongest effects in free-choice bioassays. These terpenes also elicited a response of receptors on the insect's antennae as determined by electroantennography. Conversely, the monoterpene β-myrcene showed no activity in both assays. *Bemisia tabaci* apparently uses, besides visual cues, specific plant volatile cues for the initial selection of a host. They suggested Altering whitefly choice 27referred by manipulation of the terpenoid composition of the host headspace may therefore be feasible.

III MATERIAL AND METHODS

The present investigation was conducted at the experimental plots of M/s. I&B Seeds, Kengeri, Uttarahalli, Bengaluru and screening & laboratory analysis of morphological and biochemical factors responsible for resistnce to *T. absoluta* and thrips were conducted at Department of Agricultural Entomology, during the years 2017-19. The material used and methodologies adopted for the investigation are detailed hereunder and presented under different headings.

3.1 Location of the experimental area

The experiments were laid out at the plots of M/s. I&B Seeds, Kengeri, Uttarahalli, Bengaluru located at an altitude of 930 MSL (12.90 º N, 77.50 º E). The annual rainfalls varies from 530 mm to 1200 mm, with a mean of 865 mm. All other agronomic management practices except plant protection were followed as per the recommended package and practices (Anon., 2015).

3.1.1 Layout of the experiments

The field investigations were conducted during three different seasons *i.e.* summer, *kharif* and *rabi* during 2017-18 and 2018-19. The Seeds of wild accessions, obtained from the World Vegetable Centre Genebank, Taiwan were treated with gibberellic acid @ 250 ppm overnight and germinated seeds were planted in small jiffy pots. Seedlings were grown in greenhouse under ambient temperature (28-35 °C, 16/8 h day/night). One month old seedlings were transplanted in the main field (row length = 7.20 mt) in RCBD with four replications. The minimum number of plants per plot was 12 and data was collected from 5 inner plants per plot/replication. Four replications were followed. The distance between rows was 90 cm and within rows plant spacing was 60 cm. Five tomato accessions/genotypes and two commercial hybrids were used for the field screening for one season and in rest of the seasons five wild accessions were used for screening. In order to determine the sources of resistance to invasive pest *T. absoluta* and *Thrips* sp. The five wild accessions from different parts of the world which were found promising at World Veg Centre (formerly AVRDC) were supplied by that

organisation and were evaluated. Accessions or genotypes used are as detailed in Table 2. Observations were taken to record the mean no. of eggs, larvae, *T. absoluta* damage to the leaves, fruits and the no. of thrips per tap at regular intervals. Observations were recorded on 3rd, 6th, 9th, 12th and 15th weeks after transplanting.

Table 2: Tomato genotypes screened for reaction of *T. absoluta* and *thrips* species

Sl. No.	Genotypes	Origin	Source
A	**Wild accessions**		World Vegetable Centre (Formerly AVRDC, Taiwan)
1	*S. galapagense*	Galapagos island	
2	*S. cheesmaniae*	Galapagos island	
3	*S. habrochaites*	Ecuador	
4	*S. habrochaites var. glabratum*	Ecuador	
5	*S. lycopersicum*	Brazil	
B	**Commercial hybrids****		
1	TM 308		M/S I & B Seeds, Pvt Ltd, Kengeri, Uttarahalli,Bengaluru
2	PT4208		

**used in only one trial during summer 2018.

Fruiting period was not uniform for all the genotypes. Fruiting is late and initiated after 9th weeks of transplanting in case of wild accessions. Mean value fruit damage starting from 10th week after transplanting to 15th week after transplanting was recorded to assess the difference in per cent fruit damage.

3.1.2 Screening of wild genotypes under field condition

Seven different field trials were conducted starting from *Rabi* 2017 to *kharif* 2019 as detailed in Table 3.

Table 3: List of genotypes screened under field condition in different seasons at M/S I&B Seeds Pvt. Ltd., Uttarahalli, Kengeri, Bengaluru.

Sl. No.	Genotypes	Season	Year	Period
1	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum*	*Rabi*	2017	August to November
2	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum and hybrids viz., TM308* and *PT4208*	Summer	2018	March to June
3	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum*	*Kharif*	2018	June to September
4	*S. galapagense, S. lycopersicum,* F1, F2 of their interspecific cross.	Summer	2018	March to June
5	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum*	*Rabi*	2018	September to December
6	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum*	Summer	2019	March to June
7	*S. galapagense, S. cheesmaniae, S. habrochaites, S. habrochaites var. glabratum, S. lycopersicum*	*Kharif*	2019	June to September

3.1.3 Observations recorded in the field screening experiments

3.1.3.1 *T. absoluta*

At each sampling date, five randomly selected plants were checked visually in each plot. From each selected plant, twenty leaves per canopy and ten fruits were randomly chosen and the numbers of the larval mines in each leaf, per cent damage of leaf and fruit were recorded separately. Non-destructive sampling was performed on 3rd, 6th, 9th, 12th and 15th weeks after transplanting. From each canopy 20 leaves were observed. Mean no. of eggs and larvae per canopy per 20 leaves, were recorded on 3rd, 6th, 9th, 12th and 15th weeks after transplanting (Plate 1). Per cent foliar damage was recorded by randomly selecting 20 leaves per canopy and per cent fruit damage was calculated by randomly observing 10 fruits. One pheromone trap was installed for monitoring purpose. Pheromone trap catch of male adults were recorded. Effect of

genotype, canopy, duration and interaction was analysed with 3 factorial anova by using OPSTAT Software, followed by DMRT.

To study the possible influence of meteorological variables on the incidence of *T. absoluta*, the data on pest population was recorded at weekly intervals and correlated with the weather data of the previous week. Further, moth catch in pheromone trap were recorded. Mean no. of larvae per 20 leaves and weather parameters were subjected to Multiple Linear Regression analysis techniques. Following rating scale was used for scoring *T. absoluta* damage (Ayalew, 2011).

Table 4: Rating scale adopted for assessing *T. absoluta* foliar damage on tomato genotypes

Rating scale	Characteristic feature/ Symptoms
0	No leaf damage
1	0.1% to 5% of total leaf area damaged; small & non-coalescent lesions.
2	5.1 to 20% of total leaf area damaged; small to medium-size and non-coalescent lesions
3	20.1 to 50% of leaf area damaged; medium to large-size lesions
4	50 to 80.1% of leaf area damaged; numerous and large, coalescent lesions
5	More than 80.1% of leaf area damaged, completely deformed plants.

In addition, fruit damage caused by *T. absoluta* was recorded at diffrrent weeks after transplanting by using a 0-3 visual scale, where,

Table 5: Rating scale adopted for assessing *T. absoluta* fruit damage on tomato genotypes

Rating scale	Characteristic feature/ Symptoms
0	No leaf damage
1	Few fruits are damage (<20% of total fruits are damaged)
2	20-49% of total fruits are damaged
3	≥50% of total fruits are damaged

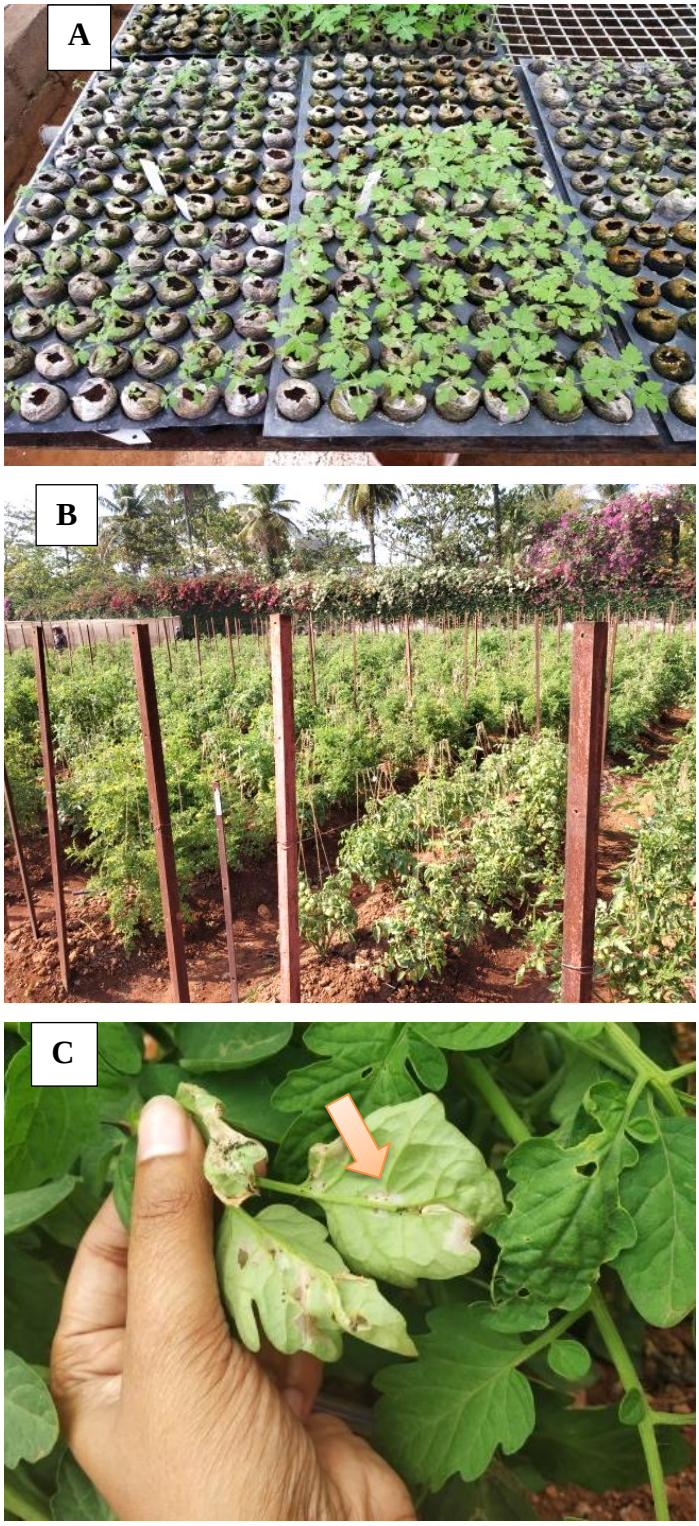


Plate 1: (A-C) Field screening against *T. absoluta* damage

(A) Seedlings raised in giffy pots at nursery, (B) Field screening of different genotype (C) Tomato leaf infested by *Tuta absoluta*

3.1.3.2 Thrips spp

Thrips occurring on tomato were collected by gently tapping the canopy on to a stiff white paper board (30cm x 30cm). Thrips so collected were picked using a fine camel hairbrush, transferred to small glass vials containing 70 per ethyl alcohol and labelled (date of collection, host, and locality) (Plate 2). Thrips were later sent to Ms. Rachna (scientist), at NBAIR**,** Hebbal, Bengalore for identification. The average number of thrips per canopy was worked out to know the abundance of the pest. Thrips complex were identified upto species level from National Bureau of Agricultural Insect Resources (NBAIR), Hebbal. Four major different species were recorded from two field trials *i.e. Gynaikothrips uzelii, Scirtothrips dorsalis, Thrips palmi* and *Thrips hawaiiensis* from the collected thrips samples (Table 9). From 2017 *rabi* season and 2018 summer season different species complexes were recorded (Plate 3).

During visual examination of plant material for the presence of Thrips damage, silvery feeding scars on the leaf surfaces of host plants, especially alongside the midrib and the veins was considered.

Heavily infested plants were often characterized by a silvered or bronze colored appearance of the leaves, stunted leaves and terminals, or scarred and deformed fruits.

85.25. **Artificial or Laboratory screening:**

Based on the field screening data pertaining to the mean population of *T. absoluta* and *Thrips sp.,* damage, further screening was done under laboratory condition by choice and no choice assay (Plate 5).

3.2.1 Rearing of *T. absoluta*

The adult moths of *T. absoluta* pests used for the artificial screening experiments were obtained from polyhouse of I &B Seeds Company and by surveying different infested farmer's fields in and around Magadi taluk of Ramanagar district, Kadur taluk of Chikkamagalur district and the Department of Horticulture, UAS, GKVK, Bengaluru, Karnataka (Plate 4). Adult male and female *T. absoluta* moths were reared in cages of 65

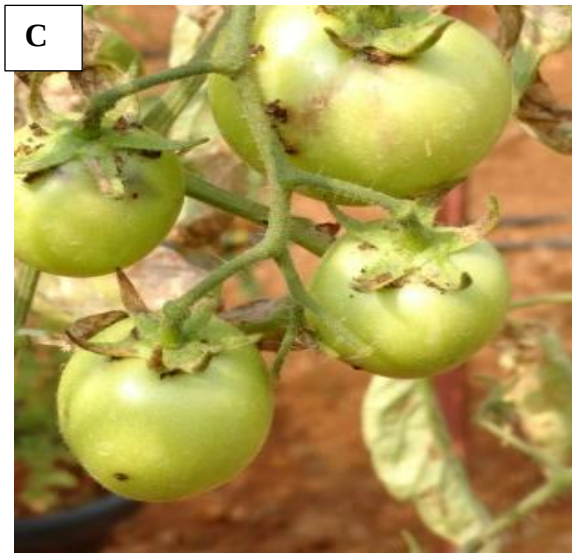
cm x 45 cm x 45 cm size of plexi–glass and kept with potted tomato plants of commercially available variety called "Rishita". Honey solution with a cotton plug was kept for adult and fresh seedlings were kept and changed regularly for oviposition. The plants were then put in similar cages where the eggs hatched. To obtain adults of the same age, pre–pupal stage larvae were placed in cages of 20 cm x 15 cm x 15 cm size and provided daily with fresh tomato leaves until pupation. Newly formed pupae were placed in a cold chamber at 10°C until all the larvae had pupated. The pupae were then sexed according to their external morphology (Solomon, 1962). Male pupae were placed in a climatic chamber a day after the female pupae (the average emergence time for males is 7.8 ± 0.28 days, while that of females is 8.7 ± 0.22 days at 25 °C.

Same age adult males and females were put into the same cage of 90 cm x 45 cm x 45 cm size for mating. They were provided with honey and water. The following morning, mating couples were separated into individual cages of 50 cm x 40 cm x 40 cm. Separation of male and females were done by using their body characteristics *i.e*. the male is somehow darker and has a narrower abdomen than the female. Sets of ten mated female adults were placed in the same vial and provided with water and honey before subjecting them for choice and no-choice assay and further used for other 33referred3333 experiments.

3.3 Choice and no choice bioassay

3.3.1 Choice assay with *T. absoluta*

Egg laying preference was observed in ventilated cages by choice assay. Choice assay was carried out by providing four week old potted seedlings to the gravid females. Number of eggs laid on abaxial and adaxial surface of leaf and on the stem was counted to assess the total egg load. Plants were arranged according to a completely randomized design with three plants per experimental unit with six replications. Plant spacing was 20 and 15 cm between and within accessions, respectively. To evaluate/assess antixenosis, 30 *T. absoluta* adults (female: male ratio 2:1) was released in the cages and the effects of these genotypes on adult performance was studied under controlled conditions (25±1°C, R.H. of 65±5% and a photoperiod of 16L: 8D h).



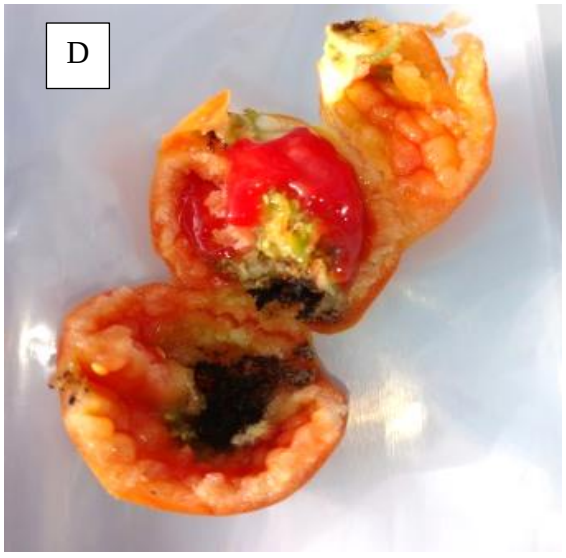
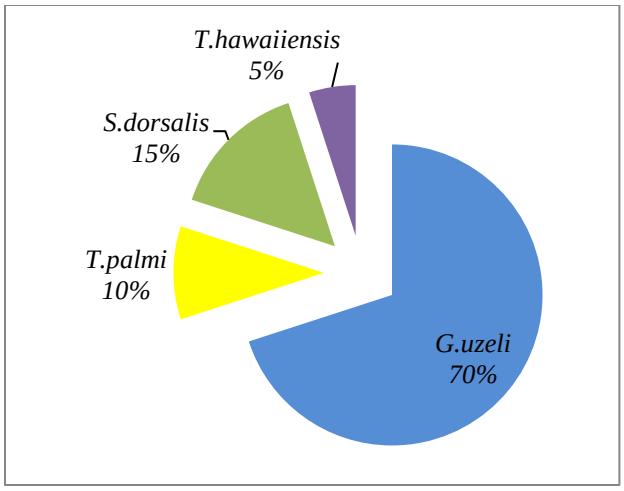
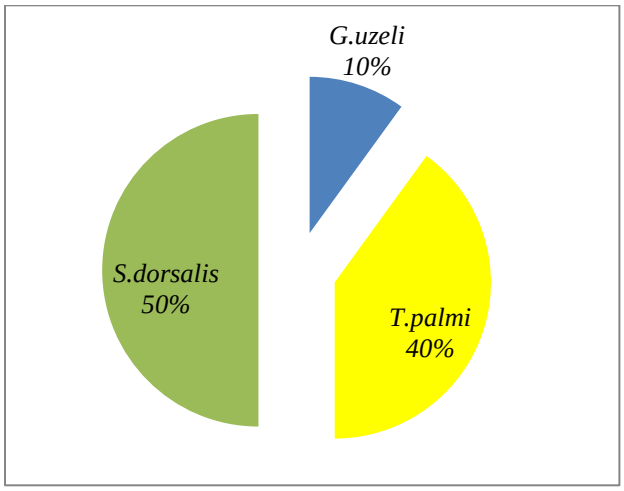


Plate 2: (A-D) Foliar and fruit damage caused by *Tuta absoluta*

(A) Larvae mining on leaves (B) Fully damaged seedling in laboratory screening (B) Pin size hole on fruit due to *T. absoluta* damage (D) Completely damaged fruit.



2017 *rabi* season trial



2018 summer season trial

Thrips palmi

Thrips hawaiiensis

Scirtothrips dorsalis

Plate 3: Species composition of thrips (%) from the samples collected during *rabi* 2017 and summer 2018

Also leaves of each accession/genotype were plugged with moist cotton and exposed to ten pairs of *T. absoluta* for choice bioassay. The experiment was replicated four times. Plants were arranged according to completely randomized design with three set of leaves per experimental unit. Square root transformation was used to normalize adult egg laying data of *T. absoluta* before analysis. Egg hatchability was recorded and converted into per cent egg hatching. The first evaluation of oviposition performed at 3 days after exposure to the moth, by counting the number of eggs present using a binocular stereoscopic microscope with 20 to 80X magnification. The evaluation was repeated once in two days, until the number of eggs counted on the susceptible control, reached a maximum. Numbers of eggs and larvae were counted and overall plant damage score was recorded.

The proportion of eggs laid was calculated by using the following formula as suggested by Rakha *et al*., (2017b).

$$\text{Proportion of egg laid} = \frac{(\text{Number of eggs laid per plant in a choice cage})}{(\text{sum of eggs laid in all the four plants within a choice cage})} \text{x}100$$

3.3.2 No-choice bioassay with *T. absoluta*

In no-choice bioassays, the suitability of various tomato accessions for oviposition by adult *T. absoluta* was studied. Colonies of *T. absoluta* reared for five generations with tomato seedlings (*S. lycopersicum*) or on leaves under laboratory conditions (25 ± 1ºC; 60 ± 5 % R.H.; photoperiod: 16 L: 8 D).

The effects of genotypes on *T. absoluta* larval density and growth (number of eggs, larvae, pupae and adults) as antibiosis assay were studied in the same condition.

Number of eggs and larvae were counted and overall plant damage score also recorded as above. Afterwards twenty early second instar larvae were released on each accession to assess the deleterious effect of different accessions on their biology. Diagramatic representation of the experiment is given in (Plate 4).

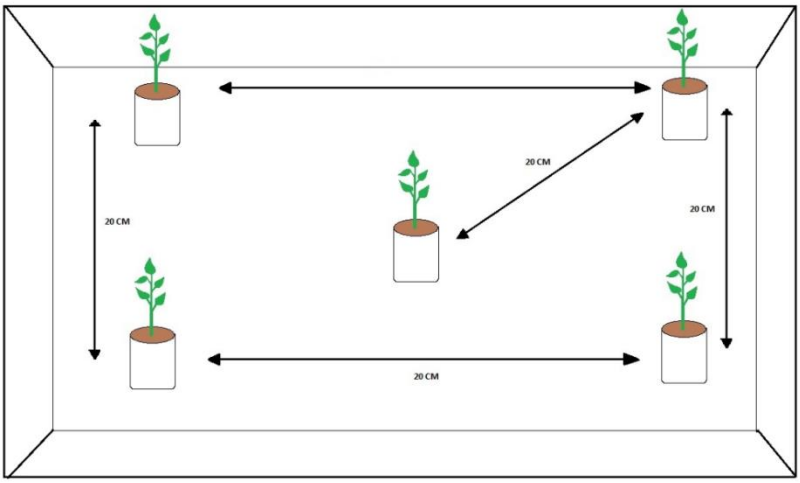
Per cent mortality, days taken for pupation, pupal weight and per cent adult emergence, were recorded in the no-choice test. After 20 days of exposure to the moth,

the damage to the plants caused by the pest, the type of injuries to the leaflets, and the percentage of the leaflets attacked were evaluated by using the scoring method proposed by Maluf *et al.* (1997). In this system, lower scores indicated less damage (higher levels of resistance) and damage scores varied from 0 to 5.

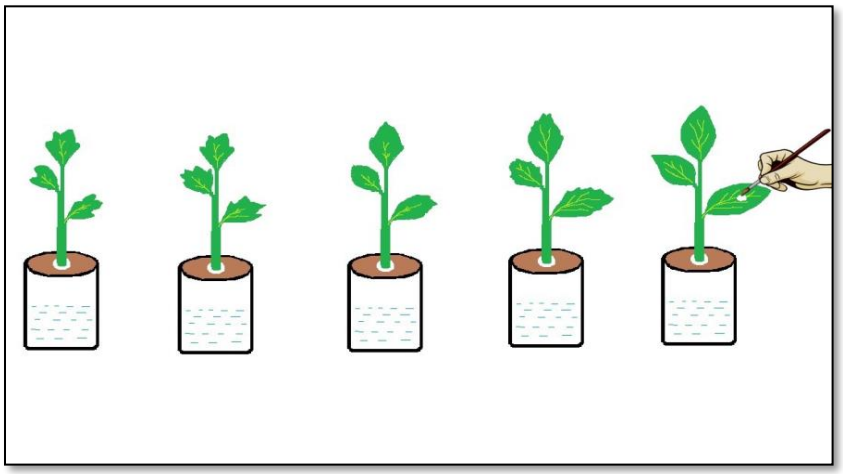
3.3.3 Thrips rearing and bioassays

Among our identified thrip species, two were reported as TOSPO vectors till now in India i.e *Thrips palmi* and *Scirtothrips dorsalis.* Only one vector species was further selected for screening the accessions under laboratory condition. *Scirtothrips dorsalis* was used for lab assay for screening those accessions. *S. dorsalis* culture was maintained on susceptible chilli cultivar planted in polybags without chemical sprays in polyhouses (M/S I&B Seeds) and on capsicum fruits under laboratory condition at 16 light and 8 dark hours (Plate 4).

Leaf Disc Tests: *Scirtothrips dorsalis* was collected from chilli plants and reared on susceptible Chilli (*Capsicum annum*) in an insect polyhouse at 25°C and 70% relative humidity (Koschier *et al*., 2000). Adult female thrips were starved for 24 hours in a cage with only water (Murai & Loomans, 2001). Leaf discs (4 cm in diameter) were taken from fully opened leaves using a leaf punch and placed in Petri dishes on water agar (15g/l agar) with the lower (abaxial) surface facing upward and placed in equidistant manner. Ten starved female adult thrips were released for oviposition and survival assay and ten second instar larvae were placed on each leaf disc by using a wet brush separately. Dishes were closed using plastic cups having mesh attached for aeration and to prevent thrips from escaping and placed in a climate room at 24°C, 16 h light, 70% RH. There were six replicates for each accession. The extent of damage based on feeding scars (by larvae) and destruction by thrips (adults) feeding, oviposition and secretion were rated together by using a relative scale from 0 (no damage) to 3 (severe damage) two days after inoculation. Per cent larval mortality was calculated by observing till 6 days regularly after release of second instar larvae onto the leaf disc.



C: Illustration of choice assay for *T.absoluta*



D: Illustration of no-choice bioassay for *T.absoluta*

Plate 4: (A) Rearing of *T. absoluta* on tomato plants (B) rearing of thrips on capsicum seedlings for laboratory assays and (C- D) illustration of laboratory bioassays

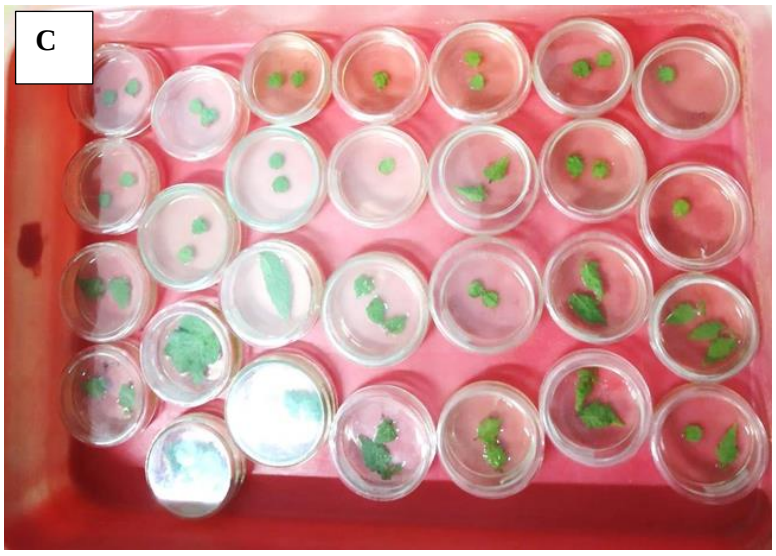


Plate 5: (A-C) Laboratory assays with *Thrips* spp.

(A) Thrips trapped in sticky exudates of glandular trichomes of tomato. (B) choice and (C) No-choice assay with *Scirtothrips dorsalis* on different genotypes

3.4 Morphological and biochemical basis of resistance

3.4.1 Morphological factors imparting resistance

3.4.1.1 Plant height: Plant height was recorded twice in a season. Once 45 DAT and another at 90 DAT. Ten plants were randomly selected in each row. Plant height from ground level to growing tip of the main stem was recorded and mean was worked out.

3.4.1.2 Number of branches: Ten plants per accession were selected randomly to count number of total branches. Branch angle and leaf angle were measured by randomly selecting three branches and three leaves per plant and expressed in degree with the help of a protractor.

3.4.1.3 Number of leaves per plant: Ten plants per accession were selected randomly and total numbers of fully opened leaves were recorded at vegetative stage (45 DAS) and reproductive stage (70 DAS).

3.4.1.4 Leaf thickness: Leaf thickness for three different canopy levels were recorded using a digital 36referr 36referre by randomly selecting 3 leaves per canopy level/plant/plot (Plate 6).

3.4.1.5 Leaf area: Total leaf area was calculated by using digital leaf area meter by collecting leaves from three different canopy levels.

3.4.1.6 Fruit size: Fruit size was recorded by splitting the fruits into two equal halves and diameter was taken with the help of a measuring scale**.** Means of all those parameters were computed and correlated with infestation.

3.4.1.7 Trichome type and density:

Trichome types were identified using scanning electron microscope at the Indian Institute of Horticultural Research (IIHR), Bangaluru, Karnataka. Density was counted per mm^2 at 2^{nd}, 5^{th}, 7^{th} leaves from the apex of a branch of three canopy levels were plucked with a forceps and used for observing the trichome types and density with four replications. Trichome type classification was carried out according to Luckwill (1943)

and determined by morphology and presence/absence of trichome glands on the entire abaxial leaf surface. Total number of trichomes present on abaxial and adaxial surface was recorded at different phenological stages of the crop. The mean trichome density was computed and correlated with infestation. Also trichome types and density was further correlated with quantity of acylsugar production of the genotypes. Regular observation for trichome count was taken under stereomicroscope. Densities were determined from the interior middle section of the abaxial surface of the second leaf from the apex of six randomly selected plants per accession by using a 0–3 visual scale, adapted from Simmons and Gurr (2005) where 3 = abundant (5 per mm^2); 2 = sparse (1–5 per mm^2); 1 = very sparse (1 per mm^2), and 0 = absent (Plate 7).

Statistical analysis:

The insect population data was subjected to square root transformation as $\sqrt{x} + 0.5$. The per cent data was transformed into angular transformation (Arcsin). The values so obtained were subjected to the analysis of variance at 5% level of significance.

Statistical analysis

Pearson's correlation coefficient was calculated to assess the relationship between moth population density, no. of larvae and leaf trichome density, by using SPSS software.

3.5 Biochemical basis of resistance

The estimation of biochemical constituents *viz.*, total sugars, reducing sugars, total phenols, crude protein and total free amino acids in leaves were collected from 45 days and 90 days old plants. Samples from both resistant and susceptible genotypes were done to establish the relationship between various biochemical contents and to compare it with resistance and susceptibility towards insect damage.

Extraction of plant tissues in alcohol

Sample extraction

The collected leaf samples were thoroughly washed with distilled water and dried under shade. One gram of plant sample pieces of all the genotypes were taken in separate

conical flask and 15 ml of 80 per cent ethanol was added. It was refluxed for 30 minutes on hot water bath. After boiling, the extract was cooled and the pieces of tissues were ground thoroughly in a mortar with pestle in slight ethanol. The supernatant was decanted into another flask and residue was again re-extracted with small quantity of hot ethanol and decanted. This extract was filtered through Whatman No. 1 filter paper and made upto a known volume with 80 per cent ethanol. The ethanol part of (alcoholic) extract was stored in refrigerator at 4°C, and was used for the estimation of total sugars, reducing sugars and phenols.

3.5.1 Total and reducing sugars

The method suggested by Somogyi (1952) was followed to estimate the total and reducing sugars.

Preparation of reagents

Alkaline copper reagent:

Solution A:

Twenty-five grams of anhydrous sodium carbonate, 25 gm of sodium potassium tartrate, 20 gm of sodium bicarbonate and 200 gm of anhydrous sodium sulphate were dissolved in 800 ml of distilled water and diluted to 1000ml. The reagent was stored in a place where the temperature did not fall below 20^0C.

Solution B:

Fifteen grams of copper sulphate was dissolved in a small volume of distilled water and one or two drops of concentrated sulphuric acid, and the volume was made up to 100 ml with distilled water. Twenty-four parts of solution A and one part of solution B were mixed to make the alkaline copper reagent solution just before use.

Arseno-molybdate reagent:

Twenty-five grams of ammonium molybdate was dissolved in 450 ml of distilled water and 25 ml of concentrated sulphuric acid was then added and mixed. Three grams

of sodium ortho-arsenate dissolved separately in 25 ml of distilled water was mixed with it and placed in an incubator at 30^0C for 24-28 hours. This reagent was stored in a glass stoppered brown bottle.

Reducing and total sugars in the extracts were estimated by following the procedure suggested by Somogyi (1952). For estimating the total sugars, hydrolysis of non-reducing sugars to reducing sugars was done by adding one ml of 1.0N hydrochloric acid to one ml of plant extract and was heated on a boiling water bath at 50^0C for 20 minutes. Later, it was cooled and a drop of phenolphthalein indicator solution was added. Then 1.0N sodium hydroxide was added drop wise till the solution turned pink due to excess alkali. The excess alkali was renutralised with 0.1N hydrochloric acid, which was added drop wise till the solution turned colorless and was made up to known volume.

One ml of hydrolysate for total sugars and one ml of plant extract for reducing sugars were taken separately in boiling tubes to which one ml of freshly prepared alkaline copper reagent was added and boiled in a water bath for exactly 20 minutes. After cooling under running tap water, one ml of arseno-molybdate reagent was added with immediate mixing. The volume was made upto 15 ml with distilled water and the blue color developed was read at 510 nm. Suitable blanks were prepared which were used to adjust the light transmission to 100 per cent. A standard curve was prepared with glucose, which was used to calculate the unknown. The quantities were expressed as milligrams per gram of the plant sample.

3.5.2 Total phenols

Estimation of total phenols in the leaf samples was done following Folin-Ciocalteau method as suggested by Bray and Thorpe (1954).

Preparation of reagents

Sodium carbonate solution:

Two gram of sodium carbonate was dissolved in 0.1N sodium hydroxide (NaoH) and then the volume was made up to 100 ml with 0.1N NaoH solution.

Folin-Ciocalteau reagent (FCR):

Hundred grams of sodium tungstate and 25 gms of sodium molybdate was dissolved in 700 ml of water. Later, 50 ml of 85 per cent orthophosphoric acid and 100 ml of concentrated Hydrochloric acid (HCl) was added to it and boiled under reflux gently for about 10 hours. It was then cooled and 150 gm of lithium sulfate dissolved in 50 ml of water was added to it. About 4-5 drops of liquid bromine was added to it. Then the mixture was boiled for about 15 minutes to remove excess bromine. Later the solution was cooled and diluted in one liter of water. This reagent was stored in brown bottle.

The normality of this reagent was determined by titrating against standard NaoH solution (0.1N). It was then diluted as per the need to make 2.0N. Just before use, one volume of this stock solution was diluted with one volume of water. The phenolic content was estimated as follows:

One ml of Folin-Ciocalteau reagent was added to 1.0 ml of the alcohol extract of the plant sample in a test tube, followed by 2.0 ml of 20 per cent sodium carbonate solution and the mixture was heated on a boiling water bath for exactly 1 minute. It was later cooled and made up to known volume (20 ml) with distilled water. The blue color developed was measured in a spectrophotometer at 650 nm. The standard curve was prepared by using catechol and concentration of phenols present in different samples of the genotypes was calculated using the standard curve and expressed as milligrams per gram of the plant sample.

3.5.3 Total soluble protein

Reagents used

Solution A: 20g of anhydrous sodium carbonate ($Na_2CO_3.2H_2O$) and 4g of sodium hydroxide were dissolved in 1000 ml of distilled water.

Solution B: 1 ml of 1.35% sodium potassium tartarate and 0.1 ml of 5.5% $CuSO_4.5H_2O$ were mixed together.

Solution C: 50 ml of solution A was mixed with 1 ml of solution B just before use.

Folin-Ciocalteu reagent (FCR): The commercial FCR was diluted 1:1 before use.

Standard bovine serum albumin (BSA) solution: A stock BSA solution was prepared containing 2 mg BSA /ml in water. This solution was diluted 1:10 to obtain 200 μg BSA/ml working standard solution.

Extraction of the sample

100 mg oven dried powdered sample was extracted in 10 ml of 0.1 M sodium phosphate buffer, pH 7.0, for one hour on a magnetic stirrer at room temperature. The extract was centrifuged at 10000 rpm for 20 minutes and the supernatant was used for the estimation of total soluble protein content. The protocol suggested by Lowry *et al.* (1951) was employed for this purpose.

Estimation of total soluble proteins

A known volume of aliquot sample was made upto 1 ml with distilled water. To this 5 ml of solution C was added and mixed well. After 10 minutes, 0.5 ml of FCR was added and mixed immediately. The blue color developed was read at 660 nm after 30 minutes against reagent blank in colorimeter. A standard graph was constructed by using BSA solution, as a standard, in the range of 20-120 μg. The total soluble protein content was expressed as mg per gram oven dried sample.

3.5.4 Total free amino acid

The amount of total free amino acid present in the plant samples were estimated following Ninhydrin method developed by Moore and Stein (1948).

Preparation of reagents

0.2 M Citrate buffer (pH 5.0): 20.5 ml of 0.1 m citric acid (21.01 g in 1000 ml) and 29.5 ml of 0.1m sodium citrate solution (29.41 g in 1000 ml) were diluted to 100 ml.

Ninhydrin reagent: 0.8 g of stannous chloride ($Sncl_2$. $2H_2O$) was dissolved in 500 ml of 0.2 m citrate buffer (pH 5.0). To this solution, 20 g ninhydrin in 500 ml, methyl cellulose (2-methyl ethanol) was added.

Diluent solvent: Equal volumes of water and n-propanol were mixed.

Stock standard leucine solution: 50 mg of leucine was added to 50 ml of water.

Working standard: 10 ml of stock leucine solution was diluted to 100 ml of water. 0.1ml of alcohol free extract of plant samples was pipetted out into separate test tubers and one milli litre of ninhydrin reagent was added and mixed well. Then the volume of each test tube was made up to 2 ml by using distilled water. All the test tubes were heated in a boiling water bath for 20 minutes. Then 5 ml of diluent solution was added while the test tubes were still on the water bath and mixed well. Meanwhile, a blank was prepared by taking 0.1 ml of 80 per cent ethanol and one milli litre of ninhydrin reagent was added, mixed and was make upto two ml. After 15 minutes of boiling, tubes were cooled under running tap water and absorbance of purple colour was measured against reagent blank at 570 nm by using spectrophotometer. The amount of total free amino acids present in the plant samples was calculated from the standard graph and expressed in mg/g.

3.5.5 Estimation of tannins by Folin-Denis method

Tannin like compound reduces phosphotungstomolybdic acid in alkaline solution to produce a highly coloured blue solution, the intensity of which is proportional to the amout of tannins. The intensity is measured in a spectrophotometer at 700nm.

Reagent:

Folin-Denis reagent

350g sodium carbonate was dissolved in one litre of water at 70-80ºC. It was filtered through glasswool after allowing to stand overnight.

Standard tannic acid solution

100mg tannic acid was dissolved in 100ml of distilled water.

Working standard solution

5ml of the stock solution was diluted to 100ml with distilled water. One ml contains 50µg tannic acid.

Procedure

Extraction of samples: 0.5 g powdered material was transferred in conical flask and added into 75ml of water. The flask was heated for 30 min. and centrifuged at 2000 rpm for 20 min. and supernatant was collected. From the supernatant 1 ml was transferred and added to 100ml volumetric flask containing 75 ml of water.

After that 5 ml Folin-Denis reagent and 10 ml of sodium carbonate solution was added with 100ml of water. Absorbance was recorded at 700 nm after 30 min. Standard graph was prepared by using 0-100 µg tannic acid.

Calculation: Tannin content of samples was estimated as tannic acid equivalents from the standard graph.

3.5.6 Acyl sugar

Trichome derived acyl sugar which has a great role in insect resistance was assayed by using the modified protocol given by Setter *et al.,* (2001).

Sampling

Leaf samples from three different canopy levels were collected once after two weeks with the help of forceps and dried in BOD chamber at 27 ˚C. After drying them for 4-5 days, the leaf extraction was carried out by using methanol. Acyl sugar level was quantified by using the standard protocol given by Setter *et al.*, (2001). Every season acyl sugar was assessed to evaluate the variation in acylsugar level at different phenological stage of the crop and further correlated with weather parameters, trichome type and density and also with insect damage.

Reagents:

1. 6 M ammonium hydroxide

362.62 ml of 29% NH_4OH was added into 137.3 ml of ddH_2O to prepare 500ml 6M ammonium hydroxide.

2. PGO reagent (Peroxidase/Glucose Oxidase)

A) PGO stock without enzymes

To 200 ml H_2O was added 3.4 g KH_2PO_4, 0.75 g para-hydroxybenzoic acid, 0.025 g 4-aminoantipyrene, 0.25 g Bovine serum albumin (BSA), 1.25 ml of 2% Sodium azide stock, PH was adjusted to 7.0 with 2N NaOH. The volume was brought upto 250ml and stored at 4ºC.

B) PGO with enzymes

- After stock preparation enzymes were added before transfering the44referred4444g ELISA plate.
- The following enzymes were added in 250 ml PGO Stock for total acyl sugar analysis assay.

- 250 units (2.21 mg) peroxidase, 500 units (86.2µl) glucose oxidase, 4mg invertase.

Enzyme assay for induced resistance

Insect feeding can lead to induced resistance in plants by producing defense related enzymes and to test that, two sets of 6 week old seedlings of each genotypes/accessions were kept inside a cage. One set was exposed to ten *T. absoluta* larvae. They were allowed to feed on the seedlings and kept for 3 days and another set was kept as control which was free of any damage. Leaves were collected from these two sets and used for PPO and peroxidase assay. Samples were drawn from healthy and infested plants of each tomato accession.

3.5.7 Polyphenol oxidases and peroxidases

3.5.7.1 Peroxidase assay (PO)

The peroxidase activity was assayed spectrophotometerically as described by Hartee, (1955).

Reagents:

Hydrogen peroxide solution: 3.3 ml of H_2O_2 was mixed with 97.70 ml of distilled water to get 100 ml of 1 per cent H_2O_2 solution. The solution was freshly prepared each time.

Pyrogallol, 0.05 M: 6.3005 g of pyrogallol was dissolved in 100 ml of distilled water. The solution was prepared every time freshly.

Phosphate buffer, 01 M, 6.5 pH:

Solution A: 27.6 g of sodium phosphate monobasic ($NaH_2PO_4.2H_2O$ Mol. wt. -156.01) was dissolved in small quantity of water and the volume was made upto 1000 ml with distilled water.

Solution B: 28.4 g of sodium phosphate dibasic (Na_2HPO_4 Mol. Wt. 142g) was dissolved in small quantity of water and made up the volume to 1000 ml with distilled water.

265 ml of solution A was mixed with 735 ml of solution B. Finally the pH was adjusted with NaOH.

Preparation of enzyme extract: One gram of leaf sample was homogenized in 3 ml of 0.1 M phosphate buffer, pH 6.5 at 4 °C. This mixture was filtered through four layer muslin cloth. The filtrate was centrifuged at 12000 rpm at 4 °C for 20 minutes. The supernatant was collected and used for estimation of peroxidase activity (Plate 8).

Assay: The reaction mixture consisted of 1.5 ml of 0.05 M pyrogallol, 0.5 ml of the enzyme extract and 0.5 ml of one per cent H_2O_2. The reaction mixture was incubated at room temperature (28±10 °C). The change in absorbance was recorded at 470 nm at a time interval of 30 sec. upto 3 min in Hitachi U-2900 spectrophotometer. The boiled enzyme preparation served as blank. The enzyme activity was expressed as change in the absorbance at 420 nm $min^{-1}g^{-1}$ on fresh weight basis.

3.5.8 Assay of polyphenol oxidase (PPO)

The polyphenol oxidase activity was determined as per the procedure suggested by Mayer *et al*. (1966).

Reagents:

Phosphate buffer, 0.1 M, 7.0pH: Solution A: 27.6 g of sodium phosphate monobasic (NaH_2PO_4. $2H_2O$ Mol.Wt.-156.01) was dissolved in small quantity of water and made up the volume to 1000 ml with distilled water.

Solution B: 28.4 g of sodium phosphate dibasic (Na_2HPO_4 Mol. Wt. 142g) was dissolved in small quantity of water and made up the volume to 1000 ml with distilled water.

610 ml of solution A was mixed with 390 ml of solution B. Finally pH was adjusted with NaOH. The buffer was stored under refrigerated condition.

Catechol, 0.1M (Mol. Wt. 111.011g): 11.011 g of catechol was dissolved in a small quantity of water and volume was made to 1000 ml with distilled water.

Preparation of enzyme extract: One gram of leaf sample was homogenized in 5 ml of 0.1M phosphate buffer, pH 7.0 at 4 °C. This mixture was filtered through a four layer muslin cloth. The filtrate was centrifuged at 10000 rpm at 4 °C for 20 minutes. The supernatant was collected and used for estimation of polyphenol oxidase activity.

Assay: One gram of leaf sample was used for phenol oxidase estimation. The reaction mixture consisted of 1.5 ml of 0.1M sodium phosphate buffer (pH 7.0) and 500µl of the enzyme extracts. To start the reaction, 500µl of 0.1 M catechol was added. The change in absorbance was recorded at 495 nm spectrophotometer. The polyphenol oxidase activity was expressed as changes in absorbance at 495 nm $min^{-1}g^{-1}$ fresh weight of leaf sample.

3.5.9 Green leaf volatile

Plant volatile profiles may play an important role in insect preferences for selection or rejection. To assess the volatile profile, branches of nine week old tomato plants of five different accessions *viz., S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var. glabratum* (VI030462) and *S. lycopersicum* (CL 5915/CH45) were brought to the laboratory for volatile collection. Before volatile collection, all the necessary glasswares and aluminium plates were washed with aqueous teepol detergent, rinsed with distilled water followed by acetone and then dried in a hot air oven at 120°C for 2 h. Porapak Q tubes (50 mg, 60/80 mesh; Supelco, Sigma Aldrich, India) of 5 mm diameter and 5 cm length were used for collection of volatiles. These tubes were washed with redistilled diethyl ether and heated at 120°C for 2 h in a hot air oven to remove contaminants. Autoclaved polythene bags were used to cover the plants. The poly bag was inserted upside down to enclose the whole plant and made completely air proof by tying at the base of the plant with rubber band and the gaps were sealed by using glass wool. Both inlet and outlet of the volatile collecting tubes were inserted into the bag. Air purified by passage through an activated charcoal filter, was pumped into the bag at 600 ml/min through the inlet port and the air was drawn out at 800 mL/min through porapak Q glass tube. All connections were made with polytetrafluoroethylene (PTFE) tubing with brass ferrules and fittings. The volatiles from different wild accessions/genotypes were entrained for 48 hours and the porapak Q

tubes containing the volatile compound were eluted with 750 µl of redistilled diethyl ether, providing a solution that contained the isolated volatile compounds that served as test sample. The sample was stored in glass vial in a freezer (-20°C) until further use.

3.5.9.1 Olfactometer bioassays

Four-arm olfactometer bioassays

A Perspex four-arm olfactometer (Pettersson, 1970) was used to determine the behavioural responses of adult *T. absoluta* to head space samples of volatiles. Prior to each experiment, all glasswares were washed with teepol, rinsed with acetone and distilled water and baked in an oven overnight at 160^{o}C. Perspex components were washed with teepol solution, rinsed with 80 per cent ethanol solution and distilled water and left to air dry. Experiments were conducted in an isolated room (25 ± 2°C, 60 % RH) to avoid contaminant odours. The olfactometer had four glass side arms leading into a central area which was divided into four odour fields (Plate 9). The central area was fitted with a filter-paper base (Whatman No.1, 12 cm diameter) to provide traction for the walking insect. The olfactometer was illuminated from above by uniform lighting from white fluorescent bulb (10 watts) covered with opaque dome to make it diffuse and was surrounded by a black wall cage (0.62 m length × 0.62 m wide × 0.62 m height) to remove any extra visual stimuli. Olfactometer bioassay was conducted as described by Jayanthi *et al*. (2012).

3.5.9.2 Identification of compounds present in different wild accessions of tomato leaf headspace volatiles through GC-MS

The compounds that are present in the plant headspace of different wild accession volatiles were identified by using Gas Chromatography, coupled with Mass Spectrometry (GC-MS). The quantities of the compounds present in the headspace samples were classified into their different chemical groups.

EAG response of *T. absoluta* was also assessed for the blend of volatiles of four wild accessions and for the susceptible check and compared with air and honey puff and the peak response was compared with bonferroni mult48referred48rison test. Preference

index was measured from single choice olfactometer bioassay by using the following formula.

$$PI = \{(SS - NSS) / (SS + NSS)\} \times 100$$

Where, SS is the number of *T. absoluta* females that responded to the blend and NSS is the number of *T. absoluta* females that responded to control.

3.5.10 Screening of *S. galapagense, S. lycopersicum* along with their F1 and F2 under field condition

Interspecific cross was made by using *S. lycopersicum* (CL5915) and *S. galapagense* (VI037241**).** Field trial was carried out to screen susceptible parent (*S. lycopersicum* CL5915), resistant parent (*S. galapagense* VI037241) and their F1 and F2. The variation in acylsugar level in each individual F2 plants, mean acylsugar level in F1 plants and both the parents were analysed and their field level resistance was observed. Based on the damage and acylsugar level the plants were grouped into 4 groups *i.e* resistant, moderately resistant, moderately susceptible and susceptible. Genotyping was done by using 25 polymorphic SNP markers. Phenotypic and genotypic data was further compared to check the difference between resistant and susceptible plants from F2 generation.

Correlation analysis

Correlation analysis was done in excel by using the WASP software. The test of significance for association between characters was done by comparing calculated ‘r’ values with table ‘r’ values at (n-2) error degrees of freedom, where “n” is the number of pairs of observations.

IV RESULTS AND DISCUSSION

Investigations pertaining to the screening of tomato genotypes against *Tuta absoluta* and major TOSPO virus vector *Thrips* spp. to evaluate the basis of resistance to these pests were conducted during 2017-18 and 2018-19. Field experiments were carried out at M/s I&B Seeds, Pvt. Ltd. Kengeri, Uttarahalli, Bengaluru and laboratory experiments were conducted at the Department of Agricultural Entomology, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru. The findings of these studies are furnished in this chapter and discussed in the light of earlier reports on similar lines.

4.1 Evaluation of tomato entries for their reaction to *T. absoluta* and Thrips.

Five wild accessions which showed resistance against multiple insect pests in earlier studies conducted at World Vegetable Centre (formerly AVRDC), Taiwan was procured through M/s I&B Seeds Pvt. Ltd. in India to reconfirm their promising performance in Indian conditions in different seasons. Those five wild accessions (Table 2) were screened in different seasons under field condition at I & B Seeds, Pvt, Ltd. Uttarahalli from *rabi* season of 2017 to *kharif* season of 2019.

Totally five wild accessions were screened during *rabi* 2017 (August to November 2017). The same five wild accessions along with two commercial tomato hybrids were screened during *summer* 2018 (March to June 2018), 5 wild accessions were screened during *rainy season* 2018 (June to September 2018). The same accessions (5 nos.) were screened again during *summer* season of 2019 (March to June 2019) and *kharif* season of 2019 (June to September 2019). Another trial was conducted with interspecific cross of the most resistant and most susceptible genotype to check the variability of resistance trait and also resistance levels in F_2, F_1, and parental lines during 2018. The observations were recorded on *T. absoluta* population, egg and larval population, foliar and fruit damage. Thrips populations in each of the field trials during different seasons were recorded and the findings are discussed in the following pages.

4.1.1 Field screening of tomato genotypes during *rabi* 2017, August–November)

The field trial was carried out at a research plot in M/s I & B Seeds, Kengeri, Uttarahalli. Field observations were recorded on total egg (Table 6) and larval load per 20 leaves at different canopy levels (Table 7), foliar and fruit damage (Table 8, 9) and thrips countper tap was recorded at 3rd, 6th, 9th, 12th and 15th week after transplanting (WAT) (Table 10). Five plants per plots in each of the four replications *i.e* totally 20 plants were laballed observed for recording observations.

4.1.1.1 Egg load of *T. absoluta* per 20 leaves

Egg load on *S. lycopersicum* (CL5915) was observed starting from 3rd week after transplanting (WAT) upto 15th WAT. The mean number of eggsper 20 leaves varied from 0.00 to 3.75 eggsper 20 leaves. Highest egg load was observed in middle canopy leaves of *S. lycopersicum* (CL5915) i.e 3.75 eggs per 20 leaves, followed by 3.25 eggs in upper canopy during 6th and 9th WAT, respectively. The egg load was significantly less in the other four wild accessions. The egg load ranged from 0-0.75 in the four wild accessions. Relatively higher egg load was observed during 3rd and 6th WAT.

It has been observed that between the different entries there was significant difference *w. r. t.* mean number of eggs per 20 leaves at different canopy levels. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) received significantly lesser egg load *i.e.* mean of 0.00-0.42 eggs per 20 leaves and 0-0.17 eggs per 20 leaves respectively. Egg load was observed only in upper and middle canopy leaves, whereas no egg load was observed in lower canopy leaves in these two wild accessions. There were significant differences w.r.t egg load, between different canopy levels (CD=0.16) and different genotypes (CD=0.21) (Table 6).Although it did not differ significantly at different weeks after transplanting.

4.1.1.2 Larval no. of *T. absoluta* per 20 leaves

Larval countper 20 leaves from different canopy levels also showed significant differences between the genotypes (CD=0.21). Highest mean number of larvae was recorded during 3WAT, followed by 9th WAT on middle canopy leaves of *S.*

lycopersicum (CL5915) *i.e*. 3.50 and 2.25 larvae per 20 leaves, respectively (Table 7). *S. lycopersicum* (CL5915) received significantly higher larval load in middle canopy, followed by upper canopy leaves (Table 6). In *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) significantly lower no. of larvae were observed across different WAT.

4.1.1.3 Leaf damage (%) due to *T. absoluta*

Foliar damage recorded was significantly highest in *S. lycopersicum* (CL5915). It ranged between 0-42.50 per cent in middle canopy of *S. lycopersicum* (CL5915) during 15th WAT, whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) significantly lower foliar damage (*i.e*. 0-3.75% and 0-1.25%) was observed (Table 8). In *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) foliar damage ranged between 0.00-3.75 per cent (Table 7). There was no significant difference between different week intervals but significant difference between genotypes *w.r.t*. per cent foliar damage (CD=1.99).

4.1.1.4 Fruit damage (%) due to *T. absoluta*

There were significant differences in per cent fruit damage among different genotypes (CD=4.21) (Table 8). Fruit initiation started from 6th WAT in case of *S. lycopersicum* (CL5915) whereas it started after 9th week after transplanting for other genotypes. Mean per cent fruit damage starting from 10th to 15th WAT was considered for comparing between genotypes. Fruit damage due to pin size holes was significantly higher and ranged from 20.00-36.22 per cent in *S. lycopersicum* (CL5915). However it was 0.00-5.00 and 0.00-6.50 per cent in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) respectively. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) were outstanding with no fruit damage even during initial fruit development upto full maturity stage (Table 9).

4.1.1.5 No. of thrips per tap

There was a distinct seasonal effect on thrips occurrence and the majority of the thrips were recorded in the flowering stage of crop development. Thrips were counted

based on the number of thripsper tap from different genotypes at different WAT. In general the thrips population was very low and no TOSPO disease symptoms were recorded throughout the growing season. Thrips number per tap ranges from 0-4.50, 0-5.50 and 0-3.50 per tap in *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL5915) respectively. Thrips population was observed from 9th to 15th WAT. It varied significantly among different genotypes (CD=0.150) at different WAT (CD=0.152). The thrips countper tap was more during flowering stage in case of *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) *i.e* 9th to 15th WAT (Table 10). Among identified thrip species, two were reported as TOSPO vector till now in India i.e *Thrips palmi* karny and *Scirtothrips dorsalis* Hood. Only one vector species *i.e., Scirtothrips dorsalis* Hood was used for laboratory assay for artificial screening of the tomato accessions. Symptoms due to thrips attack were minimal and damage scars were only seen on leaves of *S. lycopersicum* (CL5915). No symptom was observed on the fruits due to thrips attack. The same wild accessions were re-evaluated in next season along with two commercial hybrids of M/s I & B Seeds Pvt. Ltd.

4.1.2 Field screening of tomato genotypes during summer, 2018 (March to June)

Field trial was carried out at research plots of M/s I & B Seeds, Kengeri, Uttarahalli, Bengaluru. Field observations on total egg (Table 11) and larval load per 20 leaves at different canopy levels (Table 13, 14) and thrips count per tap was recorded at 3rd, 6th, 9th, 12th and 15th WAT (Table 15).

4.1.2.1 Egg load of *Tuta absoluta* per 20 leaves

Egg load on *S. lycopersicum* (CL5915) were observed from 3nd week to 15th week after transplanting. Egg loadper 20 leaves was significantly highest in *S. lycopersicum* (CL5915) during 6th WAT *i.e* 7.25 and 7.25 eggsper 20 leaves at upper and middle canopy, respectively.

Commercial varieties also received relatively higher egg load during 9th and 3rd WAT in case of TM 308 and PT 4208, respectively whereas it was significantly less in other wild accessions. The number of eggs per 20 leaves varied from 0.00-7.25, 0.00-

1.50, 0.00-1.00, 0-4.00, 0.00-2.25, 0.00-5.00, 0.00-4.75 in *S. lycopersicum* (CL5915), *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) , hybrid TM 308 and PT 4208 respectively (Table 11).

Egg load was observed to be greater in upper and middle canopy leaves as compared to lower canopy leaves in all the genotypes. There were a significant differences between egg load observed at different canopy levels (CD=0.22) and different genotypes (CD=0.33) (Table 11).

4.1.2.2 Larval no. of *T. absoluta* per 20 leaves

Mean no. of larvaeper 20 leaves at different canopy levels also showed significant differences between the genotypes. Highest larval count was recorded on upper canopy leaves of TM 308 during 9th WAT. Mean la^{rv}al load in upper, middle and lower canopy was 3.65, 2.50 and 0.00 per 20 leaves in *S. lycopersicum* (CL5915), 1.00, 0.40 and 0.15 per 20 leaves in *S. galapagense* (VI037241), 0.85, 0.40 and 0.60 per 20leaves in *S. cheesmaniae* (VI037240), 0.60, 0.40 and 0.00per 20 leaves in *S. habrochaites* (LA1777), 0.50, 0.85, 0.00 per 20 leaves in *S. habrochaites var glabratum* (VI030462), 3.65, 2.50 and 0.00 per 20leaves in TM 308 and 3.55, 0.40 and 0.00per 20 leaves in PT4208, respectively. Larval load was more in middle canopy as compared to other canopy levels in *S. lycopersicum* (CL5915) although higher larval egg load was observed in upper canopies of commercial hybrids i.e., TM 308 and PT4208 (Table 12).

4.1.2.3 Leaf damage (%) due to *Tuta absoluta*

Foliar damage recorded was highest in *S. lycopersicum* (CL5915) and ranged between 0.00-57.00 per cent whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) significantly lower leaf damage *i.e.* 0.00-2.50 and 0.00-1.25 per cent was observed. In *S. habrochaites* (LA1777) and *S. habrochaites var. glabratum* (VI030462) 0.00-6.25 and 0.00-10.00 per cent foliar damage was recorded, respectively. Again in TM 308 and PT 4208 foliar damage ranged between 8.75-43.75 and 12.50-46.25 per cent.

Significant differences were observed in the per cent foliar damage between wild genotypes and commercial hybrids (CD=3.43) (Table 13).

4.1.2.4 Fruit damage (%) due to *T. absoluta*

Fruit development started from 6th WAT in case of *S. lycopersicum* (CL5915). Per cent fruit damage ranged between 25.00-40.00 in *S. lycopersicum.* However, 0.00-5.00 per cent fruit damage was observed in *S. habrochaites* (LA1777) and 0.00-10.00 per cent in *S. habrochaites var glabratum* (VI030462). *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) recorded 0.00 per cent fruit damage starting from fruit development even upto fully maturing stage (Table 14). In commercial hybrids *i.e.* TM 308 and PT4208 fruit damage ranged between 20-50 and 25.25-40 per cent, respectively. Fruit damage differed significantly among the different genotypes (CD=4.18) at different WAT (Table 14).

4.1.2.5 No. of thrips per tap

There was a distinct seasonal effect on thrips occurrence and the majority of the thrips were recorded in the flowering stage of the crop. Mean no. of thrips were recorded based on the number of thrips per tap from different genotypes at different week intervals. Thrips population was very low and no TOSPO disease symptom was recorded throughout the season. Thrips number per tap ranged from 0.00-3.50 per tap in both *i.e. S. habrochaites* (LA1777) and *S. habrochaites var. glabratum* (VI030462) and 0.00-6.50 per tap in *S. lycopersicum* (CL5915). Thrips population was observed from 9th week to 15th WAT. It varied significantly among the different genotypes (CD=0.27) at different week intervals (CD=0.23). Symptoms due to thrips attack were minimal and damage scars were only seen on leaves of *S. lycopersicum* (CL5915). No symptom was observed on the fruits due to thrips attack (Table 15.)

Table 6: Mean no. of eggs laid per 20 leaves by *T. absoluta* at different canopy levels of different genotypes during *rabi* 2017, (August –November)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	3.00	2.50	0.50	**2.00**	0.00	0.00	0.00	**0.00**	0.00	0.25	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.50	0.75	0.00	**0.42**
6WAT	3.25	3.75	2.50	**3.17**	0.25	1.00	0.00	**0.42**	0.00	0.00	0.00	**0.00**	0.00	0.50	0.00	**0.17**	0.75	0.00	0.00	**0.25**
9WAT	3.25	2.00	0.00	**1.75**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.50	**0.17**	0.00	0.00	0.00	**0.00**
12WAT	1.00	3.25	0.00	**1.42**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.25	0.00	**0.08**	0.00	0.00	0.00	**0.00**
15WAT	1.00	3.00	0.00	**1.33**	0.00	0.00	0.00	**0.00**	0.00	0.50	0.00	**0.17**	0.00	0.00	0.00	**0.00**	0.25	0.00	0.00	**0.08**
Mean	**2.30**	**2.90**	**0.60**		**0.10**	**0.20**	**0.00**		**0.00**	**0.15**	**0.00**		**0.00**	**0.15**	**0.10**		**0.30**	**0.15**	**0.00**	
Pooled mean	**1.93[a]**				**0.10[b]**				**0.05[b]**				**0.08[b]**				**0.15[b]**			

Factors	F test	SE(m)	SE(d)	C.D.
Genotypes	**	0.07	0.11	0.21
Canopy level	**	0.06	0.08	0.16
Genotype x Canopy level	**	0.13	0.18	0.36
WAT	NS	-	-	-
Genotype x WAT	**	0.17	0.23	0.46
Canopy level x WAT	NS	-	-	-
Genotype x Canopy level X WAT	**	0.29	0.41	0.80

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. N=20Plants

Mean value of 5 plants with 4 replications.

** indicates significant at p<0.01. NS indicates non-significant

Table 7: Mean no. of larvae of *T. absoluta* per 20 leaves of different canopy levels of different genotypes during *Rabi* 2017, (August –November)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	2.00	3.50	1.00	**2.10**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	1.20	0.00	**0.40**	0.00	0.00	0.00	**0.00**
6WAT	1.50	1.00	1.75	**1.42**	0.90	1.00	0.00	**0.63**	0.00	1.25	0.00	**0.42**	0.00	1.00	0.00	**0.33**	0.00	1.00	0.00	**0.33**
9WAT	1.00	2.25	0.00	**1.08**	0.75	0.55	0.00	**0.43**	0.25	0.75	0.00	**0.33**	0.00	0.00	0.75	**0.25**	0.00	2.00	0.00	**0.67**
12WAT	0.75	2.00	0.00	**0.92**	0.00	0.00	0.00	**0.00**	0.00	0.05	0.00	**0.02**	0.00	0.00	1.75	**0.58**	0.00	0.00	0.00	**0.00**
15WAT	1.00	1.00	0.00	**0.66**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.75	0.00	0.00	**0.58**	0.00	0.00	0.00	**0.00**
Mean	**1.25**	**1.95**	**0.55**		**0.33**	**0.31**	**0.00**		**0.05**	**0.41**	**0.00**		**0.35**	**0.44**	**0.50**		**0.00**	**0.60**	**0.00**	
Pooled mean	**1.24[a]**				**0.21[c]**				**0.15[c]**				**0.43[b]**				**0.20[c]**			

Factors	F test	SE(m)	SE(d)	C.D.
Genotypes	**	0.076	0.108	0.213
Canopy level	**	0.059	0.084	0.165
Genotype x Canopy level	**	0.132	0.187	0.369
WAT	**	0.076	0.108	0.213
Genotype x WAT	**	0.171	0.241	0.476
Canopy level x WAT	**	0.132	0.187	0.369
Genotype x Canopy level X WAT	**	0.296	0.418	0.824

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. N=20Plants

Mean value of 5 plants with 4 replications. ** indicates significant at p<0.01.NS indicates non-significant

Table 8: Effect of genotypes, canopy level and weeks after transplanting on *T. absoluta* damage during *Rabi* 2017, (August – November)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	27.50	32.50	30.00	**30.00**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**	0.00	2.50	0.00	**0.83**	0.00	0.00	0.00	**0.00**
6WAT	30.00	22.50	31.25	**27.92**	3.75	1.25	0.00	**1.67**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**	0.00	1.25	0.00	**0.42**
9WAT	32.50	22.50	22.50	**25.83**	1.25	0.00	0.00	**0.42**	0.00	1.25	0.00	**0.42**	0.00	0.00	3.75	**1.25**	0.00	3.75	0.00	**1.25**
12WAT	25.00	37.50	3.75	**22.08**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**	0.00	0.00	2.50	**0.83**	0.00	0.00	0.00	**0.00**
15WAT	25.00	42.50	0.00	**22.50**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.25	0.00	0.00	**0.42**	0.00	0.00	0.00	**0.00**
Mean	**28.00**	**31.50**	**17.50**		**1.00**	**0.25**	**0.00**		**0.00**	**0.75**	**0.00**		**0.25**	**0.75**	**1.25**		**0.00**	**1.00**	**0.00**	
Pooled mean	**25.67[a]**				**0.42[c]**				**0.25[c]**				**0.75[b]**				**0.33[c]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.71	1.01	1.99
Canopy level	**	0.55	0.78	1.54
Genotype x Canopy level	**	1.23	1.75	3.44
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	1.23	1.75	3.44
Genotype x Canopy level X WAT	**	2.76	3.90	7.69

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. N=20Plants

Mean value of 5 plants with 4 replications.

** indicates significant at p<0.01. NS indicates non-significant

Table 9: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) during *Rabi* 2017, (August–November)

Fruit damage (%) at different WAT												
Genotypes	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Scale**
***S. lycopersicum* CL5915/CH45**	20.00	25.00	25.00	27.00	30.00	32.00	35.25	32.95	36.22	34.00	33.40[a]	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00[c]	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00[c]	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	4.00	5.00	4.25	4.50	2.96[b]	1
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	2.20	5.75	6.50	5.00	3.24[b]	1
F Test	**											
SEm±	1.42											
CD @ 5%	4.21											
C.V	33.55											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Values are mean of four replications, ** indicates significant at p<0.01.NS indicates non-significant

Means followed different alphabets differ significantly

Table 10: Reaction of the five different genotypes to thrips incidence at different weeks after transplanting (WAT) during *rabi* 2017, (August –November)

Genotypes	No of thrips per tap					Mean
	3WAT	6WAT	9WAT	12WAT	15WAT	
***S. galapagense* VI037241**	0.00	0.00	0.00	0.25	0.00	0.05[d]
***S. cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	0.00[d]
***S. habrochaites* LA1777**	0.00	0.00	2.00	4.50	4.25	2.15[a]
S. h. var. glabratum VI030362	0.00	0.00	0.50	5.50	3.00	1.80[c]
***S. lycopersicum* CL5915**	0.00	0.00	3.50	3.00	3.50	2.00[b]

Factors	F Test	SE(m)	SE(d)	C.D.
Genotype	**	0.05	0.07	0.15
WAT	**	0.05	0.07	0.15
Genotype x WAT	**	0.11	0.16	0.33

U= Upper, M=Middle, L=Lower, WAT=Weeks after transplanting

** indicates significant at p<0.01.NS indicates non-significant

Table 11: Mean no. of eggs laid per 20 leaves by *T. absoluta* at different canopy levels of different genotypes during summer 2018, (March-June)

	***S. lycopersicum* CL5915**				***S. galapagense* VI037241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VI030462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	5.75	5.75	0.00	**3.83**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	7.25	7.25	0.00	**4.83**	0.75	1.00	0.00	**0.58**	0.75	1.00	0.75	**0.83**	0.25	0.00	0.25	**0.17**	0.25	0.75	0.00	**0.33**
9WAT	3.25	1.75	0.00	**1.67**	1.50	2.00	0.00	**1.17**	1.00	1.00	0.25	**0.75**	1.00	1.00	0.50	**0.83**	1.75	1.00	0.00	**0.92**
12WAT	2.00	1.25	0.00	**1.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	4.00	2.00	2.00	**2.67**	2.25	1.00	0.00	**1.08**
15WAT	1.00	0.00	0.00	**0.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**3.85**	**3.20**	**0.00**		**0.45**	**0.60**	**0.00**		**0.35**	**0.40**	**0.20**		**1.05**	**0.60**	**0.55**		**0.85**	**0.55**	**0.00**	
Pooled mean	**2.35[a]**				**0.35[c]**				**0.32[c]**				**0.73[c]**				**0.47[c]**			

Commercial hybrids**								
	TM 308				**PT4208**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	2.75	2.75	0.00	**1.83**	4.75	2.25	0.75	**2.58**
6WAT	3.25	0.75	0.00	**1.33**	3.50	3.25	1.50	**2.75**
9WAT	5.00	2.50	0.00	**2.50**	2.25	1.00	0.00	**1.08**
12WAT	1.50	2.00	0.00	**1.17**	1.50	1.50	0.00	**1.00**
15WAT	2.50	1.50	0.00	**1.33**	2.25	0.75	0.00	**1.00**
Mean	**3.00**	**1.90**	**0.00**		**2.85**	**1.75**	**0.45**	
Pooled mean	**1.63[b]**				**1.68[b]**			

Factors	**F test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	0.12	0.17	0.33
Canopy level	**	0.08	0.11	0.22
Genotype x Canopy level	**	0.21	0.29	0.57
WAT	**	0.10	0.14	0.28
Genotype x WAT	**	0.27	0.38	0.74
Canopy level x WAT	**	0.17	0.25	0.48
Genotype x Canopy level X WAT	**	0.46	0.65	1.28

U= Upper, M=Middle, L=Lower, WAT=Weeks after transplanting .** indicates significant at p<0.01.NS indicates non-significant

Table 12: Mean no. of larvae of *T. absoluta* per 20 leaves of different canopy levels of different genotypes during summer 2018, (March –June)

	***S. lycopersicum* CL5915**				***S. galapagense* VI037241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	4.00	5.75	1.75	**3.83**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	2.50	3.00	2.50	**2.67**	1.25	1.00	0.00	**0.75**	2.50	1.00	2.50	**2.00**	0.00	0.00	0.00	**0.00**
9WAT	4.50	2.50	0.75	**2.58**	3.75	0.00	0.75	**1.50**	1.75	1.00	0.50	**1.08**	1.00	1.00	0.00	**0.67**
12WAT	3.25	5.75	0.50	**3.17**	0.00	1.00	0.00	**0.33**	0.00	0.00	0.00	**0.00**	2.00	1.00	0.00	**1.00**
15WAT	1.75	1.50	0.25	**1.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**3.20**	**3.70**	**1.15**		**1.00**	**0.40**	**0.15**		**0.85**	**0.40**	**0.60**		**0.60**	**0.40**	**0.00**	
Pooled mean	**2.68[a]**				**0.52[d]**				**0.62[d]**				**0.33[d]**			

	***S. habrochaites var glabratum* VI030462**				***TM 308***				***PT4208***			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	0.00	0.00	0.00	**0.00**	2.50	1.00	0.00	**1.33**	9.00	2.00	0.00	**3.67**
6WAT	0.00	1.00	0.00	**0.33**	3.00	1.00	0.00	**4.33**	4.75	0.00	0.00	**1.58**
9WAT	0.00	2.00	0.00	**0.67**	8.50	4.50	0.00	**1.00**	2.00	0.00	0.00	**0.67**
12WAT	2.50	1.25	0.00	**1.25**	3.00	0.00	0.00	**2.42**	0.00	0.00	0.00	**0.00**
15WAT	0.00	0.00	0.00	**0.00**	1.25	6.00	0.00	**2.05**	2.00	0.00	0.00	**0.67**
Mean	**0.50**	**0.85**	**0.00**		**3.65**	**2.50**	**0.00**		**3.55**	**0.40**	**0.00**	
Pooled mean	**0.45[d]**				**2.16[b]**				**1.32[c]**			

Factors	**F test**	**SE(d)**	**SE(m)**	**C.D.**
Genotypes	**	0.12	0.08	0.23
Canopy level	**	0.08	0.05	0.15
Genotype x Canopy level	**	0.20	0.14	0.39
WAT	**	0.10	0.07	0.19
Genotype x WAT	**	0.26	0.18	0.51
Canopy level x WAT	**	0.17	0.12	0.33
Genotype x Canopy level X WAT	**	0.45	0.32	0.88

U= Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. ** indicates significant at p<0.01.NS indicates non-significant

Table 13: Effect of genotypes, canopy level and weeks after transplanting on *T. absoluta* damage during summer 2018, (March –June)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	40.00	57.50	17.50	**38.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	25.00	30.00	35.00	**30.00**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**	1.25	0.00	2.25	**1.25**	2.50	1.25	7.50	**3.75**
9WAT	45.00	25.00	22.50	**30.83**	0.00	1.25	0.00	**0.42**	0.00	0.00	1.25	**0.42**	2.50	2.50	1.75	**2.08**	0.00	5.00	10.00	**5.00**
12WAT	32.50	57.50	17.50	**35.83**	0.00	2.50	0.00	**0.83**	0.00	0.00	0.00	**0.00**	6.25	2.50	0.00	**2.92**	0.00	0.00	7.50	**2.50**
15WAT	17.50	15.00	20.00	**17.50**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**	2.50	1.25	2.50	**2.08**
Mean	**32.00**	**37.00**	**22.50**		**0.00**	**0.75**	**0.00**		**0.00**	**0.25**	**0.25**		**2.00**	**1.25**	**0.75**		**1.00**	**1.50**	**5.50**	
Pooled mean	**30.50[a]**				**0.25[c]**				**1.67[c]**				**1.33[c]**				**2.66[c]**			

	TM 308				***PT4208***			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	40.00	32.50	32.50	**35.00**	37.50	13.75	25.00	**25.42**
6WAT	27.50	10.00	27.50	**21.67**	46.25	12.50	12.50	**23.75**
9WAT	25.00	42.50	22.50	**30.00**	25.00	25.00	15.00	**21.67**
12WAT	20.00	43.75	25.00	**29.58**	12.50	22.50	15.00	**16.67**
15WAT	8.75	40.00	17.50	**22.08**	26.25	22.50	20.00	**22.92**
Mean	**24.25**	**33.75**	**25.00**		**29.5**	**19.25**	**17.5**	
Pooled mean	**27.67[a]**				**22.08[b]**			

Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	1.23	1.74	3.43
Canopy level	NS	-	-	-
Genotype x Canopy level	**	2.14	3.02	5.94
WAT	NS	-	-	-
Genotype x WAT	**	2.76	3.90	7.67
Canopy level x WAT	**	1.81	2.55	5.02
Genotype x Canopy level X WAT	**	4.78	6.75	13.29

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. ** indicates significant at p<0.01.NS indicates non-significant

Table 14: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) during summer 2018, (March–June)

Fruit damage (%) at different WAT												
Genotypes	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Rating scale**
***S. lycopersicum* CL5915/CH45**	25.00	30.00	25.25	27.75	25.25	35.25	35.25	40.00	36.25	30.00	**33.67[a]**	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	2.00	5.00	5.00	2.00	**2.33[b]**	1
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	0.00	5.00	10.00	5.00	**3.33[b]**	1
TM 308	20.00	30.00	50.00	30.00	31.40	34.43	35.20	36.25	35.20	35.00	**34.58[a]**	2
PT 4208	25.25	30.00	30.75	29.50	29.25	35.00	35.25	33.25	40.00	34.00	**34.46[a]**	2
F Test	**											
SEm±	1.44											
CD @ 5%	4.18											
C.V	20.28											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th ^{WA}T was subj^{ec}ted to one way Anova followed by DMRT. ** indicates significant at p<0.01.NS indicates non-significant

Table 15: Reaction of the five different genotypes to thrips incidence at different weeks after transplanting (WAT) during summer 2018, (March–June)

	No of thripsper tap					
Genotypes	**3WAT**	**6WAT**	**9WAT**	**12WAT**	**15WAT**	**Mean**
***S. galapagense* VI037241**	0.00	0.00	0.00	0.25	0.00	**0.05^{d}**
***S. Cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	**0.00^{d}**
***S. habrochaites* LA1777**	0.00	0.00	3.50	2.25	2.00	**1.55^{c}**
S. habrochaites var glabratum VI030362	0.00	0.00	0.75	3.50	3.25	**1.50^{c}**
***S. lycopersicum* CL5915**	0.00	0.00	4.25	4.75	6.50	**3.10^{a}**
TM 308	0.00	0.00	3.50	4.50	6.25	**2.85^{b}**
PT4208	0.00	0.00	4.50	4.00	5.00	**2.70^{b}**
F Test	**					
Factors	**C.D.**		**SE(d)**		**SE(m)**	
Genotype	0.27		0.14		0.10	
WAT	0.23		0.12		0.08	
Genotype x WAT	0.60		0.30		0.21	

NB: WAT= Weeks after transplanting

**Thrips spp. (*Gynaikothrips uzeli* Zimmermann, *Thrips palmi* Karny, *Scirtothrips dorsalis* Hood)

4.1.3 Field screening of tomato genotypes during *kharif* 2018, (June-September)

The field trial was carried out at a research plot in M/s I & B Seeds, Kengeri, Uttarahalli, Bengaluru Field observations on total egg (Table 16) and larval load per 20 leaves at different canopy levels (Table 17). Besides foliar and fruit damage were recorded at different week intervals (Table 18, 19). Thrips countper tap was recorded at 3rd, 6th, 9th, 12th and 15th WAT (Table 20).

4.1.3.1 Egg load of *Tuta absoluta* per 20 leaves

The mean number of eggsper 20 leaves varied from 0.00 to 3.00 eggsper 20 leaves in *S. lycopersicum* (CL5915). Egg load on *S. lycopersicum* (CL5915) were observed starting from 3rd WAT upto 15th WAT. However, the mean egg load was relatively lesser during this season as compared to that during summer season. The egg load was significantly less in the other four wild accessions. The egg load ranged from 0.00-1.00 in all the four wild accessions.

Between the different genotypes there were significant differences *w. r. t.* mean number of eggs per 20 leaves at different canopy levels. No egg load was observed in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) in this season. Significant differences were observed w.r.t. egg load at different canopy levels (CD=0.14) and different genotypes (CD=0.18) (Table 16). However the data pertaining to different week intervals did not vary significantly.

4.1.3.2 *T. absoluta* larval no. per 20 leaves

Larval countper 20 leaves from different canopy levels also showed significant differences among accessions (CD=0.18). Highest mean number of larvae was recorded during 12th WAT followed by 3rd WAT in *S. lycopersicum* (CL5915) i.e 3.00 and 2.25 larvae per 20 leaves, respectively (Table 17). *S. lycopersicum* (CL5915) recorded significantly higher larval load in middle canopy, followed by lower canopy leaves (Table 17). In *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) no larvae were observed, whereas in *S. habrochaites* (LA1777) and *S. habrochaites var. glabratum* (VI030462) it ranged between 0.00-0.75 and 0.00-1.00 larvae per 20 leaves, respectively.

4.1.3.3 *T. absoluta* leaf damage (%)

Foliar damage recorded was highest in case of *S. lycopersicum* (CL5915) viz., 0.00-57.5% in middle canopy leaves during 15th WAT, whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) no damage was observed (Table 18). In *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) it ranged between 0.00-6.25% and 0.00-5.00 per cent, respectively (Table 18).

4.1.3.4 *T. absoluta* fruit damage (%)

Fruit development started early from 6th WAT in case of *S. lycopersicum* (CL5915). Fruit damage starting from 10th week to 15th week was considered for comparing the genotypes. 20.00-34.00 per cent fruit damage has been recorded in *S. lycopersicum* (CL5915), whereas of 0.00-5.00% and 0.00-6.50 per cent fruit damage was observed in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) respectively. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) were outstanding since they did not record any fruit damage starting from fruit development upto full maturity stage (Table 19). There were significant differences in per cent fruit damage between the different genotypes (CD=4.18) (table 19).

4.1.3.5 No. of thrips per tap

Thrips population was very low during *kharif* season and no TOSPO virus disease symptoms were recorded during the season. Thrips numberper tap ranged from 0.00-1.50, 0.00-2.50 and 0.00-3.25 per tap in *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL5915), respectively. It varied significantly among different genotypes (CD=0.17) at different week intervals (CD=0.17). The thrips count per tap was more in flowering time in case of *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) *i.e* 9th to 12th WAT (Table 20).

4.1.4 Field screening of tomato genotypes during *rabi* 2018

Field trial was carried out at a research plot in M/s I & B Seeds, Kengeri, Uttarahalli, Bengaluru. Field observations on mean egg (Table 21) larval load per 20

leaves at different canopy levels (Table 22), foliar and fruit damage (Table 23, 24) and thrips countper tap was also recorded at 3rd, 6th, 9th, 12th and 15th WAT (Table 21). Five plants per plots with four replications i.e total of 20 plants were observed.

4.1.4.1 Egg load of *T. absoluta* per 20 leaves

Egg load on *S. lycopersicum* (CL5915) were observed starting from 3rd WAT upto 15th WAT. The mean number of eggs per 20 leaves varied from 0.00 to 3.00 eggs per 20 leaves. Relatively greater egg load was observed in middle canopy leaves of *S. lycopersicum* (CL5915) i.e 3.00 eggs per 20 leaves followed by 2.75 eggs in middle canopies during 12th and 3rd WAT, respectively. The egg load was significantly less in other four wild accessions. The egg load ranges from 0.00-0.75 in all the four wild accessions.

Between the different entries significant differences were observed *w. r. t.* mean number of eggsper 20 leaves at different canopy levels. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) received significantly lesser egg load. Mean egg load was 0.20 and 0.00 eggsper 20 leaves for *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240), respectively. There was a significant difference between egg load at different canopy level (CD=0.15) and different genotypes (CD=0.20) (Table 21).

4.1.4.2 *T. absoluta* larval no. per 20 leaves

Larval countper 20 leaves from different canopy levels also showed significant differences among the accessions (CD=0.27). Highest mean number of larvae was recorded during 12th WAT followed by 15th WAT in *S. lycopersicum* (CL5915) *i.e.* 3.00 and 2.50 larvae per 20 leaves respectively (Table 22). *S. lycopersicum* (CL5915) received more larval load in middle canopy followed by upper canopy leaves (Table 22). In *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) significantly lower no. of larvae were observed. There was no significant role of different week intervals and the mean no. of larvae per 20 leaves.

4.1.4.3 *T. absoluta* leaf damage (%)

Foliar damage recorded highest in *S. lycopersicum* (CL5915). It has been observed that 0.00-52.50% foliar damage was caused in middle canopy leaves of *S. lycopersicum* (CL5915) during 6th week after transplanting, whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) very less foliar damage i.e 0.17% and 0.25% was observed (Table 22). In *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) a range of 0-6.25% and 0.00-3.75% foliar damage was observed (Table 23).

4.1.4.4 *T. absoluta* fruit damage (%)

Fruit development started from 6th WAT in case of *S. lycopersicum* (CL5915). The fruit damage which was observed in all the genotypes from 10th to 15th WAT was considered for comparing the genotypes. Per cent fruit damage was in the range of 10.00-35.30 per cent in *S. lycopersicum* (CL5915). A range of 0.00-4.62% and 0.00-6.50 per cent fruit damage was observed in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) respectively. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) did not record any fruit damage throughout the observation period w.r.t. the per cent fruit damage (Table 24). There was a significant difference in per cent fruit damage among different genotypes (CD=4.31) (Table 24).

4.1.4.5 No. of thrips per tap

Mean no. of thripsper tap ranged from 0.00-1.80, 0.00-2.25 and 0.00-4.08per tap in *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL5915), respectively. Thrips population was observed from 9th to 15th WAT. It varied significantly among different genotypes (CD=1.24) and also at different week intervals (CD=0.05). The thrips countper tap was more at flowering stage in case of *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) *i.e* at 9th to 12th WAT (Table 25).

Table 16: Mean no. of eggs laid per 20 leaves by *T. absoluta* at different canopy levels of different genotypes during *kharif*, 2018 (June-September)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	0.00	0.00	2.20	**0.73**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.80	0.00	**0.27**
6WAT	0.00	1.00	1.80	**0.93**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.50	0.75	0.00	**0.42**	0.00	1.00	0.00	**0.33**
9WAT	0.00	2.00	1.25	**1.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**
12WAT	1.00	3.00	0.00	**1.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
15WAT	1.30	0.00	1.70	**1.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.25	0.00	**0.08**
Mean	**0.46**	**1.20**	**1.39**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.15**	**0.15**	**0.00**		**0.00**	**0.41**	**0.00**	
Pooled mean	**1.02[a]**				**0.00[b]**				**0.00[b]**				**0.10[b]**				**0.14[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.06	0.09	0.18
Canopy level	**	0.05	0.07	0.14
Genotype x Canopy level	**	0.11	0.15	0.30
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	0.11	0.15	0.30
Genotype x Canopy level X WAT	**	0.24	0.35	0.68

#Values are mean of four replications. Means followed by different alphabets differ significantl

Table 17: Mean no. of larvae of *T. absoluta* per 20 leaves at different canopy levels in different genotypes during *kharif*, 2018 (June-September)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	0.00	1.25	2.25	**1.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.75	0.00	**0.25**
6WAT	0.00	1.00	1.75	**0.92**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.50	0.75	0.00	**0.42**	0.00	1.00	0.00	**0.33**
9WAT	0.00	2.00	1.25	**1.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**
12WAT	0.75	3.00	0.00	**1.25**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
15WAT	1.30	0.00	1.50	**0.93**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.25	0.00	**0.08**
Mean	**0.41**	**1.45**	**1.35**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.15**	**0.15**	**0.00**		**0.00**	**0.40**	**0.00**	
Pooled mean	**1.07[a]**				**0.00[b]**				**0.00[b]**				**0.10[b]**				**0.13[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.063	0.089	0.176
Canopy level	**	0.049	0.069	0.136
Genotype x Canopy level	**	0.109	0.154	0.304
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	0.109	0.154	0.304
Genotype x Canopy level X WAT	**	0.244	0.345	0.681

#Values are mean of four replications. Means followed by different alphabets differ significant

Table 18: Effect of genotypes, canopy level and weeks after transplanting on *T.absoluta* foliar damage (%) during *kharif*, 2018 (June-September)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	25.00	25.00	30.00	**26.67**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	5.00	0.00	**1.67**
6WAT	45.00	45.00	25.00	**38.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	3.75	6.25	0.00	**3.33**	0.00	2.50	0.00	**0.83**
9WAT	32.50	32.50	57.50	**40.83**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.25	0.00	0.00	**0.42**	0.00	0.00	0.00	**0.00**
12WAT	17.50	17.50	15.00	**16.67**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
15WAT	57.50	57.50	17.50	**44.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	2.50	0.00	**0.83**
Mean	**35.50**	**35.5**	**29.00**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**1.00**	**1.25**	**0.00**		**0.00**	**2.00**	**0.00**	
Pooled mean	**33.33[a]**				**0.00[b]**				**0.00[b]**				**0.75[b]**				**0.67[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.52	0.74	1.46
Canopy level	**	0.41	0.57	1.13
Genotype x Canopy level	**	0.91	1.28	2.53
WAT	**	0.52	0.74	1.46
Genotype x WAT	**	1.17	1.65	3.26
Canopy level x WAT	**	0.91	1.28	2.53
Genotype x Canopy level X WAT	**	2.03	2.87	5.65

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting.
#Values are mean of four replications. Means followed by different alphabets differ significant

Table 19: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) during *Kharif*, 2018 (July- September)

Per cent fruit damage												
Genotypes	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Scale**
***S. lycopersicum* CL5915/CH45**	20.00	25.75	25.00	27.00	30.00	32.00	35.25	32.95	36.25	34.00	**33.41[a]**	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	4.00	5.00	4.25	4.00	**2.88[b]**	1
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	2.25	5.76	6.50	5.00	**3.25[b]**	1
F Test	**											
SEm±	1.41											
CD @ 5%	4.18											
C.V	33.4											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Values are mean of four replications

Values with different alphabets differ significantly**.**

Table 20: Reaction of the five genotypes at different weeks after transplanting (WAT) during *kharif*, 2018 (June-September)

Genotypes	No. of thripsper tap					
	3WAT	6WAT	9WAT	12WAT	15WAT	Mean
***S. galapagense* VI037241**	0.00	0.00	0.00	0.00	0.00	0.00[d]
***S. Cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	0.00[d]
***S. habrochaites* LA1777**	0.00	0.00	1.25	1.00	1.50	0.75[c]
***S. habrochaites var glabratum* VI030462**	0.00	0.00	0.50	1.50	2.50	0.90[b]
***S. lycopersicum* CL5915**	0.00	0.00	2.50	2.25	3.25	1.60[a]

Factors	F Test	SE(m)	SE(d)	C.D.
Genotype	**	0.04	0.06	0.17
WAT	**	0.04	0.0	0.17
Genotype x WAT	**	0.09	0.13	0.26

WAT=Weeks after transplanting
Means followed by different alphabets differ significantly.

Table 21: Mean no. of eggs laid per 20 leaves by *T. absoluta* at different canopy levels of different genotypes during *rabi*, 2018 (September-December)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	1.00	1.75	1.50	**1.42**	0.50	0.00	0.00	**0.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.75	0.00	**0.25**
6WAT	1.50	2.75	1.75	**2.00**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.75	0.75	0.00	**0.50**
9WAT	2.50	2.00	0.00	**1.50**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.25	**0.08**	0.00	0.00	0.00	**0.00**
12WAT	1.00	3.00	1.00	**1.67**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
15WAT	0.50	2.25	0.00	**0.92**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**1.30**	**2.35**	**0.85**		**0.20**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.05**		**0.15**	**0.30**	**0.00**	
Pooled mean	**1.50[a]**				**0.70[b]**				**0.00[c]**				**0.02[c]**				**0.15[c]**			

Factors	F Test	SE(d)	SE(m)	C.D.
Genotypes	**	0.10	0.07	0.20
Canopy level	**	0.08	0.05	0.15
Genotype x Canopy level	**	0.17	0.12	0.34
WAT	**	0.10	0.07	0.20
Genotype x WAT	**	0.22	0.16	0.44
Canopy level x WAT	**	0.17	0.12	0.34
Genotype x Canopy level X WAT	**	0.38	0.27	0.75

#Values are mean of four replications. Means followed by different alphabets differ significantly

Table 22: Mean no. of larvae of *T. absoluta* per 20 leaves of different canopy levels of different genotypes during *rabi,* 2018 (September-December)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	1.00	1.75	1.50	**1.42**	1.50	0.00	0.00	**0.50**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.42**
6WAT	1.75	2.25	1.75	**1.92**	1.25	0.00	0.00	**0.42**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.00	0.75	0.00	**0.58**
9WAT	2.25	2.00	0.00	**1.42**	0.25	0.00	0.00	**0.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.50	0.00	0.00	**0.17**
12WAT	1.00	3.00	1.50	**1.83**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.75	0.00	0.00	**0.25**
15WAT	0.50	2.50	1.25	**1.42**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.75	0.00	0.00	**0.25**
Mean	**1.30**	**2.30**	**1.20**		**0.60**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.60**	**0.40**	**0.00**	
Pooled mean	**1.60[a]**				**0.20[b]**				**0.00[b]**				**0.00[b]**				**0.33[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.10	0.14	0.27
Canopy level	**	0.07	0.10	0.21
Genotype x Canopy level	**	0.17	0.23	0.46
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	NS	-	-	-
Genotype x Canopy level X WAT	NS	-	-	-

#Values are mean of four replications. Means followed by different alphabets differ significant

Table 23: Effect of genotypes, canopy level and weeks after transplanting (WAT) on *T.absoluta* foliar damage (%) during *rabi* 2018, (September-December)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	10.00	17.50	17.50	**15.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	32.50	52.50	22.50	**35.83**	0.00	1.25	0.00	**0.42**	0.00	1.25	0.00	**0.42**	0.00	5.00	0.00	**1.67**	0.00	5.00	0.00	**1.67**
9WAT	17.50	37.50	17.50	**24.17**	0.00	0.00	1.25	**0.42**	0.00	1.25	1.25	**0.83**	3.75	1.25	5.00	**3.33**	3.75	2.50	0.00	**2.08**
12WAT	45.00	45.00	20.00	**36.67**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.25	6.25	0.00	**2.50**	1.25	3.75	0.00	**1.67**
15WAT	32.50	32.50	35.00	**33.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**27.50**	**37.00**	**22.50**		**0.00**	**0.25**	**0.25**		**0.00**	**0.5**	**0.25**		**1.00**	**2.5**	**1.00**		**1.00**	**2.25**	**0.00**	
Pooled mean	**29.00[a]**				**0.17[b]**				**0.25[b]**				**1.50[b]**				**1.08[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.66	0.94	1.84
Canopy level	**	0.51	0.72	1.43
Genotype x Canopy level	**	1.15	1.62	3.19
WAT	**	0.66	0.94	1.84
Genotype x WAT	**	1.48	2.09	4.12
Canopy level x WAT	**	1.15	1.62	3.19
Genotype x Canopy level X WAT	**	2.56	3.62	7.13

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting

#Values are mean of four replications. Means followed by different alphabets differ significant

Table 24: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) during *rabi,* 2018 (September- December)

Per cent fruit damage												
Genotypes	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Scale**
***S. lycopersicum* CL5915/CH45**	10.00	25.00	25.00	20.00	30.00	32.00	35.3	30.3	35.3	34	32.79[a]	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00[c]	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00[c]	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	4.00	5.00	4.25	4.62	2.98[b]	1
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	2.20	5.76	6.50	5.00	3.24[b]	1
F Test	**											
SEm±	1.45											
C.V	35.54											
CD @ 5%	4.31											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Values mean of four replications

Values with different alphabets differ significantly

Table 25: Reaction of the five different genotypes to thrips incidence at different weeks after transplanting (WAT) during *rabi*, 2018 (September-December)

Genotypes	No of thrips per tap					
	3WAT	6WAT	9WAT	12WAT	15WAT	Mean
***S. galapagense* VI037241**	0.00	0.00	0.00	0.00	0.00	0.00[b]
***S. Cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	0.00[b]
***S. habrochaites* LA1777**	0.00	0.00	2.04	1.03	1.80	0.97[a]
***S. habrochaites var glabratum* VI030462**	0.00	0.00	0.80	2.25	1.31	0.87[a]
***S. lycopersicum* CL5915**	0.00	0.00	4.08	3.00	2.30	1.88[a]

Factors	F Test	SE(m)	SE(d)	C.D.
Genotype	**	0.02	0.02	1.24
WAT	**	0.02	0.03	0.05
Genotype x WAT	**	0.04	0.06	0.131

WAT=Weeks after transplanting. Values are mean of four replications

Values with different alphabets differ significantly

4.1.5 Field screening of tomato genotypes during *summer* 2019

This investigation was carried out at research plots of M/s I & B Seeds, Kengeri, Uttarahalli, Bengaluru. Field observations on total egg (Table 26) and larval load per 20 leaves at different canopy levels (Table 27) were recorded. Foliar and fruit damage (Table 28, 29) and thrips count per tap were recorded by tapping the branches gently. Observations were recorded on 3rd, 6th, 9th, 12th and 15th WAT (Table 26). Five plants per plot with four replications i.e totally 20 plants were observed during each week observation.

4.1.5.1 Egg load of *T. absoluta* per 20 leaves

Egg load on *S. lycopersicum* (CL5915) were observed starting from 3rd to 15th WAT. The mean number of eggs per 20 leaves varied from 0.00 to 6.50 eggs per 20 leaves. Significantly higher no. of egg load was observed in middle canopy leaves of *S. lycopersicum* (CL5915) i.e 6.50 eggs peI 20 leaves, followed by 5.75 eggs in miIlle canopies during 6th and 12th WAT, respectively. The egg load was significantly less in other four wild accessions. The egg load Ianged from 0.00-1.25 per 20 leIIIs in all the four wild accessions. Significantly higher egg load was observed during 3rd and 6th WAT.

Between the different entries there were significant differences *w. r. t.* mean number of eggs per 20 leaves at different canopy levels. *Solanum galapagense* (VI037241) and *S. cheesmaniae* (VI037240) received significantly lesser egg load *i.e.* mean value of 0.23 and 0.13 eggs per 20 leaves, respectively. Significantly higher egg load was observed in upper and middle canopy leaves as compared to lower canopy leaves in these two wild accessions. There were significant differences between the egg load at different canopy levels (CD=0.16) and also w.r.t. different genotypes (CD=0.20) (Table 26).

4.1.5.2 *T. absoluta* larval no. per 20 leaves

Larval countper 20 leaves from different canopy levels also showed significant differences between the accessions (CD=0.18). Highest mean number of larvae was recorded during 12th WAT, followed by 6th WAT in *S. lycopersicum* (CL5915) i.e 5.75 and

5.00 larvae per 20 leaves respectively (Table 27). *S. lycopersicum* (CL5915) received significantly higher larval load in middle canopy followed by upper canopy leaves (Table 27). In *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) very few larvae were observed.

4.1.5.3 *T. absoluta* leaf damage (%)

Foliar damage recorded was significantly higher in *S. lycopersicum* (CL5915) than other resistant wild accessions. It ranged between 0.00-40.00 per cent in middle canopy leaves of *S. lycopersicum* (CL5915) during 15th WAT, whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) significantly lesser foliar damage (1.50 and 1.88%) was observed, respectively (Table 27). In *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) it ranged between 0.00-15.00 and 0.00-6.30 per cent, respectively (Table 28).

4.1.5.4 *T. absoluta* fruit damage (%)

Fruit development started from 6th WAT in case of *S. lycopersicum* (CL5915). Mean per cent fruit damage from 10th to 15th WAT was considered for comparing the genotypes. Fruit damage was recorded in a range of 25.00-40.00 per cent in *S. lycopersicum* (CL5915). It was in the range of 0.00-4.50 and 0.00-5.00 per cent in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) respectively. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) were free from fruit damage throughout the period of observation (Table 29). There was a significant difference in per cent fruit damage among different genotypes (CD= 3.61) (table 29).

4.1.5.5 No. of thrips observed per tap

There was a distinct seasonal effect on thrips occurrence and the majority of the thrips population was recorded during the flowering stage. Thrips number per tap ranged from 0.00-2.50, 0.00-2.50 and 0.00-4.75per tap in *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL5915), respectively. Thrips population was observed from 9th to 15th WAT. It varied significantly among different genotypes (CD=0.95) at different week intervals (CD=0.13). No thrips was

observed in the wild accessions *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) (Table 30).

4.1.5.6 Field screening of tomato genotypes during *kharif* 2019

Field trial was carried out at the research plot in M/s I & B Seeds, Kengeri, Uttarahalli, Bengaluru. Field observations were recorded on the total egg (Table 31) and larval load per 20 leaves at different canopy levels (Table 32), foliar and fruit damage at different week intervals (Table 33, 34) and thrips count per tap on 3rd, 6th, 9th, 12th and 15th WAT (Table 35). Five plants per plots with four replications i.e total 20 plants were observed for every investigation.

4.1.6.1 Egg load of *Tuta absoluta* per 20 leaves

Egg load on *S. lycopersicum* (CL5915) was observed starting from 3rd to 15th WAT. The mean number of eggs per 20 leaves varied from 0.00 to 3.00 eggs per 20 leaves. Significantly higher number of eggs was observed in middle canopy leaves of *S. lycopersicum* (CL5915) i.e 3.00 eggs peI 20Ieaves, followed by 2.00 eggs in miIIle canopies during 12th and 9th week after transplanting, respectively. The egg load was significantly less in other four wild accessions. The egg loads was not found in all the four wild accessions. In general significantly higher egg load was observed during 9th and 12th WAT.

Between the different entries there was significant differences *w. r. t.* mean number of eggsper 20 leaves at different canopy levels. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) received significantly lesser egg load. Mean number of 0.00 eggs per 20 leaves were recorded for both *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240). There was significant difference in the egg load at different canopy levels (CD=0.11) w.r.t. different genotypes (CD=0.14) (Table 31).

4.1.6.2 *T. absoluta* larval no. per 20 leaves

Larval count per 20 leaves from different canopy levels also showed significant difference among accessions (CD=2.11). Highest mean number of larvae was recorded

during 9th WAT followed by 15th WAT in *S. lycopersicum* (CL5915) i.e 32.50 and 27.50 larvaeper 20 leaves, respectively (Table 32). *S. lycopersicum* (CL5915) received more larval load in middle canopy, followed by upper canopy leaves (Table 32). In *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) very few larvae were observed.

4.1.6.3 *T. absoluta* leaf damage (%)

Foliar damage was found to be highest in *S. lycopersicum* (CL5915). It has been observed that 0.00-32.50 per cent foliar damage was caused in *S. lycopersicum* (CL5915) during different WAT whereas in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) no foliar damage was observed (Table 33). However, in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) foliar damage ranged between 0.00-5.00% and 0.00-3.75 per cent (Table 32). The foliar damage differed significantly between the genotypes (CD=2.11).

4.1.6.4 *T. absoluta* fruit damage (%)

Fruit development started from 6th WAT in case of *S. lycopersicum* (CL5915). Average per cent fruit damage during 10th week to 15th week was considered for comparing the genotypes. Per cent fruit damage ranged from 20.00-50.00 per cent in *S. lycopersicum* (CL5915). No fruit damage was observed in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) respectively. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) did not suffer any fruit damage during fruit development to maturity stage (Table 34). There was significant difference in per cent fruit damage among the different genotypes (CD= 2.47) (table 34).

4.1.6.5 No. of thrips per tap

There was a distinct seasonal effect on thrips occurrence and the majority of the peak in thrips population was recorded in the flowering stage of the crop. Thrips were counted based on the number of thrips per tap from different genotypes at different week intervals. Thrips population was very low and no TOSPO disease symptoms were recorded throughout the season. Thrips number per tap ranged from 0.00-0.50, 0.00-1.50 and 0.00 per tap in *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462)

and *S. lycopersicum* (CL5915) respectively. Thrips population was observed from 9th to 15th WAT. It varied significantly among the different genotypes (CD=0.95) at different week intervals (CD=0.14). The thrips countper tap was more in flowering time in case of *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) *i.e* 9th to 12th WAT (Table 3[5]).

All the field investigations showed that *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) have high level of resistance against *T. absoluta* and thrips damage in all the seasons, followed by *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462), whereas commercial hybrids TM 308 and PT 4208 and *S. lycopersicum* (CL5915) showed high susceptibility towards *T. absoluta* and thrips attack.

During the study period, immature life stages of *T. absoluta* (eggs and larvae) were found on at least one or more of the three canopy levels (upper, middle or lower part) of their host plants but were significantly more in upper and middle canopy leaves of susceptible genotypes and commercial hybrids (Fig 1). Per cent foliar damage was found to be significantly higher in middle canopy leaves (Fig 2). It was evident that mated females of *T. absoluta* exhibited a greater preference to lay eggs on upper canopy leaves as compared to laying eggs on leaves of the middle and lower canopy of tomato plants, except susceptible genotype *S. lycopersicum*, wherein the preference of egg laying was more in middle canopy. Indeed eggs were totally absent or negligible in number on leaves of either the middle or the lower canopy of the host plant of *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240). All these field studies clearly indicated that there is significant variation in resistance level to the pests and based on the data generated on the six field screening trials characteristic feature *S. lycopersicum (CL5915)*, TM 308 and PT 4208 could be categorised as susceptible whereas other four wild genotypes could be categorized as resistant or highly resistant to *T.absoluta* and thrips.

These findings are in accordance with the earlier studies where they have shown that before flowering, *T. absoluta* females chose the under-side of the leaf for oviposition in the upper canopy (Torres *et al.,* 2001). Additionally, Leite *et al.* (1999) found that

Table 26: Mean no. of eggs laid per 20 leaves by *T. absoluta* at different canopy levels of different genotypes during summer, 2019 (March –June)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	3.25	2.75	1.75	**2.58**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	4.75	6.50	0.00	**3.75**	0.50	1.00	0.00	**0.50**	0.50	1.00	0.00	**0.50**	0.00	0.00	0.00	**0.00**	0.00	1.00	0.00	**0.33**
9WAT	4.50	1.75	0.00	**2.08**	0.25	0.00	0.75	**0.33**	0.00	0.00	0.50	**0.17**	1.00	1.00	0.00	**0.67**	0.00	0.00	0.00	**0.00**
12WAT	3.25	5.75	0.00	**3.00**	0.00	1.00	0.00	**0.33**	0.00	0.00	0.00	**0.00**	0.25	1.25	0.00	**0.50**	1.00	0.25	0.00	**0.42**
15WAT	1.75	3.25	0.00	**1.67**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**3.50**	**4.00**	**0.35**		**0.15**	**0.40**	**0.15**		**0.10**	**0.20**	**0.10**		**0.25**	**0.45**	**0.00**		**0.20**	**0.25**	**0.00**	
Pooled mean	**2.62[a]**				**0.23[b]**				**0.13[b]**				**0.23[b]**				**0.15[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.07	0.10	0.20
Canopy level	**	0.06	0.08	0.16
Genotype x Canopy level	**	0.13	0.18	0.35
WAT	**	0.07	0.10	0.20
Genotype x WAT	**	0.16	0.23	0.45
Canopy level x WAT	**	0.13	0.18	0.35
Genotype x Canopy level X WAT	**	0.28	0.40	0.78

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting. ** indicates significant at p<0.01.NS indicates non-significant

Table 27: Mean no. of larvae of *T. absoluta* per 20 leaves of different canopy levels of different genotypes during summer, 2019 (March –June)

	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var. glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	3.00	1.75	2.25	**2.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	2.25	5.00	0.00	**2.42**	0.75	1.00	0.00	**0.58**	0.25	1.00	0.00	**0.42**	0.00	0.00	0.00	**0.00**	0.00	1.00	0.00	**0.33**
9WAT	2.00	2.25	0.00	**1.42**	1.00	0.00	0.50	**0.50**	1.50	1.00	0.25	**0.92**	1.00	1.00	0.00	**0.67**	0.00	2.00	0.00	**0.67**
12WAT	3.25	5.75	0.00	**3.00**	0.00	1.00	0.00	**0.33**	0.00	0.00	0.00	**0.00**	0.75	1.75	0.00	**0.83**	2.00	2.25	0.00	**1.42**
15WAT	2.25	3.50	0.00	**1.92**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	2.55	3.65	0.45		0.35	0.40	0.10		0.35	0.40	0.05		0.35	0.55	0.00		0.40	1.05	0.00	
Pooled mean	**2.18[a]**				**0.35[c]**				**0.33[c]**				**0.38[c]**				**0.60[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.06	0.09	0.18
Canopy level	**	0.05	0.07	0.14
Genotype x Canopy level	**	0.11	0.15	0.30
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	0.11	0.15	0.30
Genotype x Canopy level X WAT	**	0.24	0.35	0.68

Table 28: Effect of genotypes, canopy level and weeks after transplanting on *T. absoluta* damage during during summer, 2019 (March –June)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	25.00	13.00	15.00	**17.50**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
6WAT	10.00	25.00	0.00	**11.67**	3.80	6.30	0.00	**3.33**	2.25	7.50	10.00	**6.58**	3.80	0.00	1.30	1.67	2.50	2.50	0.00	**1.67**
9WAT	33.00	15.00	0.00	**15.83**	5.00	0.00	1.30	**2.08**	4.75	1.25	3.00	**2.83**	3.80	3.00	0.00	2.08	0.00	5.00	0.00	**1.67**
12WAT	25.00	33.00	0.00	**19.17**	0.00	6.30	0.00	**2.08**	0.00	0.00	0.00	**0.00**	15.00	5.00	0.00	6.67	6.30	2.50	0.00	**2.92**
15WAT	15.00	40.00	0.00	**18.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Mean	**21.50**	**25.00**	**3.00**		**1.75**	**2.50**	**0.25**		**1.40**	**1.75**	**2.50**		**4.50**	**1.50**	**0.25**		**1.75**	**2.00**	**0.00**	
Pooled mean	**16.50[a]**				**1.50[b]**				**1.88[b]**				**2.08[b]**				**1.25[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	1.02	1.44	2.83
Canopy level	**	0.79	1.12	2.19
Genotype x Canopy level	**	1.76	2.49	4.91
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	1.76	2.49	4.91
Genotype x Canopy level X WAT	**	3.94	5.57	10.99

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting

Table 29: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) summer, 2019 (March –June)

Genotypes	Per cent fruit damage											
	6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Rating scale**
***S. lycopersicum* CL5915/CH45**	30.00	25.00	25.00	30.00	30.00	35.00	35.25	32.25	40.00	40.00	**35.42[a]**	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[c]**	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	0.00	2.00	2.25	4.50	**1.46[b]**	1
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	0.00	2.00	2.50	5.00	**1.58[b]**	1
F Test	**											
SEm±	1.22											
CD @ 5%	3.61											
CV	32.16											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Values are mean of four replications

Means followed by different alphabets differ significantly

Table 30: Reaction of the five genotypes to thrips incidence at different weeks after transplanting (WAT) during summer, 2019 (March –June)

No of thripsper tap						
Genotypes	**3WAT**	**6WAT**	**9WAT**	**12WAT**	**15WAT**	**Mean**
***S. galapagense* VI037241**	0.00	0.00	0.00	0.00	0.00	**0.00[b]**
***S. Cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	**0.00[b]**
***S. habrochaites* LA1777**	0.00	0.00	0.00	2.00	2.50	**0.90[b]**
***S. habrochaites var glabratum* VI030462**	0.00	0.00	0.00	2.25	2.50	**0.95[b]**
***S. lycopersicum* CL5915**	0.00	0.00	4.00	3.50	4.75	**2.45[a]**

Factors	F Test	SE(m)	SE(d)	C.D.
Genotype	**	0.31	0.33	0.95
WAT	**	0.04	0.06	0.13
Genotype x WAT	**	0.10	0.15	0.30

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting
Means followed by different alphabets differ significantly

Table 31: Mean no. of eggs laidper 20 leaves by *T. absoluta* at different canopy levels in different genotypes during *kharif*, 2019 (June- September)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	0.00	0.00	2.25	**0.75**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
6WAT	0.00	1.00	1.80	**0.93**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
9WAT	0.00	2.00	1.25	**1.08**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
12WAT	1.00	3.00	0.00	**1.33**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
15WAT	0.00	0.00	1.75	**0.58**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
Mean	**0.20**	**1.20**	**1.41**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**		**0.00**	**0.00**	**0.00**	
Pooled mean	**0.94[a]**				**0.00[b]**				**0.00[b]**				**0.00[b]**				**0.00[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.050	0.070	0.14
Canopy level	**	0.039	0.054	0.11
Genotype x Canopy level	**	0.086	0.122	0.240
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	0.086	0.122	0.240
Genotype x Canopy level X WAT	**	0.193	0.272	0.537

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting, Means followed by different alphabets differ significantly

Table 32: Mean no. of larvae of *T. absoluta* per 20 leaves of different canopy levels in different genotypes during *kharif*, 2019 (June- September)

	S. lycopersicum **CL5915/CH45**				***S. galapagense*** **VIO37241**				***S. cheesmaniae*** **VI037240**				***S. habrochaites*** **LA1777**				***S. habrochaites var glabratum*** **VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	0.00	1.25	0.75	**0.67**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
6WAT	0.00	1.00	1.75	**0.92**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.17	0.00	0.25	0.00	0.00
9WAT	0.00	2.00	1.25	**1.08**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12WAT	0.75	3.00	0.00	**1.25**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75
15WAT	1.00	0.00	1.50	**0.83**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Mean	0.35	1.45	1.05		0.00	0.00	0.00		0.00	0.00	0.00		0.00	0.10	0.00		0.00	0.10	0.00	0.35
Pooled mean	**1.35[a]**				**0.00[b]**				**0.00[b]**				**0.03[b]**				**0.12[b]**			

Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	0.053	0.075	0.147
Canopy level	**	0.041	0.058	0.114
Genotype x Canopy level	**	0.092	0.130	0.255
WAT	NS	-	-	-
Genotype x WAT	NS	-	-	-
Canopy level x WAT	**	0.092	0.130	0.255
Genotype x Canopy level X WAT	**	0.205	0.290	0.571

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting, Means followed by different alphabets differ significantly

Table 33: Effect of genotypes, canopy level and weeks after transplanting on *T.absoluta* leaf damage during *kharif*, 2019 (June- September)

	Per cent foliar damage																			
	***S. lycopersicum* CL5915/CH45**				***S. galapagense* VIO37241**				***S. cheesmaniae* VI037240**				***S. habrochaites* LA1777**				***S. habrochaites var glabratum* VIO30462**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
3WAT	7.50	12.50	32.50	**17.50**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0**	0.00	1.25	0.00	**0.41**
6WAT	15.00	25.00	17.50	**19.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	1.25	0.00	1.25	**0.83**	2.50	2.50	0.00	**1.67**
9WAT	32.50	32.50	17.00	**27.33**	0.00	0.00	0.00	**0.00**	0.00	1.25	0.00	**0.00**	1.25	2.50	0.00	**1.25**	1.25	3.75	0.00	**1.67**
12WAT	25.00	25.50	25.00	**25.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	5.00	0.00	**1.67**	1.25	2.50	0.00	**1.25**
15WAT	15.00	27.50	15.00	**19.17**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**	2.50	0.00	0.00	**0.83**
Mean	**19.00**	**24.60**	**21.40**		**0.00**	**0.00**	**0.00**		**0.00**	**0.25**	**0.00**		**0.5**	**1.5**	**0.25**		**1.50**	**2.00**	**0.00**	
Pooled mean	**21.67[a]**				**0.00[b]**				**0.08[b]**				**0.75[b]**				**1.17[b]**			

Factors	F Test	SE(m)	SE(d)	C.D.
Genotypes	**	0.76	1.07	2.11
Canopy level	**	0.59	0.83	1.64
Genotype x Canopy level	**	1.31	1.86	3.66
WAT	**	0.76	1.07	2.11
Genotype x WAT	**	1.70	2.40	4.72
Canopy level x WAT	**	1.31	1.86	3.66
Genotype x Canopy level X WAT	**	2.94	4.15	8.18

U=Upper, M=Middle, L=Lower, WAT=Weeks after transplanting
Means followed by different alphabets differ significantly

Table 34: Fruit damage (%) due to *T. absoluta* in the five genotypes at different weeks after transplanting (WAT) during *kharif*, 2019 (June- September)

Per cent fruit damage												
Genotypes	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Mean**	**Rating scale**
***S. lycopersicum* CL5915/CH45**	20.00	40.00	50.00	45.00	30.00	40.00	35.25	32.50	45.25	50.00	**38.83[a]**	2
***S. galapagense* VI037241**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[b]**	0
***S. cheesmaniae* VI037240**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[b]**	0
***S. habrochaites* LA1777**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[b]**	0
***S. h. var. glabratum* VI030462**	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	**0.00[b]**	0
F Test	**											
SEm±	0.83											
C.V	26.42											
CD @ 5%	2.47											

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Mean values of four replications

Means followed by different alphabets differ significantly

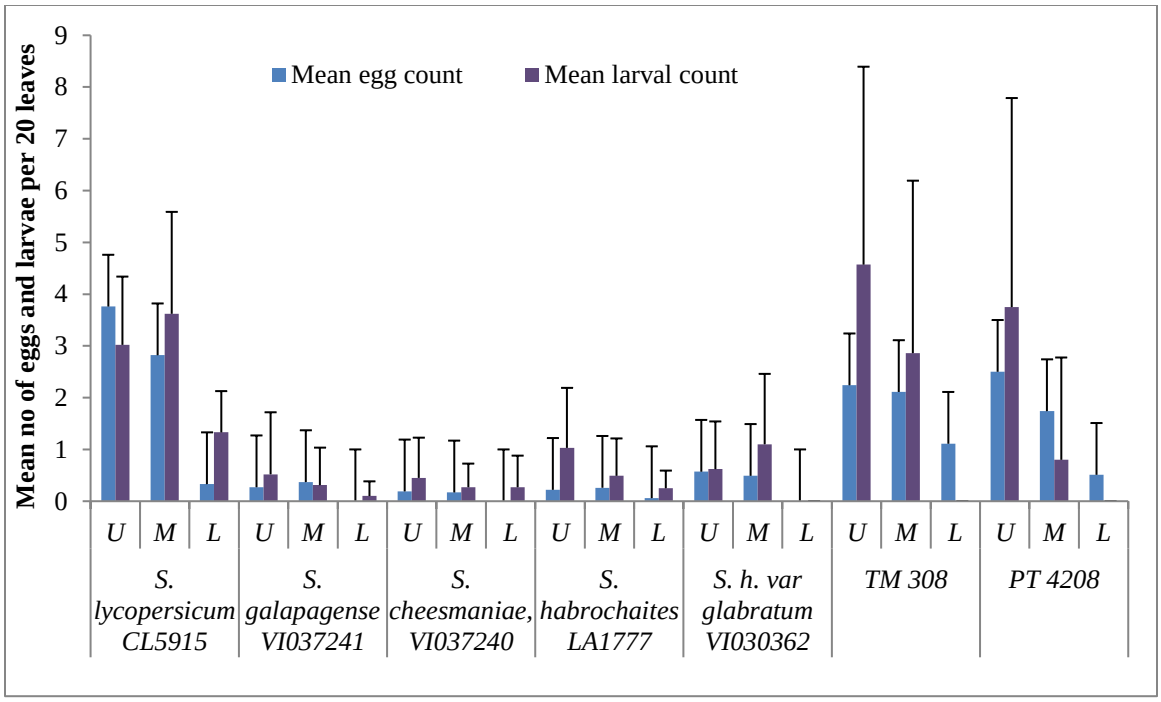


Fig. 1: Spatial distribution of eggs and larvae of *T. absoluta* at different canopy levels (Pooled data of summer 2018-19 trial)

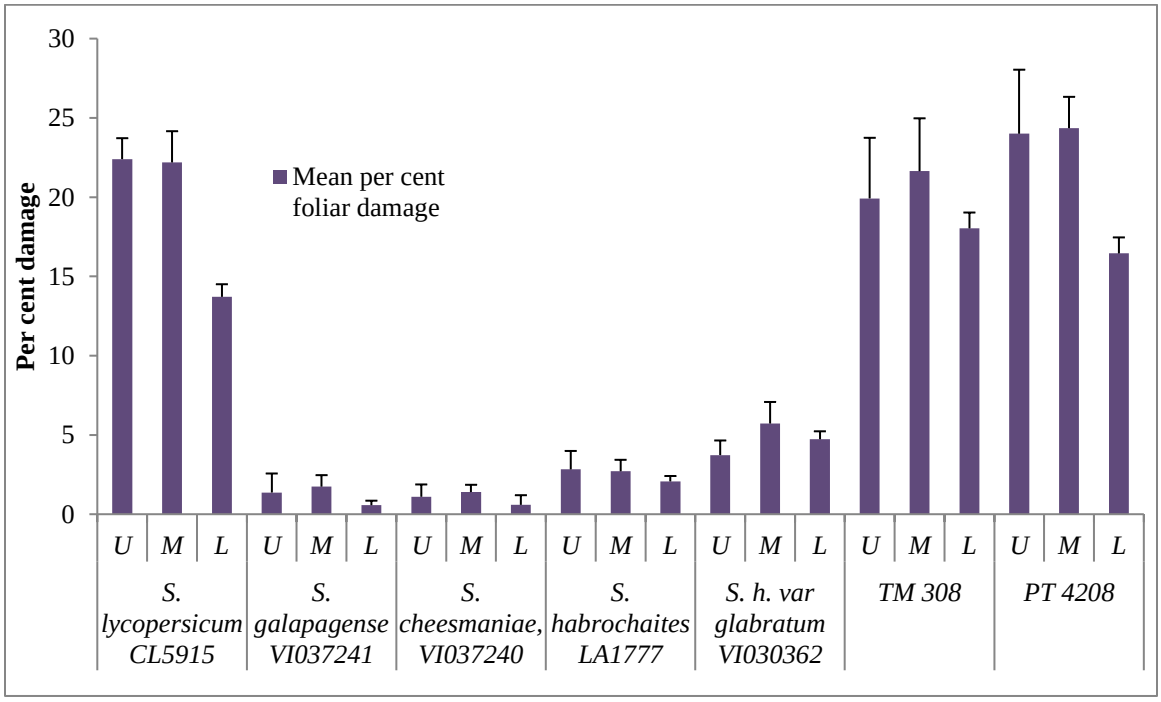


Fig. 2: Foliar damage (%) due to *T. absoluta* infestation at different canopy levels (Pooled data of summer, 2018-19 trial)

Table 35: Reaction of the five genotypes to thrips incidence at different weeks after transplanting (WAT) during *kharif*, 2019 (June- September)

	No of thripsper tap					
Genotypes	**3WAT**	**6WAT**	**9WAT**	**12WAT**	**15WAT**	**Mean**
***S. galapagense* VI037241**	0.00	0.00	0.00	0.00	0.00	**0.00[b]**
***S. cheesmaniae*, VI037240**	0.00	0.00	0.00	0.00	0.00	**0.00[b]**
***S. habrochaites* LA1777**	0.00	0.00	0.50	0.25	0.00	**0.15[b]**
***S. h. var glabratum* VI030462**	0.00	0.00	0.00	0.50	1.50	**0.40[b]**
***S. lycopersicum* CL5915**	0.00	0.00	3.00	2.50	2.75	**1.65[a]**

Factors	F Test	SE(m)	SE(d)	C.D.
Genotype	**	0.43	0.30	0.95
WAT	**	0.05	0.07	0.14
Genotype x WAT	**	0.11	0.15	0.31

WAT=Weeks after transplanting. Mean per cent of fruit damage starting from 10th WAT to 15th WAT was subjected to one way Anova. Followed by DMRT.

Mean values of four replications

Means followed by different alphabets differ significantly

T. absoluta oviposited more on leaves of the apical and middle portions, than in the basal parts as upper canopy leaves are rich in calcium, which is more or less similar to the findings of the present investigation.These findings are similarto the earlier reports of Asma *et al.,* (2013) who reported that because of the highest accessibility of food resources for their growth, it can lead to more number of larvae in the middle canopy, as compared to the number of leaves present on either apical or lower canopy of the plant.

The canopy–wise larval and egg counts in the present study were found to be higher in upper and middle canopy, respectively, compared to lower canopy which is similar to the findings of Asma *et al*. (2013).

4.1.2 Influence of meteorological variables on *T. absoluta* damage

The population of *T. absoluta* and mean weather parameters were subjected to multiple linear regression (MLR) analysis. The correlation matrix and regression co-efficient indicating relationships between the insect population and meteorological variables are presented here under.

During summer 2019, the trap catches of *T. absoluta* moth showed a negative correlation with rainfall (r = -0.35), positive correlation with maximum temperature (r = 0.76*) and minimum temperature (r =0.81*) and negative correlation with morning relative humidity (r = -0.61*) (Table 36). However the mean no. of larvae showed positive correlation with rainfall (r = 0.10), but the correlation coefficient was statistically non-significant. During *kharif* season, trap count (r = -0.36) was negatively associated with rainfall (Table 36) but it was statistically non-significant. Pheromone trap catches were found positively correlated with maximum temperature (r=0.51*) (Table 36).

When the data was subjected to multiple linear regression (MLR) analysis, results revealed that pheromone trap catches (R^2 = 0.37) was influenced to an extent of 37 per cent by rainfall, maximum temperature, minimum temperature and relative humidity (Table 36). The multiple linear regression equation fitted with weather parameters and *T. absoluta* trap catch was as follows in summer season.

$$\mathbf{Y = -123.027 -1.392\ X_1+4.41X_2-0.32\ X_3-0.209X_4+13.586}$$

The results indicated that with an increase of one per cent rainfall, minimum temperature and relative humidity would lead to a decrease of 1.392 per cent,0.32 per cent 0.209 per cent moth catches, respectively and increase of one per cent of maximum temperature would lead to an increase of 4.41 per cent of *T. absoluta* moth catches.

Mean larvaeper 20 leaves and weather data showed that to an extent of 13 per cent of larval population (R^2 = 0.13) was influenced by the weather parameters. The multiple linear regression equation fitted with weather parameters and *T. absoluta* mean larval population was as follows.

$$\mathbf{Y= 0.453-0.033\ X_1+0.038X_2-0.036X_3+0.806X_4+0.721}$$

The results indicated that with an increase of one per cent rainfall, minimum temperature and relative humidity would lead to a decrease of 0.033 per cent, increase of 0.038 per cent, respectively and increase of one per cent of maximum temperature and relative humidity would lead to an increase of 0.036 and 0.806 per cent of mean no. of larvae per 20 leaves, respectively.

When the *kharif* season data was subjected to multiple linear regression (MLR) analysis, the results revealed that pheromone trap catches (R^2 = 0.73) was influenced by rainfall, maximum temperature, minimum temperature and relative humidity to an extent of 73 per cent (Table 36). The multiple linear regression equation fitted with weather parameters and *T. absoluta* trap catch was as follows.

$$\mathbf{Y=-83.114-0.12X_1+1.325X_2+1.412X_3+0.236X_4+1.632}$$

The results indicated that with an increase of one per cent rainfall and relative humidity would lead to a decrease of 0.12 per cent, 0.23 per cent in trap catches, respectively and increase of one per cent of maximum temperature and minimum temperature would lead to an increase of 1.325 per cent and 1.412 per cent of *T.absoluta* trap catches, respectively.

Table 36: Correlation coefficient and regression equation for *T. absoluta* and weather parameters

Summer 2019	Rainfall (X_1)	Temperature		Relative humidity (%)(X_4)	R^2	Regression equation
		Maximum (X_2)	Minimum (X_3)			
Pheromone trap catches of *T.absoluta*	-0.35	0.76*	0.81*	-0.61*	0.37	**$Y=-123.027-1.392X_1+4.410X_2-0.322X_3-0.20X_4+13.586$**
Mean no. of larvaeper 20 leaves	0.10	-0.06	-0.29	0.05	0.13	**$Y= 0.453-0.033\ X_1+0.038X_2-0.227X_3+0.048X_4+0.636$**
***Kharif* 2019**						
Pheromone trap catches of *T. absoluta*	-0.36	0.51*	0.01	-0.53*	0.73	**$Y=-83.114-0.12X_1+1.325X_2-0.036X_3-0.806X_4+0.721$**
Mean no. of larvaeper 20 leaves	0.01	-0.27	-0.37	0.15	0.21	**$Y= 15.393\ -0.013\ X_1+0.190X_2-0.227X_3+0.048X_4+0.636$**

N=15 weeks for each season,*indicates significance at $p<0.05$, X_1= rainfall(mm),X_2 = maximum temperature(°),X_3 = minimum temperature(°),X_4 = relative humidity (%),

Mean larvaeper 20 leaves and weather data showed that 21 per cent of mean larval number (R^2 = 0.21) was influenced by the weather parameters. The multiple linear regression equation fitted with weather parameters and *T. absoluta* mean no. of larvae was as follows.

$$\mathbf{Y=15.393-0.01X_1+0.190X_2-0.227X_3-0.04X_4+0.636}$$

The results indicated that with an increase of one per cent rainfall, minimum temperature and relative humidity would lead to a decrease of 0.01 per cent, 0.22 per cent and 0.04 per cent and increase of one per cent of maximum temperature and minimum temperature would lead to an increase of 0.19 per cent of mean larval population, respectively. Present findings are in line with that of Haji *et al*. (1988) who demonstrated the negative effect of rainfall on the eggs and larvae of *T. absoluta.* These findings are also similar to those of Guimapi *et al.* (2016), who reported that high temperature, high relative humidity, and high availability of host enhances the spread of the pest. Tonnang *et al.,* (2015) recorded *T. absoluta* occurrence in hot and dry areas like Zinder (Niger) and Khartoum (Sudan) in Africa and suggested that this pest is extremely heat tolerant and could survive in areas with little annual rainfall as long as host plants are available which also corroborate the present findings.

In six consecutive field trials the wild accessions performed very well *w.r.t* significantly lowest foliar and fruit damage and exhibiting resistance against thrips population. Further confirmation was carried out by ovipositional choice assay to determine the antixenosis effect and also no choice assay was conducted to confirm if there is any antibiosis effect on the development of the pest. The results are discussed hereunder.

4.1.2.1 Artificial screening of genotypes under laboratory conditions.

Ovipositional preference of *T. absoluta* and thrips was carried out under laboratory condition by choice assay. Though thrips count was less in field, the preference of thrips species for egg laying was not clear. Artificial screening was carried out for further confirmation under laboratory conditions.

4.1.2.2 Choice and no-choice assay of *Scirtothrips dorsalis.*

In laboratory choice assay, *Scirtothrips dorsalis* adults showed significant differences *w.r.t* oviposition on different genotypes (CD @ 1%= 0.303). Significantly highest egg laying was observed in *S. lycopersicum* (Cl5915) followed by *S. habrochaites var glabratum* (VI030462) and no egg laying was recorded in the three wild accessions *i.e*. *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) and *S. habrochaites* (LA1777). In no choice assay wild accessions showed high resistance by causing high per cent larval mortality. Per cent larval mortality in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), *S. lycopersicum* (Cl5915) were 86.67, 96.67.33, 76.67 and 26.67 per cent, respectively (Table 37). Per cent larval mortality differed significantly among different genotypes (CD=10.28) (Fig. 3).

4.1.2.3 Egg laying assay of *T. absoluta*

Ovipositional preference of *T. absoluta* was observed for different genotypes and also on different parts of the seedlings. *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240), showed non-significant results among different parts *i.e* abaxial, adaxial leaf surfaces and the stalk. But the three other genotypes showed significant differences between different plant parts for their egg laying preference. Higher number of egg load was observed in abaxial surface and less number of eggs were observed on the stalks in case of susceptible genotype *i.e. S. lycopersicum* (CL 5915) when different plant parts were compared (Table 38) (Fig. 4).

Egg load was highest in *S. lycopersicum* (CL 5915), followed by TM 308 and PT4208 and lowest in *S. cheesmaniae* (VI037240). Mean egg load recorded from choice assay was 1.04<1.38<4.94<6.21<21.38<17.25<16.44 in *S. cheesmaniae* (VI037240) <*S. galapagense* (VI037241)<*S. habrochaites*(LA1777)<*S. habrochaites.var.glabratum* (VI030462)<*S. lycopersicum* (Cl5915), TM 308 and PT4208, respectively (Table 39). Proportion of egg load was found to be more in susceptible genotypes *i.e. S. lycopersicum* (Cl5915) followed by commercial hybrid TM 308 and PT4208 (Fig. 4). Highest per cent egg hatch was observed on PT 4208 (83.00%) followed by TM 308

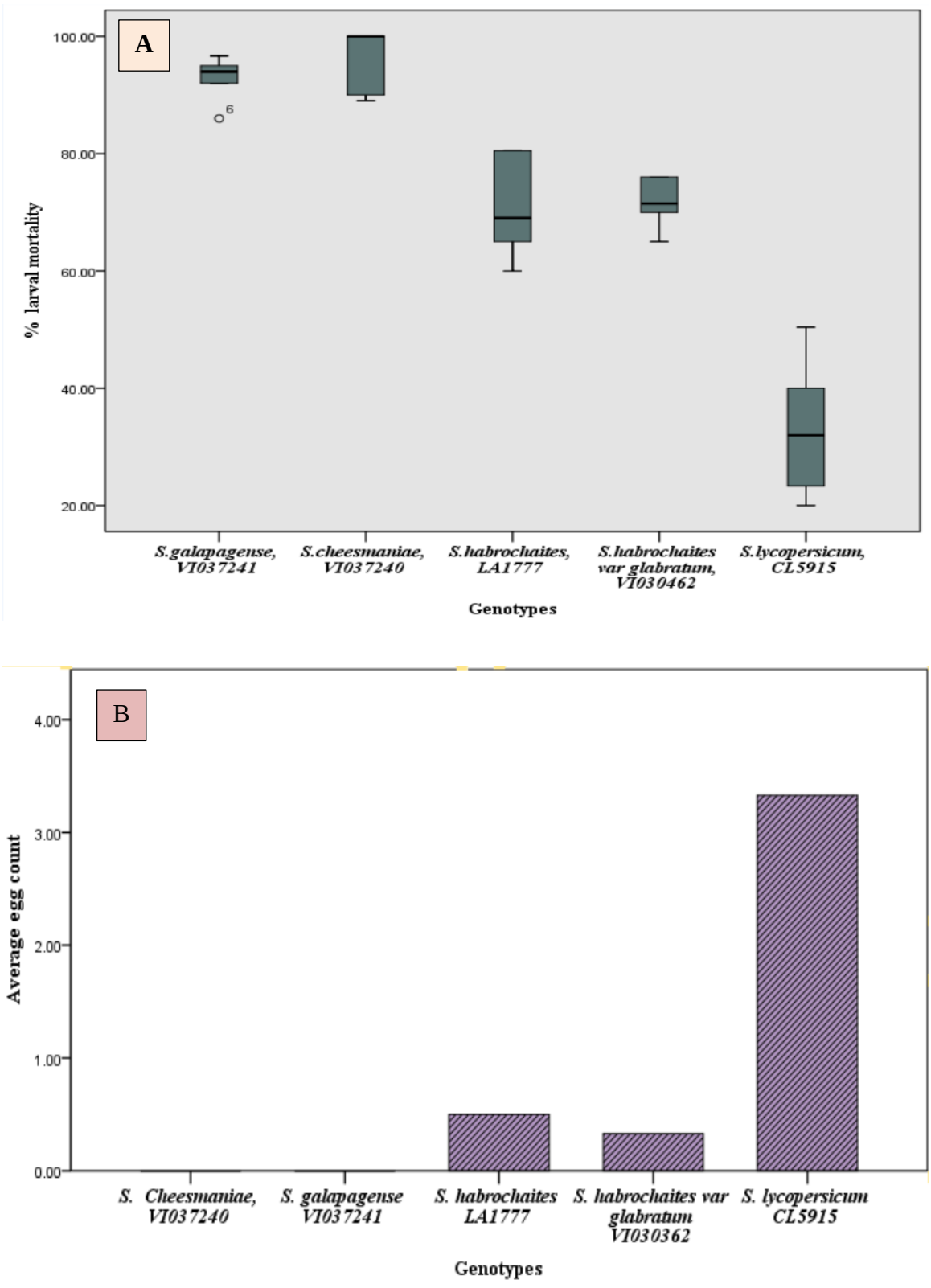


Fig. 3: Bioassay for per cent (A) larval mortality of *Scirtothrips dorsalis* (B) its ovipositional preference on different genotypes

(81.00%). Per cent egg hatch was significantly different among different genotypes (Table 40). Apart from these commercial hybrids, 76.00 per cent of the eggs hatched in the susceptible genotype: *S. lycopersicum* (Cl5915). Incubation period ranged between 4.60-5.30 days and did not differ significantly among genotypes (Table 40).

Tuta absoluta prefered to lay100referredgs on abaxial surface but in resistant genotypes the no. of eggs laid was lesser in abaxial surface as compared to adaxial surface and stalk, however, it was statistically non-significant. These findings are in line with that of Srinivasan and Uthamasamy, (2008) who found that whiteflies preferred to lay more eggs on the abaxial (4.00 to 31.50 per leaf) than on the adaxial leaf surface (1.00 to 24.50 per leaf). But in resistant accession 'COTLCVRH 1' the lowest number of eggs were recorded on the abaxial surface (4.00 eggsper leaf) and 1.00 egg per leaf on the adaxial surface. There was a linear relationship between trichome density and oviposition preference by whitefly (r = 0.91). Trichomes were most dense on 'LE 104' and it was preferred for oviposition with a mean of 42.00 (on adaxial surface) and 45.30 (on abaxial surface) eggs per leaf; a linear relationship was also observed between trichome density and oviposition preference by fruit borer (r = 0.52) in their findings.

The present results are somewhat similar those of Sikka *et al.* (1966), Lokesh and Singh (2005) who found that hair density on the veins in relation to oviposition showed a negative and significant correlation.

Choice assay

In choice assay, egg load was significantly higher in commercial hybrids TM 308, PT 4208 and *S. lycopersicum* (CL5915) as compared to the wild accessions (Table 39).

Per cent egg hatch was significantly different among genotypes (CD=1.16), but the hatching duration did not vary significantly (Table 39). Highest egg load was observed in susceptible genotype *S. lycopersicum* (CL5915), followed by commercial hybrid TM 308 and PT 4208 *i.e.*21.28, 17.25 and 16.44, respectively. Although egg load under laboratory conditions did not vary significantly in case of *S. h. var. glabratum* (VI030462) and succeptible genotype, but it was significantly different in case of *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) and *S. habrochaites* (LA1777).

These findings are in confirmation with that of Rakha *et al.,* (2017b) who reported significantly lesser egg load in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) and *S. habrochaites* (La1777) in their greenhouse studies.

No-choice assay

Impact on larval growth parameters of *T. abosoluta* was carried out by no choice assay. Per cent larval mortality varied significantly among genotypes (CD=3.18). Early second instar larvae were released on the leaves of different genotypes but most of the larvae died in late second instar or third instar stage in *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) *i.e.,* 83.60 and 82.60 per cent larvae died which were fed on the leaves of *S. cheesmaniae* (VI037240) and *S. galapagense* (VI037241). Per cent larval mortality was 40.60 and 46.00 per cent on *S. habrochaites* (LA1777) and *S. habrochaites var. glabratum* (VIO30462), respectively whereas only 15.00 per cent larvae died in case of *S. lycopersicum* (CL 5915). Per cent survival of larvae recorded was 18.40, 15.60, 52.40, 51.60, 83.60 in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var. glabratum* (VIO30462) and *S. lycopersicum* (CL 5915), respectively. Pupal weight differed significantly among all the genotypes tested (CD=0.617). Pupae attained highest weight when fed on susceptible genotype *S. lycopersicum* (CL 5915) followed by other wild accessions. Pupal weight of 2.08<2.44<2.88<3.50<4.56 was recorded in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites var. glabratum* (VIO30462), *S. habrochaites* (LA1777) and *S. lycopersicum* (CL 5915), respectively (Fig. 5). Adult emergence duration did not vary significantly among different genotypes. *S. lycopersicum* (CL 5915), showed susceptibility as the larvae could complete its life cycle and per cent mortality was also significantly lesser compared to that on the four wild accessions tested (Table 41). Adult emergence rate was low in resistant accessions although duration for adult emergence was non-significant among all the genotypes tested. Significantly lesser percentage of the larvae went to pupation on the wild accessions, but more percentage of larvae attained pupation in case of susceptible genotypes

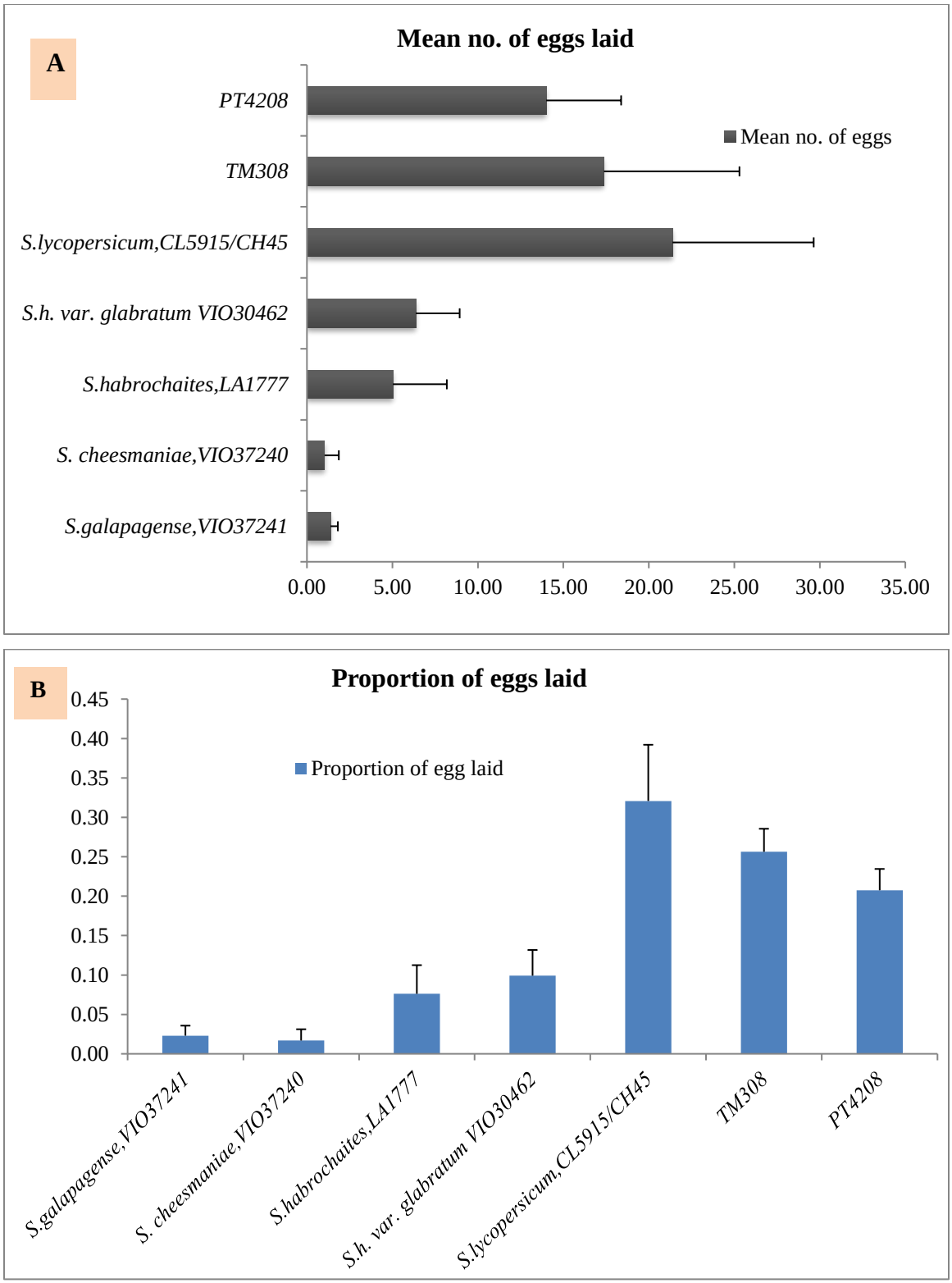


Fig. 4: Ovipositional preference (A) and proportion of eggs laid (B) by *T. absoluta* on different wild accessions/genotypes under laboratory conditions

Table 37: Ovipositional preference of *Scirtothrips dorsalis* on different genotypes/wild accessions under laboratory conditions

Genotypes	Egg laid in choice assay	Per cent larval mortality
S. galapagense,VI037241	0.00(0.70)^{c}	86.67(68.85)^{b}
S. cheesmaniae,VI037240	0.00(0.70)^{c}	96.67(80.66)^{a}
S. habrochaites,LA1777	0.00(0.70)^{c}	68.33(55.99)^{bc}
S. habrochaites var glabratum,VI030462	1.00(1.02)^{b}	76.67(61.46)^{c}
S. lycopersicum CL5915	3.00(1.90)^{a}	26.67(30.89)^{d}
F Test	**	**
SEM	0.02	6.14
CD(0.01)	0.303	10.28

N=10, Values mean of six replications

Figures in the parentheses are √x+1transformed values for eggs; per cent data are arc sign transformed; In a column, means followed by same letters do not differ significantly by DMRT (0.05).

Table 38: Ovipositional preference of *T. absoluta* on different plant parts of different genotypes/wild accessions under laboratory conditions

Mean egg load at three different parts of tomato plants in choice assay					
Accessions	***S. galapagense, VI037241***	***S. cheesmaniae, VI037240***	***S. habrochaites, LA1777***	***S. h. var glabratum, VI030462***	***S. lycopersicum CL 5915/CH45***
Abaxial leaf surface	0.60 (0.98)	0.00(0.70)	8.00 ^{a} (2.73)	11.80 ^{a}(3.37)	13.00 ^{a}(3.56)
Adaxial leaf surface	2.20(1.57)	1.60 (1.31)	9.60 ^{a} (3.09)	6.00 ^{a}(2.49)	8.20 ^{ab}(2.81)
Stalk/Branches	0.40 (0.91)	1.40 (1.22)	4.20 ^{b} (2.02)	0.60 ^{b} (0.93)	5.40 ^{b}(2.28)
F Test	NS	NS	*	*	*
CD	-	-	0.70	1.07	0.78

Figures in the parentheses are √x+1transformed values for eggs; In a column, means followed by similar letters do not differ statistically by DMRT (0.01);

** indicates significance at P<0.001

Table 39: Ovipositional preference of *T. absoluta* on different wild accession/ genotypes under laboratory conditions

Genotypes	Mean no. of egg load/branch
***S. galapagense* VI037241**	1.38 (1.36)^{c} ± 0.07
***S. cheesmaniae* VI037240**	1.04 (1.15)^{c} ± 0.15
***S. habrochaites* LA1777**	4.94 (2.27)^{bc} ± 0.32
***S. habrochaites var glabratum* VI030462**	6.21 (3.95)^{ab} ± 0.26
S. lycopersicum CL 5915/CH45	21.38 (4.29)^{a} ± 0.81
TM 308	17.25 (3.97)^{a} ± 0.77
PT 4208	16.44 (2.28)^{bc} ±0.53
F Test	**
C.D.	1.16
SE(m)	0.39
SE(d)	0.55
C.V.	30.03

**indicates significance at p<0.01 Figures in the parentheses are √x+1transformed values; In a column, means followed by same letters do not differ significantly by DMRT (0.05);

Table 40: Comparison of per cent egg hatch and incubation period (days) of *T. absoluta* on different wild accession/genotypes

Treatment	Incubation period (days)	
Genotypes	**Mean±S.E.**	**Mean±S.E.**
***S. galapagense* VI037241**	67.00 (55.33)^{f} ± 0.74	5.00 (2.44) ±0.11
***S. cheesmaniae* VI037240**	63.00 (52.92)^{e} ± 0.74	5.3 (2.51) ± 0.06
***S. habrochaites* LA1777**	70.20 (56.98)^{d} ±0.21	5.3 (2.51) ± 0.06
***S. habrochaites var glabratum* VI030462**	71.00 (57.40)^{d} ±0.36	5.00 (2.44) ±0.11
S. lycopersicum CL 5915/CH45	76.00 (60.65)^{c} ±1.10	4.60 (2.37) ± 0.07
TM 308	81.00 (64.15)^{b} ±0.39	4.60 (2.37) ±0.13
PT 4208	83.00 (65.93)^{a} ±1.26	5.30 (2.51) ± 0.06
F test	**	NS
C.D.	1.16	-
SE(m)	0.39	-
SE(d)	0.55	-
C.V.	30.03	-

Figures in the parentheses are √x+1transformed values; In a column, means followed by same letters do not differ significantly by DMRT (0.05); *indicates F test is significant at p<0.05,NS=Non-signific

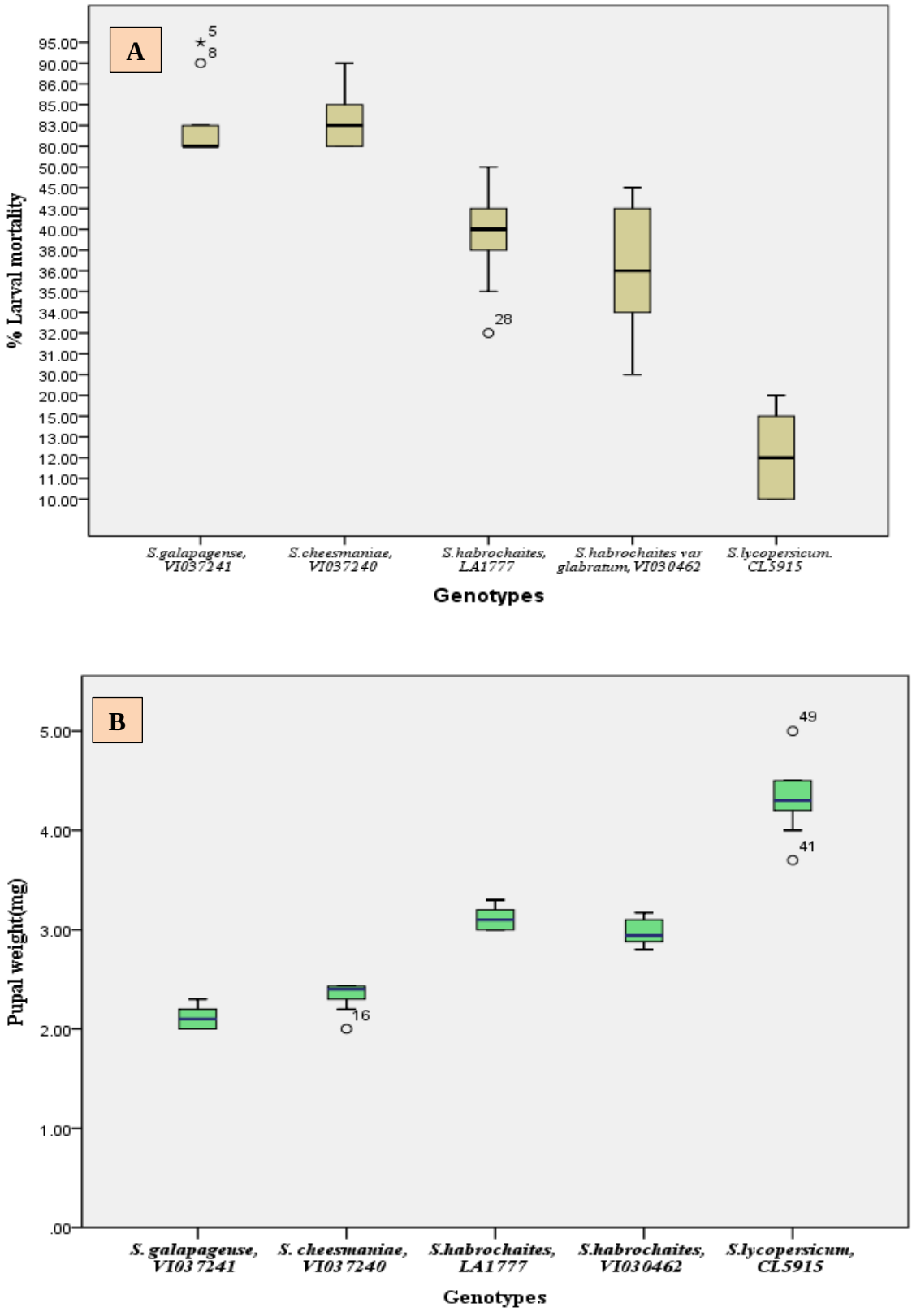


Fig. 5: Assessment of larval mortality (A) and pupal weight (B) in no-choice assay

Table 41: No choice assay on the life cycle parameters of *T. absoluta* on different accessions under laboratory conditions

Genotypes	Larval mortality (%)	% Survival of larvae till pupation	Pupal duration (in days)	Adult emergence (%)	Adult emergence duration (days)	Pupal weight (mg)
*S. galapagense,*VI037241	82.60 (65.42)^{a}	18.40 (25.36)^{c}	11.80^{ab}	14.20 (22.11)^{c}	11.00	2.08^{e}
*S. cheesmaniae,*VI037240	83.60 (66.29)^{a}	15.60 (23.15)^{c}	12.40^{bc}	14.20(22.09)^{c}	11.00	2.44^{d}
S. habrochaites, LA1777	40.60(39.56)^{b}	52.40 (46.35)^{b}	12.00^{bc}	48.00 (43.82)^{b}	10.50	3.50^{b}
S. habrochaites var glabratum VI030462	46.00 (42.68)^{b}	51.60 (45.89)^{b}	12.00^{c}	44.60 (41.88)^{b}	10.00	2.88^{c}
*S. lycopersicum,*CL5915/CH45	15.00 (22.68)^{c}	83.60 (66.203)^{a}	11.00^{a}	76.00 (60.66)^{a}	10.00	4.56^{a}
F test	**	**	**	**	NS	**
SE(m)	1.05	0.878	0.1	0.716	-	0.208
SE(d)	1.49	1.241	0.141	1.012	-	0.294
C.D.	3.18	2.60	0.297	2.126	-	0.61
C.V.	4.97	4.74	1.889	4.198	3.50	16.56

Mean of five replications.** indicates F test is significant at p<0.05

Figures in the parentheses are arc sign transformed value; In a column, Ieans followed by same letters do not differ significantly by DMRT (0.05); NS indicates non-significant

These results are in accordance with the findings of Rakha *et al.*, (2017b), where they reported higher per cent larval mortality caused in no-choice assay when the *T. absoluta* larvae which were subjected to feed on wild accessions. The present findings can also be supported by similar reports in case of resistance evaluation of *T. urticae* and *B. tabaci* by Rakha *et al.* (2017a) from greenhouse studies.

4.2 Morphological basis imparting resistance

4.2.1 Plant height

Plant height differed significantly among different genotypes at 45 DAT (CD=5.93) and 90 DAT (CD=20.24). Plant heights were significantly highest in TM 308 (72.25) at 45 DAT but *S. habrochaites var glabratum* VI030462 attained highest plant height at 90 DAT (Table 42).

4.2.2 Leaf numbers, branch and leaf angle

Number of leaves/plant varied significantly among genotypes at 45 (CD = 4.396) and 90 DAT (CD=9.124), respectively (Table 42). Total no. of leaves were significantly highest (694.75/plant) in *S. galapagense* (VI037241) at 45 DAT whereas in *S. cheesmaniae* (VI037240 recorded highest leaf number per plant at 90 DAT (739.33/plant), while *S. lycopersicum* (CL5915/CH45) recorded the lowest leaf no. (154.50 and 180/plant) both at 45 and 90 DAT, respectively. (Table 43).

4.2.3 Branch and leaf angle

The branch and leaf angle were measured and found to be significantly different in different genotypes (CD=3.043) and (CD=1.804), respectively. Branch angle was 61.25, 60.00, 50.00, 80.50, 80.00, 75.00, 92.50 for *S. lycopersicum* (CL5915/CH45), *S. galapagense* (VI037241), in *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), TM 308 and PT 4208, respectively. Leaf angle was 65.00, 80.00, 70.00, 90.00, 90.25, 85.75 and 87.25 for *S. lycopersicum* (CL5915/CH45), *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), TM 308 and *PT* 4208, respectively (Table 44).

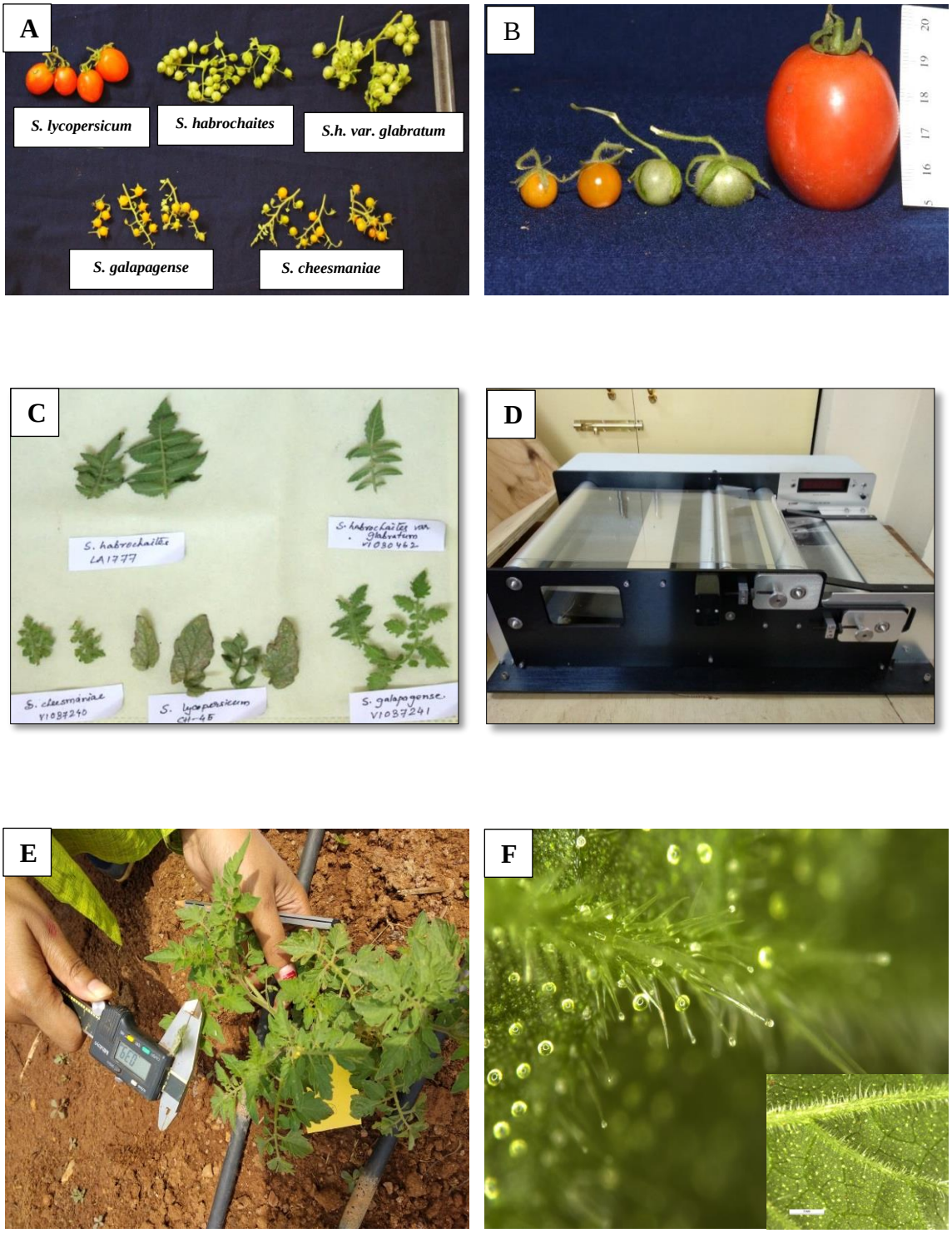


Plate 6: (A-B) Fruit size of different genotypes, (C-D) Leaf area measurement with digital leaf area meter (E) Measuring leaf thickness with digital vernier caliper (F) Dense glandular trichomes on leaf surface of resistant wild accession

4.2.4 Stem and leaf thickness (mm)

Stem thickness was highest (10.88 and 10.98 mm) in *S. lycopersicum* (CL5915/CH45) at 45 and 90 DAT (Table 45) and it differed significantly among different genotypes at 45 DAT (CD=1.00) and 95 DAT (CD=1.017). Lowest stem thickness (4.18 and 4.20 mm) was recorded in *S. habrochaites var glabratum* (VI030462) at 45 and 90 DAT respectively. Leaf thickness was significantly higher in susceptible accessions and lower in wild accessions and it differed significantly at different canopy levels (Table 46). In susceptible genotype and commercial hybrids the leaf thickness was more as compared to resistant wild accessions. Lower canopy leaves were thicker as compared to middle and upper leaves (Table 46).

4.2.5 Leaf area (cm^2)

Leaf area was significantly higher in susceptible genotypes i.e TM 308, PT4208 and *S. lycopersicum* (CL5915/CH45) than in resistant *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) but not in *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462). Mean leaf area was significantly lesser for *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240). Mean leaf area by pooling of three canopy leaves were 1.68,1.30,12.68.10.87,11.39,17.79,12.81 in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), *S. lycopersicum* (CL5915/CH45), TM308 and PT 4208, respectively (Table 47).

4.2.6 Fruit diameter and rind thickness

Fruit size of commercial varieties and *S. lycopersicum* (CL5915) was significantly higher than that recorded in wild accessions and it differed significantly among genotypes (CD=0.725). Fruit diameter and rind thickness recorded for *S. lycopersicum* (CL5915/CH45), *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), TM 308 and PT4208 were 4.82,1.32, 1.70,1.05, 1.70, 8.57, 7.87 cm and 5.05, 1.13, 1.14, 0.65,1.97,5.12,5.22 mm, respectively (Table 48).

Table 42: Comparative plant heights of different genotypes

Mean plant height(cm)		
45 DAT		**90 DAT**
Treatment	**Mean ± S.E**	**Mean ± S.E**
***S. lycopersicum* CL5915/CH45**	$27.75^{d} \pm 1.03$	$56.50^{d} \pm 1.32$
***S. galapagense* VI037241**	$26.25^{de} \pm 0.96$	$72.25^{cd} \pm 1.43$
***S. cheesmaniae* VI037240**	$20.50^{e} \pm 1.75$	$59.00^{d} \pm 1.58$
***S. habrochaites* LA1777**	$36.25^{c} \pm 1.31$	$141.25^{b} \pm 2.05$
***S. habrochaites var glabratum* VI030462**	$35.50^{c} \pm 0.86$	$182.50^{a} \pm 16.52$
TM 308	$72.25^{a} \pm 3.63$	$91.25^{c} \pm 3.54$
PT 4208	$65.75^{b} \pm 2.49$	$85.25^{c} \pm 5.57$
F Test	**	**
SE(m)	1.98	6.76
SE(d)	2.80	9.56
C.D.	5.93	20.24
C.V.	9.76	13.76

DAT=Days after transplanting, .** indicates F test is significant at $p<0.05$

Table 43: Comparative number of leaves/plant among different genotypes

Mean total number of leaves/plant		
45 DAT		**90 DAT**
	Mean± S.E	**Mean± S.E**
***S. lycopersicum* CL5915/CH45**	$154.50^{g} \pm 1.50$	$180.00^{g} \pm 1.5$
***S. galapagense* VI037241**	$694.75^{a} \pm 1.75$	$724.00^{b} \pm 2.00$
***S. cheesmaniae* VI037240**	$649.25^{b} \pm 0.25$	$739.33^{a} \pm 4.66$
***S. habrochaites* LA1777**	$263.00^{d} \pm 1.00$	$285.66^{d} \pm 0.33$
***S. habrochaites var glabratum* VI030462**	$304.50^{c} \pm 1.50$	$375.00^{c} \pm 5.00$
TM 308	$242.50^{e} \pm 2.50$	$240.00^{e} \pm 0.50$
PT 4208	$196.00^{f} \pm 1.50$	$202.00^{f} \pm 1.00$
F Test	**	**
SE(m)	1.46	2.92
SE(d)	2.07	4.14
C.D.	4.39	9.14
C.V.	0.821	1.293

Table 44: Comparative leaf and branch angles between different genotypes (pooled mean of summer 2018-19)

Plant anatomical parameters		
Branch angle (°)		**Leaf angle(°)**
Treatment	**Mean± S.E**	**Mean± S.E**
S. lycopersicum CL5915/CH45	61.25^{d}±1.25	65.00^{e}±2.10
S. galapagense VI037241	60.00^{d}±2.20	80.00^{c}±2.20
S. cheesmaniae VI037240	50.00^{e}±1.30	70.00^{d}±0.50
S. habrochaites LA1777	80.50^{b}±0.50	90.00^{a}±2.30
S. habrochaites var glabratum VI030462	80.00^{b}±0.40	90.25^{a}±0.25
TM 308	75.00^{c}±1.50	85.75^{b}±0.75
PT 4208	92.50^{a}±2.50	87.25^{b}±1.43
F Test	**	**
SE(m)	1.016	0.603
SE(d)	1.437	0.852
C.D.	3.043	1.804
C.V.	2.850	1.485

Table 45: Comparative stem thickness (mm) of different genotypes (pooled mean of summer 2018-19)

Stem thickness (mm)		
45 DAT		**90 DAT**
Genotypes	**Mean± S.E**	**Mean± S.E.**
***S. lycopersicum* CL5915/CH45**	10.88^{a} ± 0.25	10.98^{a} ± 0.27
***S. galapagense* VI037241**	6.15^{d} ± 0.33	6.15^{c} ± 0.33
***S. cheesmaniae* VI037240**	6.97^{cd} ± 0.48	6.60^{b} ± 0.59
***S. habrochaites* LA1777**	7.60^{c} ± 0.58	8.10^{a} ± 0.50
***S. habrochaites var glabratum* VI030462**	4.18^{e} ± 0.01	4.20^{d} ± 0.17
TM 308	10.38^{ab} ± 0.06	10.45^{a} ± 0.18
PT 4208	9.83^{a} ±0.44	10.23^{a} ± 0.43
F Test	**	**
SE(m)	0.33	0.34
SE(d)	0.47	0.48
C.D.	1.00	1.01
C.V.	8.34	8.390

DAT=Days after transplanting,** indicates F test is significant at $p<0.05$

Table 46: Comparative leaf thickness (mm) of different genotypes at different canopy levels (Pooled mean of summer 2018-19)

Leaf thickness (mm) at different canopy levels								
Genotypes	**45DAT**				**90DAT**			
	U	**M**	**L**	**Mean**	**U**	**M**	**L**	**Mean**
***S. lycopersicum* CL5915/CH45**	0.29	0.31	0.59	**0.40**	0.41	0.53	0.63	**0.52**
***S. galapagense* VI037241**	0.22	0.26	0.31	**0.26**	0.18	0.24	0.37	**0.26**
***S. cheesmaniae* VI037240**	0.17	0.22	0.33	**0.24**	0.20	0.27	0.40	**0.29**
***S. habrochaites* LA1777**	0.27	0.42	0.62	**0.44**	0.22	0.26	0.31	**0.26**
***S. habrochaites var glabratum* VI030462**	0.16	0.22	0.31	**0.23**	0.22	0.20	0.31	**0.24**
TM 308	0.30	0.36	0.35	**0.34**	0.31	0.40	0.60	**0.44**
PT 4208	0.24	0.36	0.52	**0.37**	0.34	0.46	0.52	**0.44**

Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	0.003	0.004	0.010	**	0.002	0.003	0.007
Canopy	**	0.002	0.003	0.006	**	0.001	0.002	0.004
Genotypes x Canopy	**	0.005	0.007	0.015	**	0.004	0.006	0.011

U=Upper, M=Middle, L=Lower

DAT=Days after transplanting, .** indicates F test is significant at p<0.05

Table 47: Comparative leaf area (cm^2) of different genotypes (pooled mean from three canopy levels)

Genotypes	Mean±S.E
***S. lycopersicum* CL5915/CH45**	$11.39^{c} \pm 0.61$
***S. galapagense* VI037241**	$1.68^{d} \pm 0.06$
***S. cheesmaniae* VI037240**	$1.30^{d} \pm 0.01$
***S. habrochaites* LA1777**	$12.68^{b} \pm 0.85$
***S. habrochaites var glabratum* VI030462**	$10.87^{c} \pm 0.70$
TM 308	$17.79^{a} \pm 0.35$
PT 4208	$12.81^{b} \pm 0.60$
F test	**
SE(m)	0.33
SE(d)	0.47
C.D.	1.05
C.V.	5.96

.** indicates F test is significant at p<0.05

Table 48: Comparison between fruit diameter and rind thickness of different genotypes (pooled mean of summer 2018-19)

Fruit rind size(mm)		Fruit diameter(cm)
Treatment	**Mean± S.E.**	**Mean± S.E.**
***S. lycopersicum* CL5915/CH45**	$5.05^{a} \pm 0.02$	$4.82^{b} \pm 0.26$
***S. galapagense* VI037241**	$1.13^{c} \pm 0.05$	$1.32^{c} \pm 0.22$
***S. cheesmaniae* VI037240**	$1.14^{c} \pm 0.04$	$1.70^{c} \pm 0.05$
***S. habrochaites* LA1777**	$0.65^{c} \pm 0.06$	$1.05^{c} \pm 0.08$
***S. habrochaites var glabratum* VI030462**	$1.97^{b} \pm 0.02$	$1.70^{c} \pm 0.05$
TM 308	$5.12^{a} \pm 0.42$	$8.37^{a} \pm 0.23$
PT 4208	$5.22^{a} \pm 0.34$	$7.87^{a} \pm 0.42$
F Test	**	**
SE(m)	0.20	0.24
SE(d)	0.29	0.34
C.D.	0.61	0.72
C.V.	14.12	12.63

#N=10 #NB: Mean value of four replications

, .** indicates F test is significant at p<0.05

4.2.7 Trichome type and density

Trichome type and densities play an important role in conferring herbivore resistance. Trichome type in abaxial and adaxial leaf surface was observed under scanning electron microscope (Table 49, 50). Trichome density/mm^2 was further assessed with ImageJ software and total numbers of different types were significantly different among accessions. Trichome count differed at different canopy level leaves (Table 51). Higher number of glandular trichomes/mm^2 has been recorded from wild accessions whereas very less number of total glandular trichomes was found in *S. lycopersicum* (CL 5915) (Table 53). Total number of non-glandular type of trichomes varied significantly among different genotypes (Table 52) and was significantly highest in *S. lycopersicum* (CL5915). Glandular trichomes varied significantly among genotypes at different canopies (Table 52). Trichome density was significantly higher in upper and middle canopy than in the lower canopy (Table 54).

In these findings, resistant wild accessions possess significantly higher glandular trichome density trichomes than the susceptible genotypes. These findings are in line with Darbain *et al.* (2016) who reported that glandular trichome length and density showed significant negative correlation with *T. absoluta* infestation and length of normal trichomes also showed significant negative correlation with pest infestation. They suggested density of glandular trichomes might play an important role in tomato cultivars susceptibilities which are in accordance with our present findings. The present findings are almost in agreement with that of Seetharam and Ravikumar (2003), who reported that smooth (soft) leaves of sunflower were associated with susceptibility to sucking pests.

Higher glandular trichome density and especially presence of type I and type IV trichomes confers resistance against *T. absoluta* and thrips in the present investigation. These findings can be supported by earlier findings where they suggested all insect resistant accessions possess glandular trichomes type I and IV on their leaves, the vast majority of them being type IV, strongly suggesting that these trichomes are essential for plant resistance to insects (Firdaus *et al.* 2012; Lucatti *et al.* 2013, Gurr and Mcgranth 2001).

Table 49: Mean trichome density (No. /mm^2) on abaxial leaf surface of different genotypes at different canopy levels (Pooled mean of summer 2018-19).

Trichome Count/mm^2 (abaxial surface)								
Trichome types								
	I	**II**	**III**	**IV**	**V**	**VI**		**VII**
Upper canopy						**VI-C/1 lobed**	**VI-A/4 lobed**	
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	18.00	0.00	3.00	0.00
S. galapagense VI037241	4.50	0.00	5.00	27.00	0.00	0.00	5.00	0.00
S. cheesmaniae VI037240	3.00	0.00	6.00	32.00	0.00	0.00	4.00	0.00
S. habrochaites LA1777	6.00	0.00	8.00	10.00	14.00	24.00	0.00	2.00
S. habrochaites var glabratum VI030462	0.00	0.00	15.00	3.00	18.00	13.00	0.00	1.00
Middle canopy								
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	18.00	0.00	3.00	0.00
S. galapagense VI037241	3.50	0.00	5.00	22.00	0.00	0.00	2.00	0.00
S. cheesmaniae VI037240	2.00	0.00	5.00	28.00	0.00	0.00	4.00	0.00
S. habrochaites LA1777	4.00	0.00	8.00	5.00	15.00	16.00	0.00	1.20
S. habrochaites var glabratum VI030462	0.00	0.00	13.00	3.00	18.00	11.00	0.00	1.00
Lower canopy								
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	18.00	0.00	3.00	0.00
S. galapagense VI037241	3.00	0.00	3.00	12.00	0.00	0.00	2.00	0.00
S. cheesmaniae VI037240	1.00	0.00	5.00	20.00	0.00	0.00	2.00	0.00
S. habrochaites LA1777	6.00	0.00	8.00	4.00	5.00	14.00	0.00	0.00
S. habrochaites var glabratum VI030462	0.00	0.00	10.00	3.00	11.00	8.00	0.00	0.00

Table 50: Mean trichome density (No./mm^2) on adaxial leaf surface of different genotypes at different canopy levels. (Pooled mean of summer 2018-19)

Trichome No./mm2 (adaxial surface)								
Trichome types								
	I	**II**	**III**	**IV**	**V**	**VI**		**VII**
Upper canopy						**VI-C/1 lobed**	**VI-A/4 lobed**	
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	22.00	0.00	2.00	0.00
S. galapagense VI037241	0.00	0.00	0.00	13.00	0.00	0.00	0.00	0.00
S. cheesmaniae VI037240	2.00	0.00	0.00	18.00	0.00	0.00	0.00	0.00
S. habrochaites LA1777	1.00	0.00	7.00	4.00	0.00	8.00	0.00	2.00
S. habrochaites var glabratum VI030462	0.00	0.00	13.00	2.00	13.00	11.00	0.00	1.00
Middle canopy								
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	22.00	0.00	2.00	0.00
S. galapagense VI037241	0.00	0.00	0.00	12.00	3.50	0.00	0.00	0.00
S. cheesmaniae VI037240	1.00	0.00	0.00	14.00	2.00	0.00	0.00	0.00
S. habrochaites LA1777	1.00	0.00	8.00	3.00	10.50	6.00	0.00	2.00
S. habrochaites var glabratum VI030462	0.00	0.00	13.00	2.00	13.00	7.00	0.00	1.00
Lower canopy								
S. lycopersicum CL5915/CH45	0.00	0.00	0.00	0.00	6.00	0.00	2.00	0.00
S. galapagense VI037241	0.00	0.00	0.00	10.00	3.00	0.00	0.00	0.00
S. cheesmaniae VI037240	1.00	0.00	0.00	11.00	2.00	0.00	0.00	0.00
S. habrochaites LA1777	1.00	0.00	4.00	3.20	12.00	5.00	0.00	2.00
S. habrochaites var glabratum VI030462	0.00	0.00	11.00	2.00	11.00	5.00	0.00	1.00

Table 51: Comparative density of total non-glandular trichomes of different genotypes at different canopy levels

Mean trichome density (No./mm^2)				
	Upper	**Middle**	**Lower**	**Mean**
***S. lycopersicum* CL5915/CH45**	11.66	14.83	3.33	9.94[a]
***S. galapagense* VI037241**	3.00	2.00	3.00	2.66[d]
***S. cheesmaniae* VI037240**	3.00	2.00	3.00	2.66[d]
***S. habrochaites* LA1777**	2.00	2.00	6.00	3.33[c]
***S. habrochaites var glabratum* VI030462**	7.00	8.00	5.00	6.66[b]
Mean	5.33	5.76	4.06	

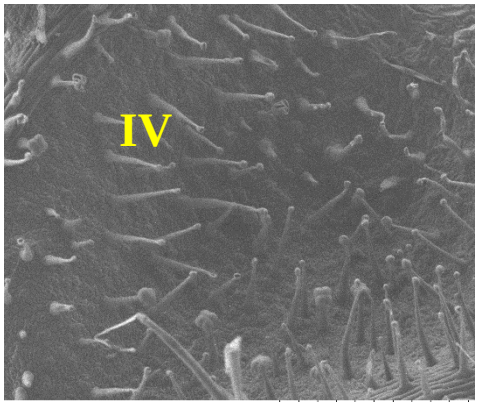
F Test	******		
Factors	0.224	**SE(m)**	**C.D.**
Genotypes	0.173	0.077	0.224
Canopy	0.388	0.060	0.173
Genotypes X Canopy	**C.D.**	0.133	0.388

** indicates F test is significant at $p<0.05$

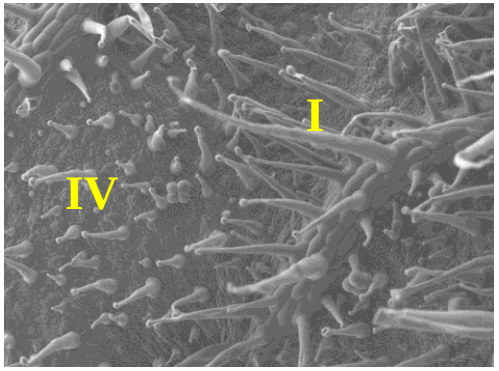
Table 52: Comparative density of total non-glandular trichomes in different genotypes

			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	***S. lycopersicum* CL5915/CH45**	***S. galapagense* VI037241**	7.2778*	1.16849	.001	3.9323	10.6232
		***S. cheesmaniae* VI037240**	7.6111*	1.16849	.001	4.2657	10.9566
		***S. habrochaites* LA1777**	6.6111*	1.16849	.001	3.2657	9.9566
		***S. habrochaites var glabratum* VI030462**	3.2778	1.16849	.057	-.0677	6.6232
	***S. galapagense* VI037241**	***S. lycopersicum* CL5915/CH45**	-7.2778*	1.16849	.001	-10.6232	-3.9323
		***S. cheesmaniae* VI037240**	.3333	1.16849	.998	-3.0121	3.6788
		***S. habrochaites* LA1777**	-.6667	1.16849	.979	-4.0121	2.6788
		***S. habrochaites var glabratum* VI030462**	-4.0000*	1.16849	.012	-7.3455	-.6545
	***S. cheesmaniae* VI037240**	***S. lycopersicum* CL5915/CH45**	-7.6111*	1.16849	.001	-10.9566	-4.2657
		***S. galapagense* VI037241**	-.3333	1.16849	.998	-3.6788	3.0121
		***S. habrochaites* LA1777**	-1.0000	1.16849	.911	-4.3455	2.3455
		***S. habrochaites var glabratum* VI030462**	-4.3333*	1.16849	.006	-7.6788	-.9879
	***S. habrochaites* LA1777**	***S. lycopersicum* CL5915/CH45**	-6.6111*	1.16849	.000	-9.9566	-3.2657
		***S. galapagense* VI037241**	.6667	1.16849	.979	-2.6788	4.0121
		***S. cheesmaniae* VI037240**	1.0000	1.16849	.911	-2.3455	4.3455
		***S. habrochaites var glabratum* VI030462**	-3.3333	1.16849	.051	-6.6788	.0121
	***S. habrochaites var glabratum* VI030462**	***S. lycopersicum* CL5915/CH45**	-3.2778	1.16849	.057	-6.6232	.0677
		***S. galapagense* VI037241**	4.0000*	1.16849	.012	.6545	7.3455
		***S. cheesmaniae* VI037240**	4.3333*	1.16849	.006	.9879	7.6788
		***S. habrochaites* LA1777**	3.3333	1.16849	.051	-.0121	6.6788

Based on observed means. The error term is Mean Square (Error) = 6.144. *. The mean difference is significant at the 0.01 level

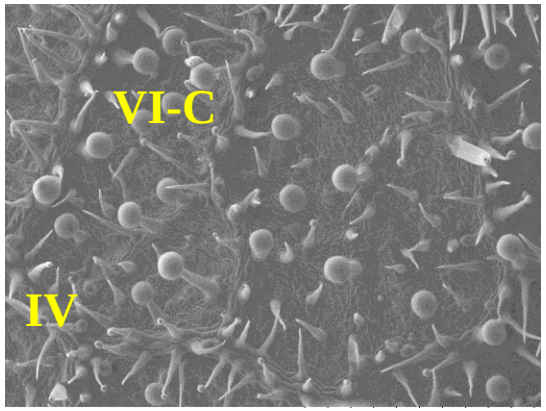


S. galapagense, VI037241

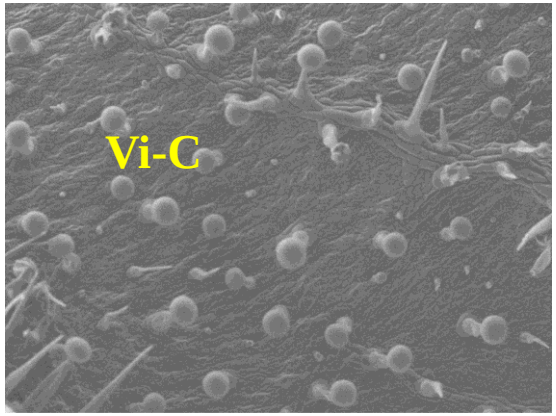


S. cheesmaniae, VI037240

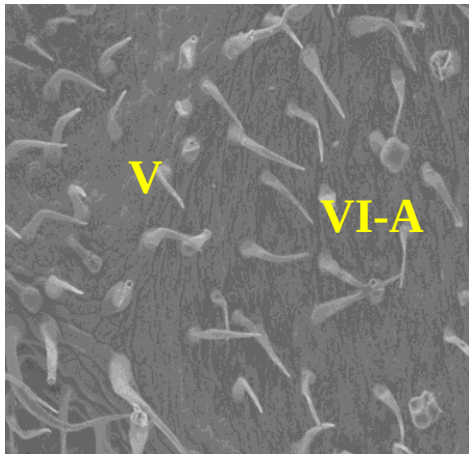
1 mm



S. habrochaites, LA1777



S. habrochaites var. glabratum,



S. lycopersicum, CL5915/CH45

1 mm

Plate 7: Density of trichomes/mm^2 in different genotypes observed under scanning electron microscope

Table 53: Comparative density of mean glandular trichomes at different canopy levels of different genotypes

Mean total glandular trichome density (No./mm^2)				
	Upper	**Middle**	**Lower**	**Mean**
***S. lycopersicum* CL5915/CH45**	5.00	3.50	2.00	3.50^{e}
***S. galapagense* VI037241**	44.00	36.00	29.00	36.33^{b}
***S. cheesmaniae* VI037240**	46.00	38.00	29.00	37.00^{a}
***S. habrochaites* LA1777**	18.00	22.00	22.00	20.67^{c}
***S. habrochaites var glabratum* VI030462**	21.00	18.00	15.00	18.00^{d}
Mean	26.40	23.50	19.40	

Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	******	**0.108**	**0.153**	**0.315**
Canopy	******	**0.084**	**0.119**	**0.244**
Genotypes X Canopy	******	**0.188**	**0.265**	**0.546**

** indicates F test is significant at $p<0.05$

Table 54: Comparative density of total glandular trichomes in different genotypes

	(I) Genotype	(J) Genotype	Mean Difference (I-J)	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Tukey HSD	***S. lycopersicum* CL5915/CH45**	***S. galapagense* VI037241**	-32.9278*	.001	-37.3498	-28.5058
		***S. cheesmaniae* VI037240**	-33.4833*	.001	-37.9054	-29.0613
		***S. habrochaites* LA1777**	-17.0389*	.001	-21.4609	-12.6169
		***S. habrochaites var glabratum* VI030462**	-14.2611*	.001	-18.6831	-9.8391
	***S. galapagense* VI037241**	***S. lycopersicum* CL5915/CH45**	32.9278*	.001	28.5058	37.3498
		***S. cheesmaniae* VI037240**	-.5556	.996	-4.9776	3.8665
		***S. habrochaites* LA1777**	15.8889*	.001	11.4669	20.3109
		***S. habrochaites var glabratum* VI030462**	18.6667*	.001	14.2446	23.0887
	***S. cheesmaniae* VI037240**	***S. lycopersicum* CL5915/CH45**	33.4833*	.001	29.0613	37.9054
		***S. galapagense* VI037241**	.5556	.996	-3.8665	4.9776
		***S. habrochaites* LA1777**	16.4444*	.001	12.0224	20.8665
		***S. habrochaites var glabratum* VI030462**	19.2222*	.001	14.8002	23.6442
	***S. habrochaites* LA1777**	***S. lycopersicum* CL5915/CH45**	17.0389*	.001	12.6169	21.4609
		***S. galapagense* VI037241**	-15.8889*	.001	-20.3109	-11.4669
		***S. cheesmaniae* VI037240**	-16.4444*	.001	-20.8665	-12.0224
		***S. habrochaites var glabratum* VI030462**	2.7778	.389	-1.6442	7.1998
	***S. habrochaites var glabratum* VI030462**	***S. lycopersicum* CL5915/CH45**	14.2611*	.001	9.8391	18.6831
		***S. galapagense* VI037241**	-18.6667*	.001	-23.0887	-14.2446
		***S. cheesmaniae* VI037240**	-19.2222*	.001	-23.6442	-14.8002
		***S. habrochaites* LA1777**	-2.777	.389	-7.1998	1.6442

#NB:*Indicates significance level at p<0.001

The findings of Seetharam and Ravikumar (2003) wherein hairiness (trichomes) are linked to resistance to sucking pests in sunflower are agreeable with the present findings. A similar trend was observed by Parnell *et al*., (1949) wherein, the trichome length and their angles of insertion contributed towards leafhopper resistance in cotton. Further, Ramey (1962) observed that dense pubescence confers resistance to thrips in cotton, similarly in case of Cassava (Schoonhoven, 1974). The multivariate analysis pertaining to thrips vector, SND and trichome length showed that the mean of all the above variables are significantly different from each other (P=0.01). The present study can be compared with that of Gaikwad *et al.* (1991) who reported the different morpho-physical plant characters and their correlation in the leaves of brinjal. The present findings can be compared with that of Lit and Bernardo (1990) who reported significant and negative linear correlation among hair length, number of primary branches, and density of leaf hairs and causes larval liking and reduced adult oviposition on the brinjal plants.

4.3 Biochemical basis of resistance

4.3.1 Chlorophyll content

Total chlorophyll content of the leaves varied significantly among genotypes. A range of 1.21-1.91 mg/g chlorophyll content was recorded at 45 DAT and 0.83-1.92 mg/gwas recoreded at 90 DAT (Table 55). Significantly higher chlorophyll content was recorded from the wild accessions which showed resistance against *T. absoluta* and thrips.

4.3.2 Amino acid content

Amino acid content was significantly higher in resistant accessions than in the susceptible genotypes (Table 56). The range varied from 5.40-6.56 mg/g in susceptible genotype *S. lycopersicum* (CL5915) and commercial varieties TM 308 AND PT4208. In resistant genotypes the amino acid content varied from 1.31-2.37 mg/g. Amino acid content showed high positive correlation with the susceptibility at 45 and 90 DAT, respectively (r=0.97 and r=0.99). The results are in conformity with that of Anantharaju and Muthiah (2008) who reported a significant positive association between spotted pod

borer infestation in pigeonpea and total amino acids. These findings are also in close agreements with the reports of Kumar *et al.* (2015) and Kandakoor *et al.* (2013) in tomato and groundnut respectively.

4.3.3 Total soluble protein and phenol content

In commercial hybrid and susceptible genotypes the total soluble protein was found to be significantly lesser than in the wild accessions.Total soluble protein in *S. cheesmaniae* (VI037240), *S. galapagense* (VI037241), *S. habrochaites var glabratum* (VI030462), *S. habrochaites* (LA1777), *S. lycopersicum (CL 5915)* TM 308 and PT 4208 was 12.77>12.41>12.56>12.37>11.37>11.25>10.5, respectively (Table 57).

Phenol content was significantly higher in leaves of *S. habrochaites var glabratum* (VI030462) with a mean value of 0.60 mg/g followed by *S. habrochaites* (LA1777), *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) and *S. lycopersicum* (CL 5915/CH45) (Table 58). Higher phenol content was having significant negative correlation with the insect foliar damage (Table 71). The present results are in confirmation with the findings of Singh *et al.* (1990) who reported significant negative correlation between total phenol content and pod damage by *A. catalaunalis* in sesame. The present findings are also in close agreement with that of Vijaykumar *et al*. (2009 and 2012) who reported higher amount of total phenols in gall midge resistant rice genotypes as compared to that in the susceptible ones. Similar results were also reported by Anantharaju and Muthiah (2008) who reported as negative association between spotted pod borer incidence and phenol content in pigeon pea. In majority of plants, phenols acts as prime biochemical factor for resistance due to their anti-feedant as well as antibiosis property on insect growth and reproduction. Higher phenolic content was associated with lower damage by *Scirtothrips dorsalis* in chilli (Manoj, 1994). BPH resistant rice varieties had higher content of phenols in comparison to the susceptible ones (Peraiah *et al*., 1982). Chhabra *et al*. (1993) reported higher content of total phenols in blackgram genotypes, showing resistance to whitefly and leafhoppers. Kotireddy (1971) reported that rice cultivars resistant to *Pyricularia oryzae* Cav. contained more total phenols than the susceptible variety.

Table 55: Pooled mean chlorophyll content of leaves of different genotypes at 45 and 90 DAT

Genotypes	Chlorophyll content (mg/g)	
	45 DAT	90 DAT
S. galapagense,VI037241	1.86[b]	1.87[b]
S. cheesmaniae,VI037240	1.91[a]	1.92[a]
S. habrochaites,LA1777	1.76[c]	1.71[c]
S. habrochaites var glabratum,VI030462	1.71[d]	1.63[d]
S. lycopersicum CH45	1.63[e]	0.83[g]
TM 308	1.21[g]	0.91[f]
PT4208	1.30[f]	1.02[e]
F Test	**	**
SE m±	0.015	0.013
CD @ 5%	0.049	0.05
CD @ 1%	0.06	0.03

#NB: Mean of four replications. .** indicates F test is significant.

Table 56: Pooled mean amino acid content of leaves of different genotypes at 45 and 90 DAT

Genotypes	Free amino acid mg/g	
	45DAS	90DAS
S. galapagense,VI037241	2.37[c]	1.87[b]
S. cheesmaniae,VI037240	1.28[d]	1.26[b]
S. habrochaites,LA1777	1.47[d]	1.46[b]
S. habrochaites var glabratum,VI030462	1.34[d]	1.31[b]
S. lycopersicum CH45	5.42[b]	5.40[a]
TM 308	5.70[b]	5.41[a]
PT4208	6.56[a]	6.02[a]
F Test	**	**
SE m±	0.14	0.25
CD @ 5%	0.38	0.87
CD @ 1%	0.53	1.03

Values with different alphabets differ significantly.

At Coimbatore, restorer lines RHA587 and RHA3376 were free from necrosis disease and both the entries i.e., RHA587 (57.9, 140.2 and 228mg/100g) and RHA3376 (68.1, 120.1, 192.4 mg /100g) recorded higher total phenol content at vegetative, flowering and maturity stages, respectively (Anon., 2007-08).

4.3.4 Tannin content and Sugar content

Tannin content of leaf samples varied between 4.15-5.50 µg/g and 2.85-2.85 µg/g at 45 DAT and 90 DAT, respectively (Table 59). Tannin content in fruits ranged between 10.5-14.5 µg/g. Tannin content in leaves of *S. cheesmaniae* (VI037240) and *S. galapagense* (VI037241) did not vary significantly in the susceptible genotype *S. lycopersicum* (CL5915) at 45 DAT and 95 DAT, whereas it significantly differed in case of TM308 and PT4208 at 45 DAT and only with PT4208 during 90 DAT (Table 60).

Tannin content was found to be significantly higher in fruits of *S. habrochaites* (LA1777), followed by *S. habrochaites var glabratum* (VI030462) *i.e.* 14.50 and 11.75 µg/g, respectively. Tannin content in fruits were recorded to be lowest in the commercial hybrid PT 4208 *i.e.* 9.35 µg/g, whereas comparatively higher tannin content was found in the resistant wild accessions than in the commercial hybrids and susceptible genotype *S. lycopersicum* (CL 5915).

Total sugar level ranged from 35.00-66.25 mg/g at 45 DAT and 20.00-75.00 mg/g at 90 DAT (Table 60). Total sugar level was recorded to be significantly highest in TM 308 (66.25 mg/g), followed by PT 4208 (60.25 mg/g) and *S. lycopersicum* (56.50 mg/g) during 45 DAT whereas it was found to be significantly highest in *S. lycopersicum* (75.00 mg/g), followed by TM 308 (65.00 mg/g) and PT4208 (63.00 mg/g) during 90 DAT. Total sugar content was found to be significantly lowest in *S. cheesmaniae,* VI037240 (30.50 and 20.00 mg/g) at 45 and 90 DAT respectively.

Reducing sugar content ranged from 19.75-48.50 mg/g at 45 DAT and 18.75-48.50 mg/g at 90 DAT. Non-reducing sugar level varied from 7.50-26.00 mg/g at 45 DAT and 9.56-26.25 mg/g at 90DAT (Table 60).

Table 57: Pooled mean total soluble protein content of leaves of different genotypes at 45 and 90 DAT

Genotypes	Total soluble protein in mg/g	
	45DAT	90DAT
S. galapagense,VI037241	12.41[a]	11.56[ab]
S. cheesmaniae,VI037240	12.77[a]	12.12[a]
S. habrochaites,LA1777	12.37[ab]	12.12[a]
S. habrochaites var glabratum,VI030462	12.56[a]	11.00[bc]
S. lycopersicum CL5915/CH45	11.37[bc]	11.00[bc]
TM 308	11.25[c]	10.37[c]
PT4208	10.5[c]	11.25[abc]
F Test	**	**
SE m±	0.343	0.368
CD @ 5%	1.01	1.09
CD @ 1%	1.39	-

#NB: Mean of four replications
.** indicates F test is significant

Table 58: Pooled mean total phenol content of leaves of different genotypes at 45 and 90 DAT

Genotype	Phenol content mg/g	
	45DAT	90DAT
*S. galapagense,*VI037241	0.38[d]	0.31[b]
*S. cheesmaniae,*VI037240	0.29[e]	0.33[b]
*S. habrochaites,*LA1777	0.55[b]	0.46[a]
*S. habrochaites var glabratum,*VI030462	0.60[a]	0.49[a]
S. lycopersicum CL5915/CH45	0.29[e]	0.25[c]
TM 308	0.43[c]	0.33[b]
PT4208	0.24[f]	0.23[c]
F Test	**	*
SE m±	0.05	0.03
CD @ 5%	0.03	1.09
CD @ 1%	0.05	-

#NB: Mean of four replications

Table 59: Pooled mean tannin content of leaves of different genotypes at 45 and 90 DAT

Tannin content in µg/g			
Genotypes	**Leaves**		**Fruits**
	45DAT	**90DAT**	**105DAT**
*S. galapagense,*VI037241	5.17^{ab}	4.62^{ab}	10.75^{bc}
*S. cheesmaniae,*VI037240	4.37^{bc}	3.6^{cd}	11.62^{b}
*S. habrochaites,*LA1777	5.50^{a}	5.00^{a}	14.50^{a}
*S. habrochaites var glabratum,*VI030462	4.53^{bc}	4.12^{bc}	11.75^{b}
S. lycopersicum CL5915/CH45	5.00^{ab}	3.87^{bc}	10.25^{cd}
TM 308	4.37^{bc}	3.62^{cd}	10.5^{c}
*PT*4208	4.15^{c}	2.85^{d}	9.35^{d}
F Test	*	**	**
SE m±	0.28	0.281	0.353
CD @ 5%	0.83	0.83	1.04
CD @ 1%	-	1.14	1.43

NB: Mean of four replications

Table 60: Pooled mean total content of sugar, reducing sugars and non-reducing sugars of different genotypes at 45 and 90 DAT

Genotypes	**Total Sugar in mg/g**		**Total reducing sugar**		**Total non - reducing sugar**	
	45DAT	**90DAT**	**45DAT**	**90DAT**	**45DAT**	**90DAT**
*S. galapagense,*VI037241	30.75^{cd}	24.75^{d}	20.25^{ef}	18.75^{e}	7.50^{d}	11.75^{c}
*S. cheesmaniae,*VI037240	30.50^{cd}	20.00^{f}	19.75^{f}	20.75^{de}	8.50^{cd}	9.56^{d}
*S. habrochaites,*LA1777	35.00c	22.00^{e}	22.00d^{e}	22.00^{d}	11.62^{bc}	12.25^{c}
*S. habrochaites var glabratum,*VI030462	23.75^{d}	20.00^{f}	23.50^{d}	23.50^{d}	3.37^{e}	0.43^{e}
S. lycopersicum CH45	56.50^{b}	75.00^{a}	31.00^{c}	31.50^{c}	26.00^{a}	26.25^{a}
TM 308	66.25^{a}	65.00^{b}	43.50^{b}	44.25^{b}	25.00^{a}	21.75^{b}
PT4208	60.75^{ab}	63.00^{c}	48.50^{a}	48.50^{a}	13.00^{b}	12.12^{c}
F Test	**	**	**	**	**	**
SE m±	2.41	0.53	0.72	1.04	1.09	0.62
CD @ 5%	7.11	1.60	2.18	4.40	3.21	1.84
CD @ 1%	9.83	2.19	2.99	3.21	4.40	2.52

NB: Mean of four replications, .** indicates F test is significant

The present findings are in accordance with the studies by Sharma *et al*. (2009) where the tannin content of leaves and pods had significant negative correlation with per cent pod damage by *Helicoverpa armigera.* Kandakoor *et al.* (2013) reported that higher tannin content had significant negative correlation with the thrips number and its damage in groundnut and significant positive correlation was observed between thrips incidence and total sugars content in groundnut. The present findings are in line with that of Bhavani *et al.* (2012) who reported that sugarcane genotypes susceptible to *Chilo infuscatellus* contained higher percentage of total sugars than the resistant ones. The present results are also in line with Kumar *et al.* (2015) who indicated that total sugars had a significant positive correlation with pod fly damage in pigeon pea. The findings are in conformity with that of Singh *et al.* (1990) who reported that the reducing sugars in leaves of sesame genotypes had a significant and positive impact on per cent leaf and pod damage by *A. catalaunalis.* These findings are in close agreement with Kumar *et al.* (2015) who reported a significant positive relationship with the susceptibility of pigeon pea to pod fly. Since, reducing sugars are considered to be an essential component in insect nutrition and it plays a vital role in host selection by phytophagous insects. Hence their concentration in plant is positively associated with feeding behavior of insects.

Negative association of sugars with seed cotton yield indicated that higher sugar content makes the plant parts more palatable to insects (Mundas, 1992).Mustard aphid population showed significant positive correlation with sugar content, indicating that higher amounts of sugar was needed for better survival of the aphid, providing better nutritional condition for its growth and development and thus sugar content in plants was generally associated with susceptibility (Sachan and Sachan, 1991). These observations of earlier workers are in close agreement with the present findings.

4.3.5 Polyphenol oxidase and Peroxidases

Induced resistance was measured with a rise in PPO and peroxidases levels. PPO and peroxidase level in healthy plants did not vary significantly among genotypes, whereas it varied among genotypes when infested with larvae of *T. absoluta* (Table 61 and 62).

Healthy leaf samples contained PPO in the a range of 0.002-0.006 unit/mg/min which did not vary significantly among genotypes (Table 61), whereas infested leaf samples showed significant differences among genotypes. Significant difference in PPO content was recorded between infested leaves of resistant wild accession *S. habrochaites* (LA1777) (0.060 unit/mg/min) and *S. lycopersicum* (CL5915) (0.050 unit/mg/min) whereas with other wild accessions it did not differ significantly (CD=0.007). There is an increase in PPO content in wild genotypes than susceptible genotypes which shows accumulation of PPO content due to insect infestation and may act as defence towards insect damage. These findings can be supported by similar reports of Thipyapong *et al,* (2006) who revealed that the growth rates of both common cutworm and cotton bollworm larvae were significantly correlated with PPO activity levels. The PPO-overexpressing transgenic plants clearly showed an increase in resistance; growth rates of common cutworm were up to 1.7 times lower than on controls and larvae consumed less foliage. In addition, increased PPO activity led to higher larval mortality. These results suggest a critical role for PPO-mediated phenolic oxidation in insect resistance which can be related to the results of the present investigation wherein infested resistant wild accession i.e. *S. habrochaites* (LA1777) registered significantly higher PPO content.

Peroxidase content was also analysed from healthy and infested leaf samples of all the five genotypes. There was non-significant difference among healthy leaf samples of different genotypes, whereas leaf samples from infested plants showed significant differences among resistant wild accessions and susceptible genotypes. Infested leaf sample of *S. galapagense* (VI037241) showed the highest PO content (48.25 unit/mg) followed by *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL 5915) with a mean value of 43.00, 41.00, 38.00, 21.00 Unit/mg respectively. In susceptible genotype the PO content found significantly lesser after infestation.

The results of the present investigation are in line with that of Taggar *et al.* (2012) who indicated that in general, whitefly infestation increased the peroxidase activity and decreased the catalase activity. Resistant genotypes NDU 5-7 and KU 99-20 recorded higher peroxidase and catalase activities at 30 and 50 DAS under whitefly-stress

Table 61: Induced PPO activity in healthy and *T. absoluta* infested plants of different genotypes

PPO content (unit/mg/min)		
Genotypes	**Infested plants**	**Healthy plants**
*S. galapagense,*VI037241	0.054[ab]	0.003
*S. cheesmaniae,*VI037240	0.052[b]	0.003
*S. habrochaites,*LA1777	0.060[a]	0.002
*S. habrochaites var glabratum,*VI030462	0.056[ab]	0.006
S. lycopersicum CL5915	0.052[b]	0.002
F Test	**	NS
CD @ 5%	0.007	-
CV	1.67	25.87

Polyphenol oxidase activity changes in OD at 420 nm (units/mg of protein/min)

Table 62: Induced PO activity in healthy and *T. absoluta* infested plants of different genotypes

PO Unit/mg		
Genotypes	**Infested plants**	**Healthy plants**
*S. galapagense,*VI037241	48.25[a]	22.33
*S. cheesmaniae,*VI037240	43.00[ab]	26.00
S. habrochaites, LA1777	41.00[b]	24.66
*S. habrochaites var glabratum,*VI030462	38.00[b]	25.00
S. lycopersicum CL5915	21.00[c]	20.66
F Test	**	NS
CD @ 5%	6.40	-
CV	8.843	13.73

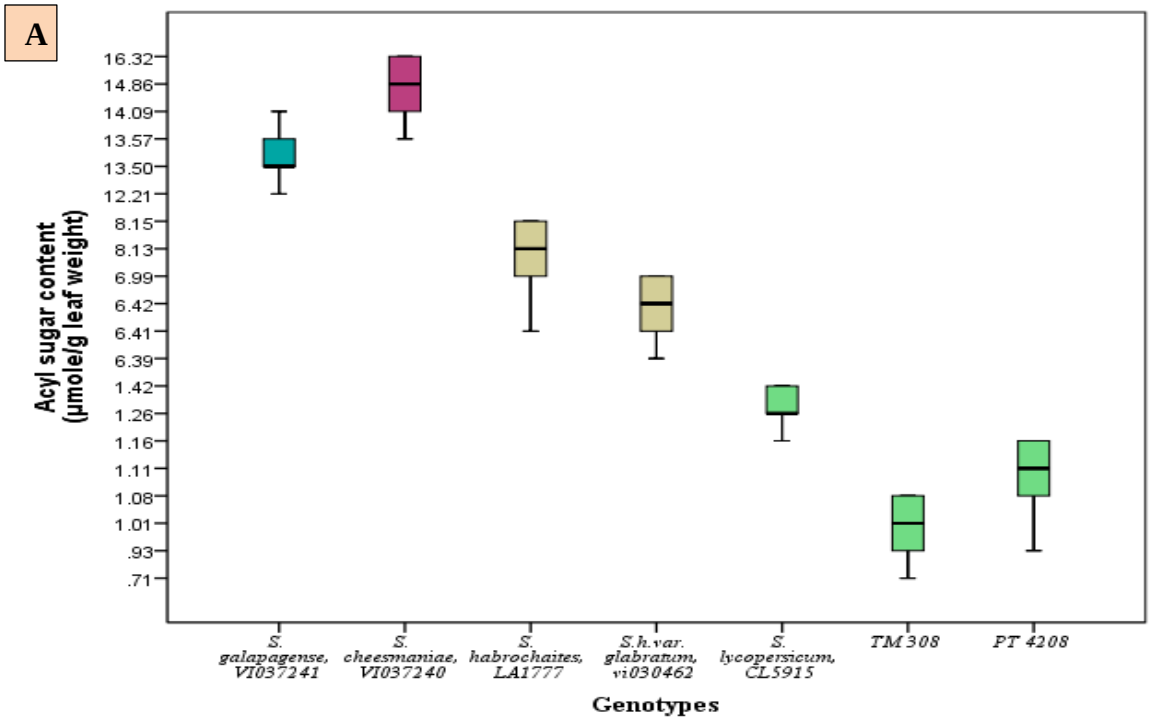
.** indicates F test is significant.

conditions as compared with non-stressed plants. Their findings suggest that the enhanced activities of the enzymes may contribute to bio-protection of black gram against *B. tabaci* infestation.

The present findings are in conformity with that of Youssef *et al,* (2018) who observed activity of polyphenols oxidase on the phyllody infected sesame (5.70units/mg protein) which was higher than that in the healthy (3.20/mg protein) sesame plants. These changes in the enzyme content in the plants indicated the attempt by the plants to resist the plant disease and it is also in agreement with that of Beltagi *et al.* (2013) who found that the activity of peroxidase and polyphenol oxidase increased in the infected plants as compared to that in the healthy plant.

4.3.6 Acyl sugar

Acyl sugar content for upper, middle and lower canopy leaves for susceptible and resistant genotypes were quantified. Acyl sugar content was quantified and data of two different seasons revealed that it varied significantly among different genotypes in summer (CD=1.523) and *kharif* season (CD=0.95). Acyl sugar from upper, middle and lower canopy leaves of *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), *S. lycopersicum* (CL5915/CH45), TM 308 and PT 4208 was 14.00, 16.5, 8.25, 6.00, 1.25,0.75, 1.25 µmoles/g, 13.50, 14.86, 6.41, 6.99, 1.08, 0.93 and 12.21,13.57, 8.13, 6.39, 1.42, 1.01, 1.11 µmoles/g of leaf weight, respectively. Acyl sugar content did not vary at different canopy levels during summer season whereas there was significant differences in the same during *kharif* season (CD=0.95). Mean acyl sugar content was higher in upper canopy leaves than in the middle and lower canopy though it is not significantly different (Table 63). Mean acyl sugar level during *kharif* season reduced drastically but differs significantly among different genotypes (Table 64). The results indicated that highest mean value *i.e.* 9.28 µmoles/g in upper canopy leaves of *S. cheesmaniae* (VI037240) and lowest acylsugar level in lower canopy leaves of *S. lycopersicum* (CL5915/CH45) during *kharif* season. Acyl sugar in all the resistant wild accessions was significantly more whereas it is significantly lesser in the susceptible genotypes (Fig. 6).



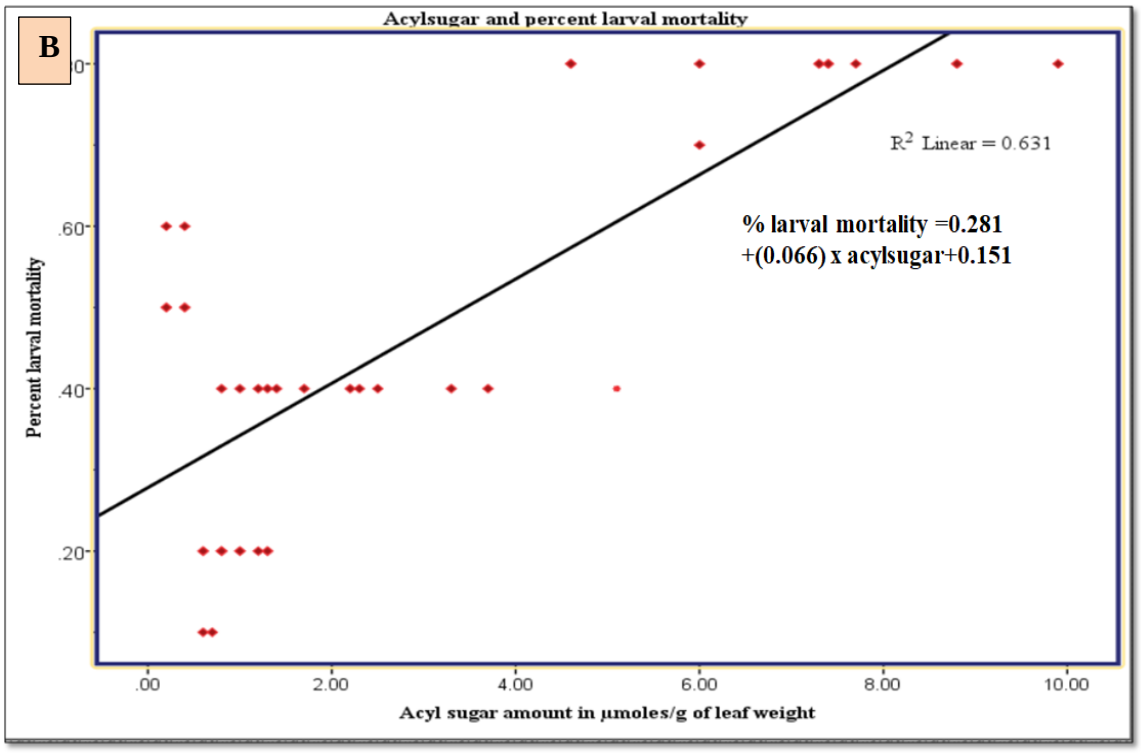


Fig. 6: Acyl sugar content from middle canopy leaves of different genotypes (A) and its correlation with larval mortality (B) of *T.absoluta*

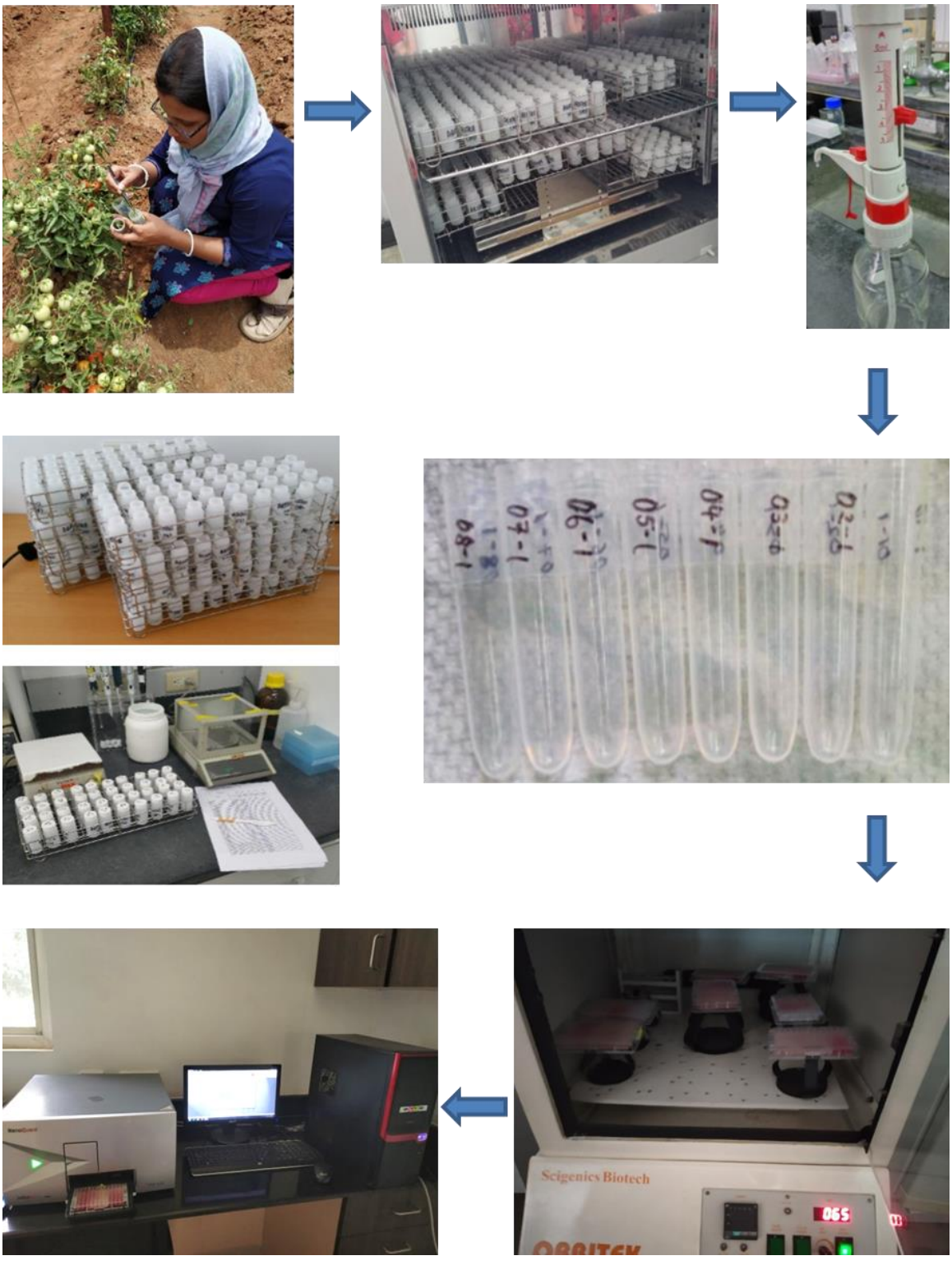


Plate 8: Assessment of acylsugar content of different genotypes

Table 63: Acyl sugar content of different genotypes at different canopy levels (pooled mean of summer season 2018-19)

Acyl sugar at different canopy level (µmoles/g)				
Genotypes	**Upper**	**Middle**	**Lower**	**Mean**
S. galapagense, VI037241	14.00	13.50	12.21	**16.93**
S. cheesmaniae, VI037240	16.50	14.86	13.57	**14.92**
S. habrochaites, LA1777	8.25	6.41	8.13	**7.56**
*S. habrochaites var glabratum,*VI030462	6.00	6.99	6.39	**6.60**
S. lycopersicum CL5915	1.25	1.16	1.42	**1.28**
TM 308	0.75	1.08	1.01	**0.93**
PT 4208	1.25	0.93	1.11	**1.07**
Mean	**6.87**	**7.07**	**7.19**	
Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	0.53	0.76	1.52
Canopy level	NS	-	-	-
Genotypes x Canopy levels	NS	-	-	-

Acyl sugar level in µmoles/g of leaf weight. Mean of four replications. .** indicates F test is significant.NS=Non-significant

Table 64: Acyl sugar content of different genotypes at different canopy levels (pooled mean *of kharif* 2018-19)

Genotypes	**Upper**	**Middle**	**Lower**	**Mean**
*S. galapagense,*VI037241	8.50	6.65	6.19	**7.11**
*S. cheesmaniae,*VI037240	9.28	7.94	7.01	**8.08**
*S. habrochaites,*LA1777	4.75	1.85	1.41	**2.67**
*S. habrochaites var glabratum,*VI030462	4.67	1.71	1.08	**2.49**
S. lycopersicum CL5915	1.15	2.54	1.00	**1.51**
Mean	**5.67**	**4.14**	**3.38**	
Factors	**F Test**	**SE(m)**	**SE(d)**	**C.D.**
Genotypes	**	0.335	0.473	0.959
Canopy level	**	0.259	0.367	0.743
Genotypes x Canopy levels	**	0.58	0.82	1.661

#Acyl sugar level in µmoles/g of leaf weight. Mean of four replications. .** indicates F test is significant.

Present findings are in close agreement with the earlier reports of Rakha *et al.,* (2017a) who suggested that high acyl sugar content showed resistance against *Bemesia tabaci, T. absoluta* and *Tetranychus urticae* in tomato.

These findings are in conformation with that of Vosman *et al.* (2018) who identified broad spectrum resistance towards insects in close relatives of the cultivated tomato. Trichome type IV containing species from the *Lycopersicon* group of Solanum section Lycopersicon showed resistance to a range of pest insects, especially accessions of *S. galapagense* are highly resistant. Comparison of the metabolite content of *S. galapagense* to the genetically very similar *S. cheesmaniae,* which does not contain type IV trichomes, shows large differences in the levels of both acyl sugars and several O-methylated forms of the flavonol myricetin. The results obtained for *S. galapagense* and *S. cheesmaniae* accessions with regard to their resistance to the *T.absoluta* and *Scirtothrips dorsalis*, as shown in the present study, are very similar to those studies previously reported for *B. tabaci* by Lucatti *et al.* (2013).

4.3.7 Green leaf volatile

Green leaf volatile of all the five genotypes were extracted and analysed. Olfactometer bioassay was carried out with *T. absoluta* gravid female. Results showed significant differences *w.r.t* time spent and entry frequency when tested with blend of different genotypes as choice. Totally 226 different compounds were found from extracted green leaf volatiles (Table 68). Bioassay with gravid females showed significant differences *w.r.t* time spent and entry frequency when tested with blend of different genotypes as choice. Single choice and dual choice was given to record the response. In single arm choice assay behavioural response was measured based on its time spent (min) and entry frequency towards any particular arm of an olfactometer. Gravid female showed strong response by spending more time towards susceptible plant volatile blends whereas spent less time towards control or solvent treated arm in single choice assay (Table 65). Highly significant differences were found in this choice assay. Strong significant differences were recorded in time spent when *S. cheesmaniae* (VI037240) volatile blend was compared with solvent control (Table 65) whereas *T.*

absoluta female showed non-significant results towards time spent to other wild accessions (Table 65). Entry frequency was found to be significant only in case of *S. lycopersicum* and *S. galapagense* when compared with solvent control (Table 66) in dual choice assay. These findings showed that the female of *T. absoluta* has higher preference towards susceptible genotype as compared to the control solvent.

Dual choice was given to compare between susceptible and resistant accession as treatment and diethyl ether as control. More number of gravid females spent more time towards susceptible genotype than control and the resistant accession called *S. habrochaites var glabratum* VI030462, whereas the entry frequency did not differ significantly (Table 66). In case of choice between resistant wild accession *S. cheesmaniae* and *S. galapagense* with susceptible genotype *S. lycopersicum* it did not show significant differences w.r.t entry frequency, but differed significantly in case of time spent (Table 67). Time spent in dual choice between *S. habrochaites* (LA1777) and *S. lycopersicum* (CL5915) varied significantly and the moth spent more time on the susceptible genotype as compared to that on *S. habrochaites* (LA1777) and control arm. Entry frequency also followed the same trend and highest (mean value of 1.00) entry frequency was recorded towards the arm which was treated with volatile blend of susceptible genotype. The result indicated that among *S. habrochaites* and susceptible genotype *S. lycopersicum*, more number of females showed tendency to spend more time and entry frequency towards susceptible arm or control (Table 67). Hence the results were not so clear about their preference, GCEAG assay was carried out which showed differences in response peak where puff of different genotypes were given. The exact compound for repulsion or attraction was not clear but there were differences in the response peak (Table 69). EAG study revealed that the response peak differed significantly ($F_{(6, 63)} = 96.76$, $p<0.001$) between susceptible and other resistant wild accessions (Fig.8) except *S. galapagense* (VI037241) although it showed resistance towards *T.absoluta* under field conditions. EAG analysis showed significant difference between response peak of *S. lycopersicum* and *S.h.var. glabratum* and *S. cheesmaniae* (Table 70). The preference index recorded was 54.63, -20, 10, -11 and -2.4 per cent for *S. lycopersicum* (CL5915), *S. habrochaites* (LA1777), *S. habrochaites var glabratum*

(VI030462), *S. cheesmaniae* (VI037240), *S. galapagense* (VI037241), respectively (Fig. 8). The volatile blend has some role in response level but the exact compounds behind the preference or rejection has not been not clearly understood from these studies. Further investigation is required to decipher this. Principal component analysis showed that the susceptible genotype falls far apart than the resistant accessions when the different volatile compound released by them was compared. There is a stark difference among the volatile profile of susceptible genotypes and resistant wild accessions which may play a role in susceptibility to the insect infestation under field condition (fig. 8). Principal component analysis was aimed at studying the data structures in reduced dimensions with retention of maximum amount of variability present in the data. Principal component analysis (PCA) resolved the compounds into 5 distinct principal component (PC) clusters. Of these clusters, PC1 and PC2 captured over 64.10% of the total variation hence were used for further statistical analysis and production of a two dimension plot for better visualization (Fig. 9). In wild accessions, some elements were found at higher levels than in the susceptible check (table 67). Some volatile *viz.,* Limonene, α-Pinene, δ-EIemene, β-Caryophyllene, (+)-4-Carene, β-Pinene, γ-Elemene, β-Ocimene ,α-Santalene were found more in wild accessions, whereas there were very less or nil in susceptible genotype: *S. lycopersicum* (CL5915). The present findings can be justified by the similar studies carried out by Antonious and Snyder (2006) where the extracts from the leaves were found to contain methyl ketones; 2–tridecanone and 2–undecanone and three sesquiterpene hydrocarbons; *(E)*–caryophyllene, *α*–curcumene, and *α*–zingiberene. They have repellence and toxicity towards two–spotted spider mites. After grouping of all the volatile chemicals together, it showed that monoterpenes and sesquiterpenes (Fig.7) are found to be more in wild accessions and alcohols and alkenes were more in the susceptible genotype (Table 69).

Present findings can be supported by similar studies where they have suggested that volatile profile of wild accessions may have significant role not only for repelling insects but attracting the parasitoids. Interestingly, earlier studies have proved that hexanal, Z-3-hexen-1-ol and verbenene, as well as methyl salicylate and δ-elemene that are emitted in higher relative amounts by the wild tomato accessions, are produced by

Heat map of major volatile compounds of different genotypes

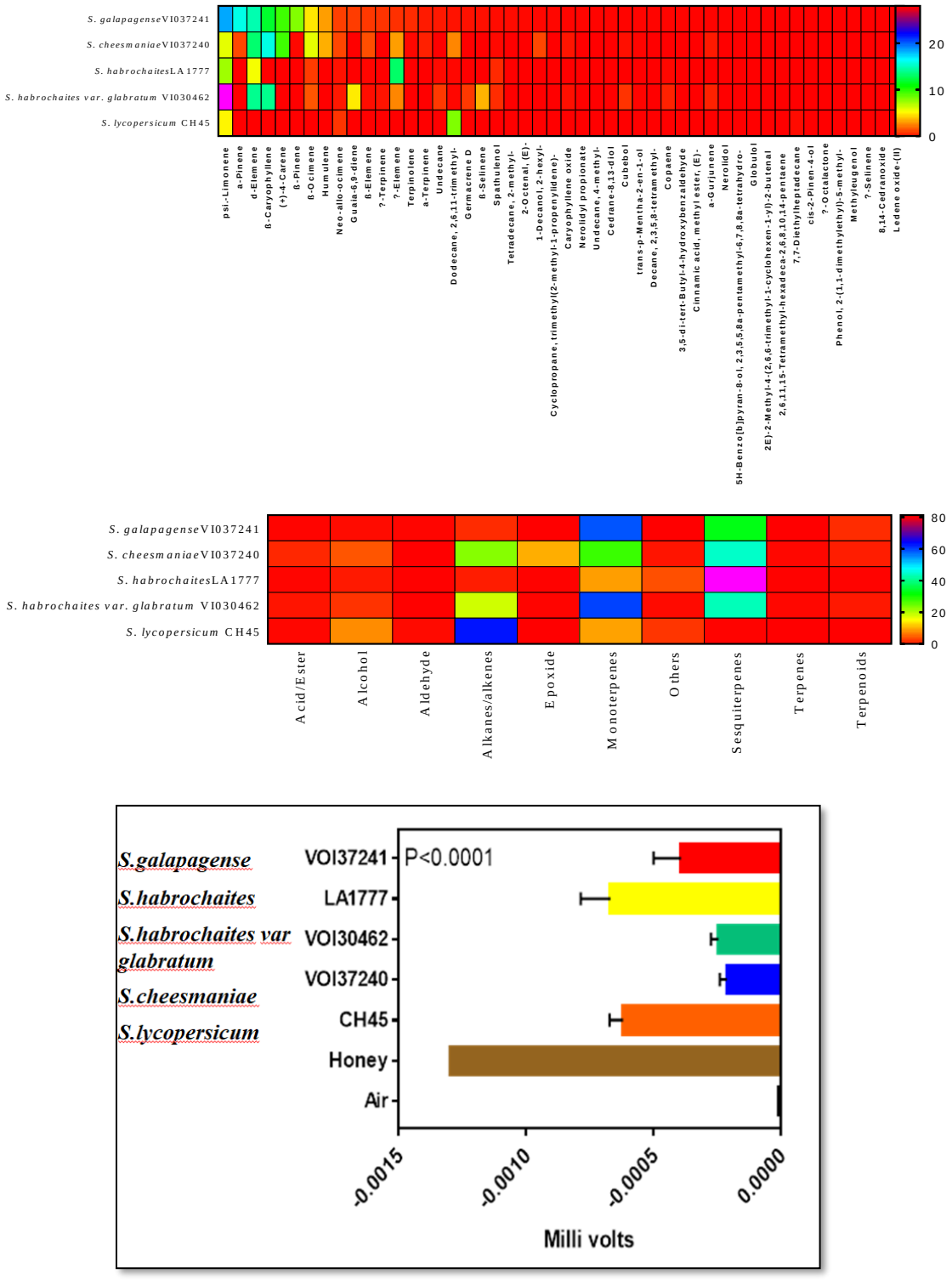
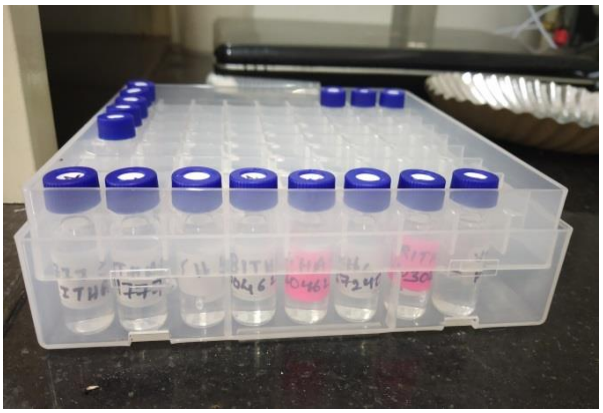
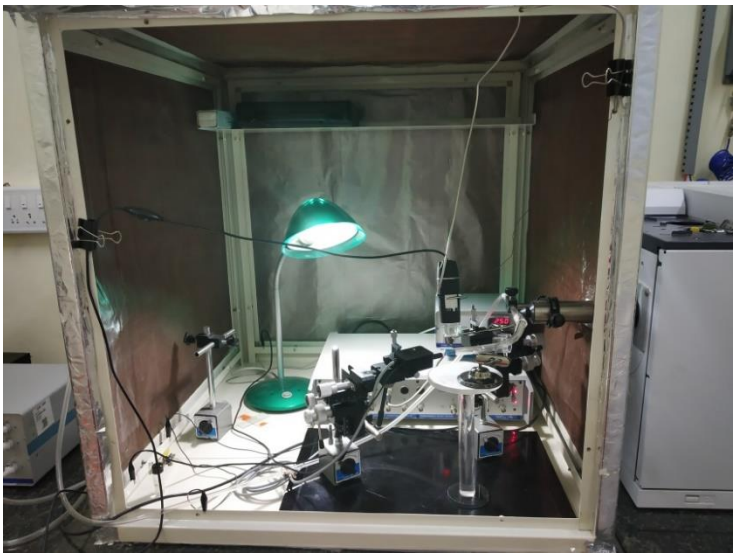


Fig. 7: Heat map of different volatile groups and *T. absoluta* response to different puffs through EAG



Collection and extraction of plant volatiles



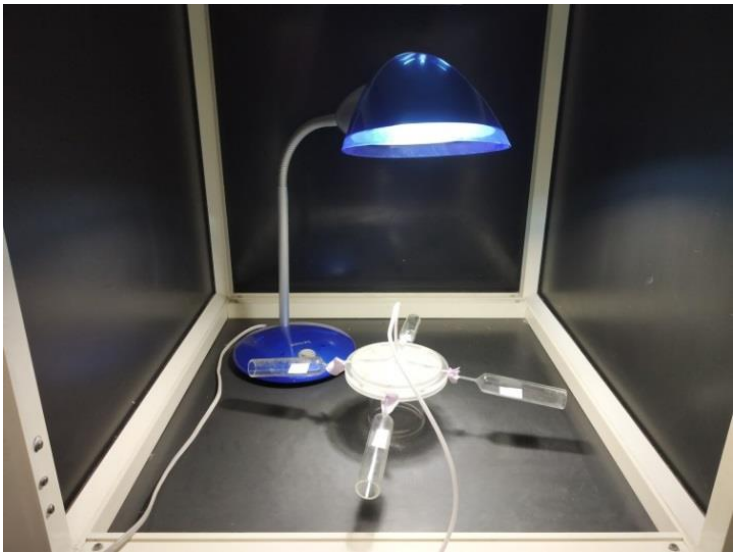


Plate 9: Choice assay with gravid female moth of *T.absoluta* with plant volatiles of different genotypes

Table 65: Olfactometer assay with blend of leaf volatiles with solvent as control (single choice) to estimate the time spent (min) by gravid female on different genotypes

Time spent(min)					
Wilcoxon signed rank test (Two tail)					
Genotype	**Positive sum**	**Negative sum**	**Test Statistics**	**Critical value**	**Significance**
***S. lycopersicum* (CL5915/CH45)**	51.00±2.06	-4.00±0.90	4.00	8.00	Significant
***S. habrochaites var. glabratum* (VI030462)**	30.00±2.28	-21.00±0.68	21.00	8.00	Non-significant
***S. habrochaites* (LA1777)**	20.00±1.69	-35.00±0.76	20.00	8.00	Non-significant
***S. cheesmaniae* (VI037240)**	3.00±1.10	-41.00±0.84	3.00	8.00	Significant
***S. galapagense* (VI037241)**	24.00±1.26	-30.00±1.85	24.00	8.00	Non-significant

Table 66: Olfactometer assay with blend of leaf volatiles with solvent as control (single choice) to estimate the entry frequency by gravid female on different genotypes

	Mean±SD		**Chi square value**	**DF**	**Significance**
Genotype	**Treatment**	**Control**			
***S. lycopersicum* CL5915/CH45**	21.00±1.44	5.33±0.42	47.66	9.00	Significant
***S. habrochaites* LA1777**	4.00±.69	6.33±.24	7.00	9.00	Non-significant
***S. habrochaites var glabratum* VI030462**	9.00±0.73	12.00±.44	16.38	9.00	Non-significant
***S. cheesmaniae* VI037240**	4.00±.51	7.33±.30	9.41	9.00	Non-significant
***S. galapagense* VI037241**	11.00±.63	6..33±.50	20.61	9.00	Significant

Significant at P= 0.05, NS= Non significant, S= Significant. DF=Degrees of freedom

Table 67: Choice assay in terms of time spent and estimation of entry frequency in olfactometer assay with volatile blends of different accessions

Mann Whitney comparison test						
	Time spent (min)			Entry frequency		
	***S. lycopersicum* CL5915/CH45**	***S. habrochaites var glabratum* VI030462**	**Solvent as control**	***S. lycopersicum* CL5915/CH45**	***S. habrochaites var glabratum* VI030462**	**Solvent as control**
Mean time spent	1.63[a]	0.61[b]	1.12[b]	0.60 [a]	0.30[a]	0.45[a]
Standard Deviation	1.46	0.87	1.05	0.50	0.47	0.36
Standard Error	0.33	0.20	0.23	0.11	0.11	0.08
	Time spent (min)			Entry frequency		
	***S. lycopersicum* CL5915/CH45**	***S. habrochaites LA1777***	**Solvent as control**	***S. lycopersicum* CL5915/CH45**	***S. habrochaites LA1777***	**Solvent as control**
Mean time spent	3.27[a]	0.65[b]	1.96[b]	1.00[a]	0.60[c]	0.80[b]
Standard Deviation	1.85	0.57	1.05	0.46	0.50	0.34
Standard Error	0.41	0.13	0.23	0.10	0.11	0.08
	Time spent (min)			Entry frequency		
	***S. lycopersicum* CL5915/CH45**	***S. cheesmaniae VI037240***	**Solvent as control**	***S. lycopersicum* CL5915/CH45**	***S. cheesmaniae VI037240***	**Solvent as control**
Mean time spent	2.92[a]	1.65[b]	2.28[b]	1.50[ns]	1.10[ns]	1.30[ns]
Standard Deviation	2.07	1.07	1.12	0.83	0.55	0.57
Standard Error	0.46	0.24	0.25	0.18	0.12	0.13
	Time spent (min)			Entry frequency		
	***S. lycopersicum* CL5915/CH45**	***S. galapagense VI037241***	**Solvent as control**	***S. lycopersicum* CL5915/CH45**	***S. galapagense VI037241***	**Solvent as control**
Mean time spent	3.22[a]	0.33[b]	1.77[a]	0.90[ns]	0.50[ns]	0.70[ns]
Standard Deviation	2.91	0.54	1.56	0.72	0.69	0.57
Standard Error	0.65	0.12	0.35	0.16	0.15	0.13

Significant at 5%, P=0.05, NS=Non-significant

Table 68: Quantity of plant volatiles recorded in (area %) from different genotypes/accessions by GCMS analysis

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
1	Limonene	18.72	6.15	7.70	28.04	5.41
2	α-Pinene	16.30	1.56	0.00	0.00	0.00
3	δ-EIemene	15.07	13.63	5.80	14.34	0.00
4	β-Caryophyllene	12.20	16.19	0.00	14.31	0.00
5	(+)-4-Carene	9.85	9.85	0.00	0.00	0.00
6	β-Pinene	8.34	0.16	0.00	0.00	0.00
7	β-Ocimene	5.07	6.14	1.28	1.85	0.00
8	Humulene	3.46	3.83	0.00	0.00	0.00
9	Neo-allo-ocimene	1.37	1.52	0.37	0.51	1.13
10	Guaia-6,9-diene	1.30	0.00	0.00	5.18	0.00
11	β-Elemene	1.22	1.70	0.10	0.27	0.00
12	γ-Terpinene	1.11	0.00	0.00	0.40	0.00
13	γ-Elemene	1.04	3.47	13.48	2.93	0.00
14	Terpinolene	0.93	0.14	0.00	0.00	0.00
15	α-Terpinene	0.55	0.70	0.00	0.00	0.00
16	Undecane	0.51	0.00	0.21	1.24	0.00
17	Dodecane, 2,6,11-trimethyl-	0.39	2.93	0.12	0.13	8.41
18	Germacrene D	0.37	0.00	0.00	1.21	0.00
19	β-Selinene	0.31	0.00	0.00	3.94	0.00
20	Spathulenol	0.24	0.16	0.89	0.95	0.00
21	Tetradecane, 2-methyl-	0.22	0.00	0.00	0.00	0.00
22	2-Octenal, (E)-	0.17	0.00	0.00	0.00	0.00
23	1-Decanol, 2-hexyl-	0.15	1.54	0.00	0.00	0.00
24	Cyclopropane,trimethyl(2-methyl-1-propenylidene)-	0.11	0.00	0.00	0.00	0.00
25	Caryophyllene oxide	0.09	0.42	0.00	0.31	0.00
26	Nerolidyl propionate	0.09	0.00	0.00	0.01	0.00
27	Undecane, 4-methyl-	0.08	0.00	0.00	0.00	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
28	Cedrane-8,13-diol	0.08	0.00	0.00	0.00	0.00
29	Cubebol	0.08	0.32	0.00	1.12	0.00
30	trans-p-Mentha-2-en-1-ol	0.07	0.07	0.00	0.08	0.00
31	Decane, 2,3,5,8-tetramethyl-	0.07	0.00	0.00	0.00	0.00
32	Copaene	0.07	0.00	0.15	0.72	0.00
33	3,5-di-tert-Butyl-4-hydroxybenzaldehyde	0.07	0.00	0.00	0.00	0.00
34	Cinnamic acid, methyl ester, (E)-	0.05	0.00	0.00	0.00	0.00
35	α-Gurjunene	0.05	0.53	0.00	0.71	0.00
36	Nerolidol	0.05	0.00	0.00	0.00	0.00
37	5H-Benzo[b]pyran-8-ol, 2,3,5,5,8a-pentamethyl-6,7,8,8a-tetrahydro-	0.02	0.00	0.00	0.00	0.00
38	Globulol	0.02	0.00	0.00	0.00	0.00
39	2E)-2-Methyl-4-(2,6,6-trimethyl-1-cyclohexen-1-yl)-2-butenal	0.02	0.00	0.00	0.00	0.00
40	2,6,11,15-Tetramethyl-hexadeca-2,6,8,10,14-pentaene	0.02	0.00	0.02	0.00	0.00
41	7,7-Diethylheptadecane	0.02	0.00	0.00	0.00	0.24
42	cis-2-Pinen-4-ol	0.01	0.00	0.00	0.00	0.00
43	γ-Octalactone	0.01	0.00	0.00	0.01	0.00
44	Phenol, 2-(1,1-dimethylethyl)-5-methyl-	0.01	0.00	0.00	0.00	0.00
45	Methyleugenol	0.01	0.00	0.00	0.00	0.00
46	γ-Selinene	0.01	0.00	0.00	0.00	0.00
47	8,14-Cedranoxide	0.01	0.00	0.00	0.00	0.00
48	Ledene oxide-(II)	0.01	0.00	0.00	0.12	0.00
49	1,4-Methanoazulen-9-ol,decahydro-1,5,5tetramethyl	0.01	0.00	0.00	0.00	0.00
50	n-Tetradecanoic acid	0.01	0.00	0.00	0.02	0.00
51	Decahydro-2,6-dimethyl-3-octylnaphthalene	0.01	0.21	0.00	0.00	0.00
52	Butanoic acid, 3-methyl-	0.00	0.21	0.00	0.14	0.00
53	Pentanoic acid, 3-methyl-	0.00	1.52	0.00	0.00	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
54	Butyric acid, 2-methyl-	0.00	0.49	0.00	0.00	0.00
55	Octane, 2,4,6-trimethyl-	0.00	0.12	0.03	0.00	0.00
56	cis-Sabinene hydrate	0.00	0.77	0.00	0.03	0.00
57	Pentadecane	0.00	2.41	0.00	0.00	10.02
58	β-Myrcene	0.00	0.10	0.00	0.00	0.00
59	trans-Sabinene hydrate	0.00	0.31	0.00	0.00	0.00
60	4-Thujanol	0.00	0.26	0.00	0.00	0.00
61	Decane	0.00	0.01	0.00	0.00	0.00
62	cis-p-Mentha-2,8-diene-1-ol	0.00	0.03	0.00	0.00	0.00
63	3-Carene	0.00	1.05	0.23	0.50	1.01
64	trans-β-Ocimene	0.00	0.48	0.00	0.00	0.00
65	β-cis-Ocimene	0.00	0.94	0.00	0.00	0.00
66	Cyclooctane, 1,4-dimethyl-, trans-	0.00	0.15	0.00	0.08	0.00
67	Isopulegol	0.00	0.15	0.00	0.00	0.00
68	2,3-Dimethyldecane	0.00	2.81	0.00	0.00	0.00
69	Undecane, 3,7-dimethyl-	0.00	1.30	0.00	0.00	0.00
70	trans-p-2-Menthen-1-ol	0.00	0.07	0.00	0.00	0.00
71	cis-β-Terpineol	0.00	0.22	0.00	0.00	0.00
72	Camphane, 2-hydroxy	0.00	0.84	0.00	0.00	0.00
73	Naphthalene	0.00	2.37	0.00	0.00	0.00
74	α-Terpineol, (-)-	0.00	0.33	0.00	0.00	0.00
75	.trans-p-Menth-1-en-3-ol	0.00	0.24	0.00	0.00	0.00
76	3-Thujen-2-one	0.00	0.08	0.00	0.00	0.00
77	.3-Carvomenthenone	0.00	0.34	0.00	0.00	0.00
78	1-Tridecene	0.00	2.05	0.00	0.00	0.00
79	Tetradecane	0.00	3.82	0.00	0.00	0.00
80	Benzoic acid, 3,4-dimethyl-	0.00	0.08	0.00	0.00	0.00
81	.β-Patchoulene	0.00	0.28	0.00	0.00	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
82	Epicubebol	0.00	0.81	0.00	0.00	0.00
83	1,3-Benzodioxole, 5-(1-propenyl)-	0.00	0.00	0.00	0.00	0.00
84	Isolongifolene	0.00	0.08	0.00	0.00	0.00
85	α-cis-Bergamotene	0.00	1.13	0.00	0.00	0.00
86	beta-Guaiene	0.00	1.78	0.00	0.00	0.00
87	Alloaromadendrene	0.00	0.84	0.00	0.00	0.00
88	β-copaene	0.00	0.66	0.00	0.00	0.00
89	δ-Selinene	0.00	1.90	0.00	0.00	0.00
90	2-Hexyl-1-decanol	0.00	1.54	0.00	0.00	0.00
91	Hexadecane	0.00	1.55	0.00	0.00	5.88
92	β-Spathulenol	0.00	0.16	0.00	0.00	0.00
93	Isoaromadendrene epoxide	0.00	11.00	0.00	0.00	0.00
94	Isospathulenol	0.00	0.16	0.00	0.00	0.00
95	Longipinocarveol, trans-	0.00	0.16	0.00	0.00	0.00
96	Selin-6-en-4α-ol	0.00	0.04	0.00	0.00	0.00
97	2H-2,4a-Methanonaphthalen-8(5H)-one, 1,3,4,6,7,8a-hexahydro-1,1,5,5-tetramethyl-	0.00	0.17	0.00	0.00	0.00
98	Patchouli alcohol	0.00	0.07	0.00	0.00	0.00
99	α-Bisabolol	0.00	0.07	0.00	0.00	0.00
100	Heptadecane	0.00	0.07	0.00	0.00	1.44
101	Dodecahydro-3a,6,6,9a-tetramethylnaphtho 2,1-furan	0.00	0.16	0.00	0.00	0.00
102	.Methyl farnesate	0.00	0.14	0.00	0.00	0.00
103	4a-Hydroxy-6-isopropenyl-4,8a-dimethyloctahydro-1(2H)-naphthalenone	0.00	0.11	0.00	0.00	0.00
104	Butanoic acid, 3-methyl-	0.00	0.00	0.14	0.00	0.00
105	Undecane	0.00	0.00	0.21	0.00	0.00
106	2-Undecanethiol, 2-methyl-	0.00	0.00	0.13	0.00	0.00
107	Isoterpinolene	0.00	0.00	0.15	0.00	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
108	1R,4R-p-Mentha-2,8-dien-1-ol	0.00	0.00	0.01	0.00	0.00
109	Neo-allo-ocimene	0.00	0.00	0.37	0.00	0.00
110	Limonene epoxide	0.00	0.00	0.07	0.00	0.00
111	Ethyl-benzaldehyde	0.00	0.00	0.01	0.00	0.00
112	Terpinen-4-ol	0.00	0.00	0.01	0.00	0.00
113	Benzofuran,2,3,3a,4,5,7a-hexahydro-3,6-dimethyl-, (3S,3aS,7aR)-	0.00	0.00	0.11	0.00	0.00
114	α-Terpineol	0.00	0.00	0.02	0.00	0.00
115	.cis-Carveol	0.00	0.00	0.05	0.29	0.00
116	D-Carvone	0.00	0.00	0.01	0.05	0.00
117	1-Octanol, 2-butyl-	0.00	0.00	0.03	0.00	0.00
118	Copaene	0.00	0.00	0.15	0.00	0.00
119	Longifolene	0.00	0.00	1.52	0.00	0.00
120	α-Cedrene	0.00	0.00	0.03	0.00	0.16
121	α-Santalene	0.00	0.00	30.78	0.00	0.00
122	Epi-β-Santalene	0.00	0.00	4.55	0.00	0.00
123	β-Cedrene	0.00	0.00	17.00	0.00	0.00
124	1H-Cyclopropa[a]naphthalene, 1a,2,6,7,7a,7b-hexahydro-1,1,7,7a-tetramethyl-	0.00	0.00	0.05	0.00	0.00
125	β-Funebrene	0.00	0.00	3.71	0.00	0.00
126	β-Bisabolene	0.00	0.00	2.29	0.00	0.00
127	β-Sesquiphellandrene	0.00	0.00	3.95	0.00	0.00
128	Selina-3,7(11)-diene	0.00	0.00	1.02	0.00	0.00
129	Germacrene B	0.00	0.00	0.85	0.42	0.00
130	(3E,7E)-4,8,12-Trimethyltrideca-1,3,7,11-tetraene	0.00	0.00	0.14	0.00	0.00
131	Ledene alcohol	0.00	0.00	0.13	0.55	0.00
132	Aristol-1(10)-en-9-ol	0.00	0.00	0.18	0.00	0.00
133	α-Bisabolol	0.00	0.00	0.78	0.00	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
134	2-Hexadecanol	0.00	0.00	0.02	0.00	0.00
135	Dodecahydro-3a,6,6,9a-tetramethylnaphtho[2,1-β]furan	0.00	0.00	0.01	0.00	0.00
136	Cyclohexanone, 2,3,3-trimethyl-2-(3-methylenebut-1-en-1-yl)-6-acetyloxy-	0.00	0.00	1.14	0.00	0.00
137	β-Santanol acetate	0.00	0.00	0.02	0.00	0.00
138	Methyl farnesate	0.00	0.00	0.03	0.00	0.00
139	(E)-α-Santalic acid	0.00	0.00	0.07	0.00	0.00
140	trans-Valerenyl acetate	0.00	0.00	0.02	0.00	0.00
141	1,3,6,10-Cyclotetradecatetraene, 3,7,11-trimethyl-14-(1-methylethyl)-, [S-(E,Z,E,E)]-	0.00	0.00	0.01	0.00	0.00
142	Acetyl-6-ethyl-1,1,4,4-tetramethyltetralin	0.00	0.00	0.05	0.00	0.00
143	6-(1-Hydroxymethylvinyl)-4,8a-dimethyl-3,5,6,7,8,8a-hexahydro-1H-naphthalen-2-one	0.00	0.00	0.00	0.00	0.00
144	Phenylacetic acid, 2,7-dimethyloct-7-en-5-yn-4-ester	0.00	0.00	0.02	0.00	0.00
145	geranyl-α-terpinene	0.00	0.00	0.07	0.00	0.00
146	Pentanoic acid	0.00	0.00	0.00	0.10	0.00
147	D-Limonene	0.00	0.00	0.00	28.04	0.00
148	γ-Terpinene	0.00	0.00	0.00	0.40	0.00
149	Linalool	0.00	0.00	0.00	0.65	0.00
150	Phenylethyl Alcohol	0.00	0.00	0.00	0.27	0.00
151	Limonene oxide, trans-	0.00	0.00	0.00	0.23	0.00
152	4,8-Decadien-3-ol, 5,9-dimethyl-	0.00	0.00	0.00	0.01	0.00
153	3,6,9,12-Tetraoxatetradecan-1-ol, 14-[4-(1,1,3,3-tetramethylbutyl)phenoxy]-	0.00	0.00	0.00	0.00	0.00
154	4,7,7-Trimethylbicyclo[4.1.0]heptan-2-ol	0.00	0.00	0.00	0.02	0.00
155	Methyl salicylate	0.00	0.00	0.00	0.23	0.00
156	(-)-cis-Isopiperitenol	0.00	0.00	0.00	0.24	0.00
157	2,6-Octadiene-1,8-diol, 2,6-dimethyl	0.00	0.00	0.00	0.04	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
158	2-Isopropyl-5-methyl-1-heptanol	0.00	0.00	0.00	0.03	0.00
159	Tridecane	0.00	0.00	0.00	0.31	0.00
160	α-Cubebene	0.00	0.00	0.00	0.10	0.00
161	Eugenol	0.00	0.00	0.00	0.15	0.00
162	Azulene, 2,3,3a,4,7,8-hexahydro-3a,6-dimethyl-1-(1-methylethyl)-	0.00	0.00	0.00	0.15	0.00
163	.alfa.-Copaene	0.00	0.00	0.00	0.72	0.00
164	8-Isopropenyl-1,5-dimethyl-1,5-cyclodecadiene	0.00	0.00	0.00	3.48	0.00
165	Guaia-6,9-diene	0.00	0.00	0.00	5.18	0.00
166	o-Menth-2-ene, 4-isopropylidene-1-vinyl-	0.00	0.00	0.00	0.38	0.00
167	β-Selinene	0.00	0.00	0.00	3.94	0.00
168	α-Selinene	0.00	0.00	0.00	1.49	0.00
169	α-Himachalene	0.00	0.00	0.00	0.43	1.75
170	Cadina-1(10),4-diene	0.00	0.00	0.00	1.40	0.00
171	Tetradecane, 2,6,10-trimethyl	0.00	0.00	0.00	0.44	0.00
172	Murolan-3,9(11)-diene-10-peroxy	0.00	0.00	0.00	0.22	0.00
173	1,4-Benzenediol, 2,3,5-trimethyl-	0.00	0.00	0.00	0.38	0.00
174	Germacrene D-4-ol	0.00	0.00	0.00	0.27	0.00
175	β-Guaiene	0.00	0.00	0.00	0.20	0.00
176	Isoaromadendrene epoxide	0.00	0.00	0.00	0.21	0.00
177	Viridiflorol	0.00	0.00	0.00	0.28	0.00
178	Cedrenol	0.00	0.00	0.00	0.12	0.00
179	7-epi-cis-sesquisabinene hydrate	0.00	0.00	0.00	0.11	0.00
180	Ledene oxide-(II)	0.00	0.00	0.00	0.12	0.00
181	5-Methoxy-2,2,6-trimethyl-1-(3-methyl-buta-1,3-dienyl)-7-oxa-bicyclo[4.1.0]heptane	0.00	0.00	0.00	0.08	0.00
182	Geranyl isovalerate	0.00	0.00	0.00	0.07	0.00
183	Longifolenaldehyde	0.00	0.00	0.00	0.03	0.00

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
184	Aromadendrane-4,10-diol	0.00	0.00	0.00	0.14	0.00
185	Nerolidyl acetate	0.00	0.00	0.00	0.13	0.00
186	Tricyclo[6.3.1.0(1,5)]dodecan-9-ol, 2-benzoyloxy-4,4,8-trimethyl-	0.00	0.00	0.00	0.02	0.00
187	2,2,6-Trimethyl-1-(3-methylbuta-1,3-dienyl)-7-oxabicyclo[4.1.0]heptan-3-ol	0.00	0.00	0.00	0.01	0.00
188	Cyclohexanemethanol, 4-ethenyl-α,α,4-trimethyl-3-(1-methylethenyl)-, acetate, [1R-(1α,3α,4β)]-	0.00	0.00	0.00	0.04	0.00
189	(1R,7S,E)-7-Isopropyl-4,10-dimethylenecyclodec-5-enol	0.00	0.00	0.00	0.01	0.00
190	2H-Pyran, 2-(7-heptadecynyloxy)tetrahydro	0.00	0.00	0.00	0.01	0.00
191	(6E,8E,10E)-2,6,11,15-Tetramethyl-2,6,8,10,14-hexadecapentaene	0.00	0.00	0.00	0.03	0.00
192	.(2E)-2-(4,7-Dimethyl-3,4,4a,5,6,8a-hexahydro-1(2H)-naphthalenylidene)-1-propanol	0.00	0.00	0.00	0.07	0.00
193	2-Heptadecanol	0.00	0.00	0.00	0.00	0.00
194	Cyclopropanebutyric acid, 2-[(2-nonylcyclopropyl)methyl]-, methyl ester	0.00	0.00	0.00	0.00	0.00
195	Methyl 2-hydroxy-eicosanoate	0.00	0.00	0.00	0.00	0.00
196	Camphene	0.00	0.00	0.00	0.00	1.32
197	trans-β-Ocimene	0.00	0.00	0.00	0.00	1.41
198	1-Octanol, 3,7-dimethyl-	0.00	0.00	0.00	0.00	2.05
199	Dodecane	0.00	2.81	0.00	0.13	14.96
200	Undecane, 4,7-dimethyl	0.00	0.00	0.00	0.00	3.78
201	2,4,6-Octatriene, 2,6-dimethyl-, (E,E)-	0.00	0.00	0.00	0.00	0.10
202	Myrtenal	0.00	0.00	0.00	0.00	0.57
203	3,5-Decadiyne, 2,2-dimethyl-	0.00	0.00	0.00	0.00	0.08
204	Benzoic acid, ethyl ester	0.00	0.00	0.00	0.00	0.33
205	Naphthalene	0.00	0.00	0.00	0.00	0.99

Sl. No.	Compounds	*S. galapagense* VI037241	*S. cheesmaniae* VI037240	*S. habrochaites* LA1777	*S. h. var glabratum* VI030462	*S. lycopersicum* CL5915/CH45
206	Decane, 3,7-dimethyl-	0.00	0.00	0.00	0.00	0.50
207	Tetradecane	0.00	0.00	0.00	0.00	3.12
208	Tetradecane, 4-methyl-	0.00	0.00	0.00	0.00	1.77
209	Tetradecane, 2,6,10-trimethyl-	0.00	0.00	0.00	0.00	5.09
210	α-Isocomene	0.00	0.00	0.00	0.00	2.09
211	1,5,8-Trimethyl-1,2-dihydronaphthalene	0.00	0.00	0.00	0.00	0.03
212	Spiro[4.5]decan-7-one, 1,8-dimethyl-8,9-epoxy-4-isopropyl-	0.00	0.00	0.00	0.00	0.05
213	1-Hexadecanol, 2-methyl-	0.00	0.00	0.00	0.00	0.26
214	5,6,6-Trimethyl-5-(3-oxobut-1-enyl)-1-oxaspiro[2.5]octan-4-one	0.00	0.00	0.00	0.00	0.08
215	2-Buten-1-one, 1-(2,6,6-trimethyl-1-cyclohexen-1-yl)-	0.00	0.00	0.00	0.00	0.37
216	.(3E)-4-(1-Hydroperoxy-2,2-dimethyl-6-methylenecyclohexyl)-3-penten-2-one	0.00	0.00	0.00	0.00	0.74
217	α-Cedrol	0.00	0.00	0.00	0.00	0.37
218	1-Dodecanol, 3,7,11-trimethyl-	0.00	0.00	0.00	0.00	5.89
219	Hexadecane, 2,6,11,15-tetramethyl	0.00	0.00	0.00	0.00	5.26
220	(-)-Isolongifolol, methyl ether	0.00	0.00	0.00	0.00	0.03
221	Longifolenaldehyde	0.00	0.00	0.00	0.00	0.06
222	2-Hexadecanol	0.00	0.00	0.00	0.00	0.07
223	1-Hexadecanol, 2-methyl-	0.00	0.00	0.00	0.00	0.20
224	4a-Hydroxy-6-isopropenyl-4,8a-dimethyloctahydro-1(2H)-naphthalenone	0.00	0.00	0.00	0.00	0.09
225	1-Oxa-spiro[4.5]deca-6,9-diene-2,8-dione, 7,9-di-tert-butyl-	0.00	0.00	0.00	0.00	0.23
226	3-Ethyl-3-methylnonadecane	0.00	0.00	0.00	0.00	0.04

Table 69: Different groups of volatile recorded from GCMS profiling on different genotypes

	Area in (%)				
Sum of chemicals	***S. galapagense* *VI037241***	***S. cheesmaniae* VI037240**	***S. habrochaites* LA1777**	***S. habrochaites var. glabratum* VI030462**	***S. lycopersicum* CH45**
Acid/Ester	0.23	2.46	0.28	1.23	0.33
Alcohol	0.70	5.36	1.56	3.23	8.88
Aldehyde	0.26	0.00	0.01	0.03	0.63
Alkanes/alkenes	2.73	23.96	1.78	19.32	63.77
Epoxide	0.00	11.08	0.07	0.21	0.00
Monoterpenes	59.65	28.84	10.02	60.77	10.28
Others	0.00	1.26	5.02	0.63	3.32
Sesquiterpenes	33.73	45.28	81.28	44.24	0.16
Terpenes	0.00	0.43	0.07	0.40	0.00
Terpenoids	2.75	1.79	0.16	1.48	0.00

Table 70: EAG response of *Tuta absoluta* females to different tomato plant volatiles

Bonferroni's multiple comparisons test	Mean Diff. in response peak	Significant
Air vs. Honey	-0.00129	****
Air vs. *S. lycopersicum* CL5915/CH45	-0.0006123	****
Air vs. *S. cheesmaniae* VOI37240	-0.0002053	NS
Air vs. *S. habrochaites var glabratum*VOI30462	-0.0002378	NS
Air vs. *S. habrochaites* LA1777	-0.000662	****
Air vs. *S. galapagense* VOI37241	-0.0003852	***
Honey vs. *S. lycopersicum* CL5915/CH45	-0.0006777	****
Honey vs. *S. cheesmaniae* VOI37240	-0.001085	****
Honey vs. *S. habrochaites var glabratum* VOI30462	-0.001052	****
Honey vs. *S. habrochaites* LA1777	-0.000628	****
Honey vs. *S. galapagense* VOI37241	-0.0009048	****
S. lycopersicum CL5915/CH45 vs. *S. cheesmaniae* VOI37240	-0.000407	***
S. lycopersicum CL5915/CH45 vs. *S. habrochaites var glabratum*VOI30462	-0.0003745	**
S. lycopersicum CL5915/CH45 vs. *S. habrochaites* LA1777	-4.966e-005	NS
S. lycopersicum CL5915/CH45 vs. *S. galapagense* VOI37241	-0.0002271	NS
S. cheesmaniae VOI37240 vs. *S. habrochaites var glabratum*VOI30462	-3.253e-005	NS
S. cheesmaniae VOI37240 vs. *S. habrochaites* LA1777	-0.0004567	****
S. cheesmaniae VOI37240 vs. *S. galapagense* VOI37241	-0.0001799	NS
*S. habrochaites var glabratum*VOI30462 vs. *S. habrochaites* LA1777	-0.0004242	***
*S. habrochaites var glabratum*VOI30462 vs. *S. galapagense* VOI37241	-0.0001474	NS
S. habrochaites LA1777 vs. *S. galapagense* VOI37241	-0.0002768	NS

Significant at P= 0.001, NS= Non significant, **= Significant.

cultivated tomato plants that are stressed after oviposition by *T. absoluta*, and their levels increase with increased oviposition (Buttery *et al.*, 1987; Proffit *et al.*, 2011; Balayiannis *et al.*, 2015). These compounds have been associated with attraction of predators of different stages of *T. absoluta* like *Aphidius ervi* Marshall (Hymenoptera: Braconidae) and *Macrolophus pygmaeus* Rambur (Heteroptera, Miridae) (De Backer *et al.*, 2014; Balayiannis *et al.*, 2015).

The present finding suggests that all the wild accessions which showed resistance are having different potential green leaf volatiles to repel or deter *T.absoluta*. These results lay down some groundwork for exploiting semiochemical traits of the wild tomato species in novel management of *T. absoluta* and help in understanding the role of different volatiles for their choice of preference.

4.3.8 Correlation between *T. absoluta* damage and morphological and biochemical traits

Correlation studies of foliar damage and morphological and biochemical factors are represented in Table 70 and discussed below. Total no. of leaves per plant at 45 DAT and 65 DAT was significantly negatively correlated with foliar damage (r=-0.73 and r=-0.77 respectively). Stem thickness at 45 and 90 DAT was positively correlated with susceptibility or higher foliar damage (r=0.88 and r=0.85, respectively). Leaf thickness at 45 and 90 DAT was found to be significantly positively correlated with pest damage (r= 0.92 and 0.95 respectively). Total no. of non-glandular trichomes were found to be positively correlated with the foliar damage but statistically non-significant, whereas total glandular trichomes showed high significant negative correlation with the foliar damage (r=-0.92). Total glandular trichomes showed highly significant positive correlation (R^2=0.94) with high acyl sugar level and total glandular trichomes showed significant negative correlation with egg load by *T. absoluta* (R^2=0.89) (Fig. 10).

Correlation studies with biochemical factors revealed that there was non-significant correlation between chlorophyll content and foliar damage. Significant positive correlation was found between total sugar content and foliar damage (r=0.96 &0.98 at 45 and 90 DAT respectively). Phenol content (r=-0.48 and -0.65 at 45 and 90

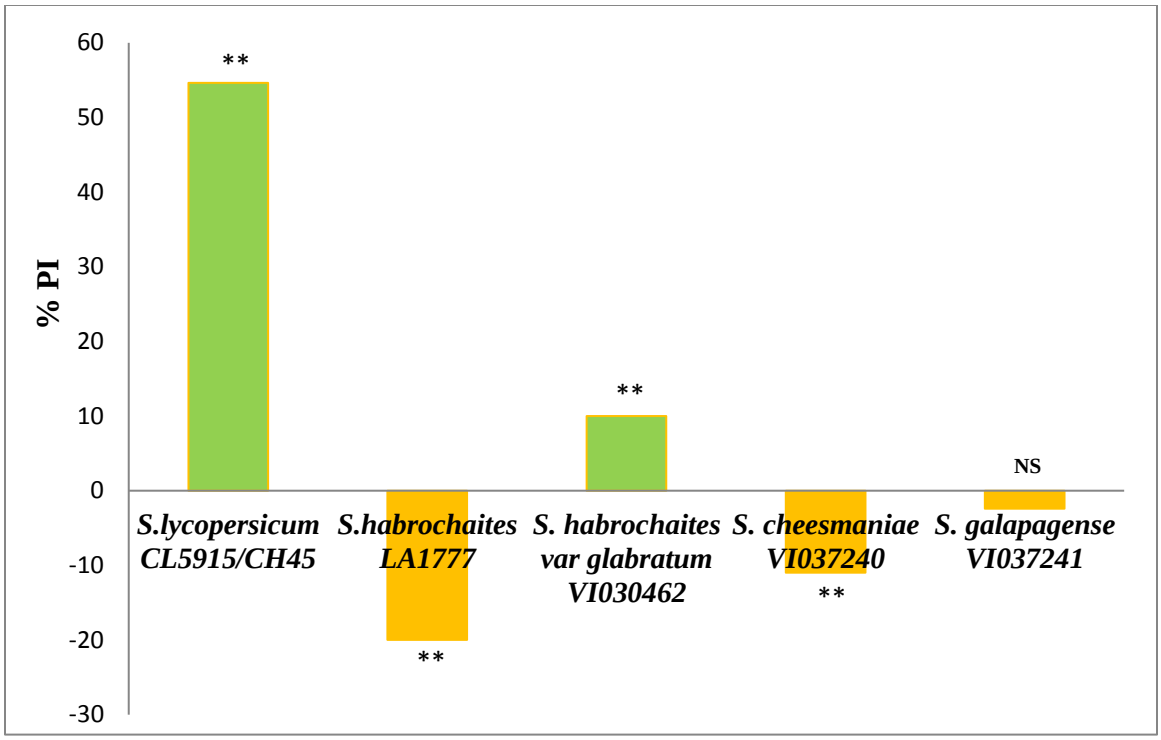


Fig. 8: Preference index of *T. absoluta* over control in single choice assay

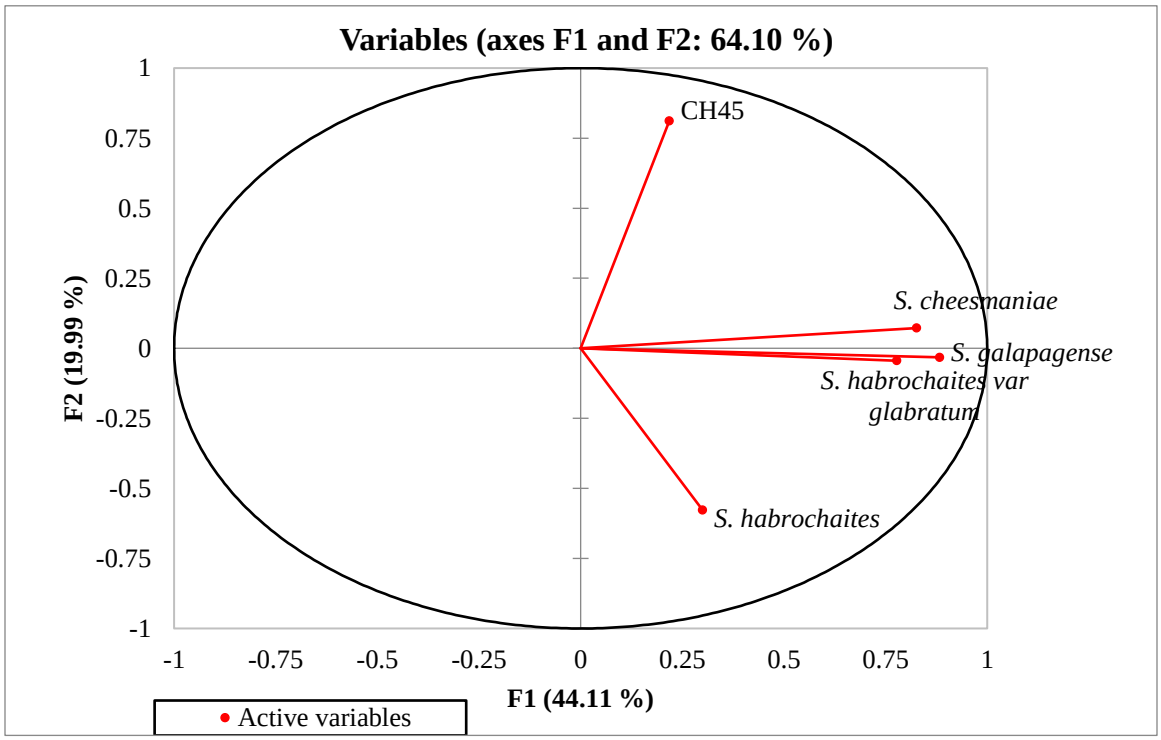


Fig. 9: Principle component analysis of different volatile chemicals extracted from different genotypes

DAT respectively) and tannin content at 90 DAT (r=-0.66) was significantly negatively correlated with foliar damage. Trichome metabolite acylsugar showed strong negative correlation with foliar damage (r=-0.89). Acyl sugar content showed significant negative correlation with larval mines, oviposition preference, egg load under field conditions (Table 69). The results showed that under field conditions, the no. of leaf mines per 20 leaves (r= -0.71**), per cent leaf damage (r= -0.66**), per cent fruit damage (r= -0.59**), and egg counts per 20 leaves were significantly negatively correlated with acyl sugar content. Similarly, egg counts under laboratory choice bio-assay showed significant negative correlation between total no. of eggs laid and acylsugar content at p = 0.001 (Table 71). Regression analysis indicated that larval mortality was influenced by acylsugar content of leaves (R^2 = 0.63) to an extent of 63.00 per cent and regression equation was as follows.

% larval mortality =0.281 + (0.066) x acylsugar+0.151

The results indicated that an increase of one per cent acylsugar content would lead to an increase of larval mortality by 0.06 per cent (Fig. 6).

The present findings are similar with those of Jayaraj and Sellamma, 1988; Jenkins, 1989 and Watson, 1989. In cotton, the insect resistance is associated with various morphological traits. There are certain morphological characteristics in cotton such as hairiness (glabrous v/s hairy), leaf shape (okra v/s normal) and the presence or absence of nectar-producing glands on leaves or flowers make the plants less attractive to pests, this can reduce their survival or growth. Hairiness is one of the important easily recognizable insect resistant trait in cotton. In numerous species there is a negative correlation between the trichome density and insect feeding, oviposition responses and the nutrition of larvae. Specialized hooked trichomes may impale adults or larvae as well. Hairiness has been reported to have resistance against the sucking insect pests of cotton.

Screening of *S. galapagense, S. lycopersicum* along with their F1 and F2 under field condition

Six field trials had shown high resistance levels in *S. galapagense* (VI037241) and for further confirmation, this wild accession was selected as resistant parent and

Table 71: Correlation between *T. absoluta* damage and different morphological and biochemical parameters

Morphological parameters	Per cent damage (Correlation coefficient = r)
Plant height @45DAT	0.69^{NS}
Plant height @ 9DAT	-0.34^{NS}
Total no. of leaves/plant @45 DAT	-0.73^{*}
Total no. of leaves/plant @90 DAT	-0.77^{*}
Branch angle	0.38^{NS}
Leaf angle	-0.12^{NS}
Stem thicknes@45DAT	0.88^{*}
Stem thickness@90DAT	0.85^{*}
Leaf thickness @45 DAT	0.92^{*}
Leaf thickness @90 DAT	0.95^{*}
Leaf area	0.69^{NS}
Rind thickness	0.99^{NS}
Fruit size	0.79^{NS}
Non glandular trichome	0.73^{NS}
Total glandular trichome	-0.92^{*}
Biochemical parameters	Per cent damage (Correlation coefficient = r)
Per cent foliar damage	1.00
Chlorophyll @45 DAT	-0.86^{NS}
Chlorophyll @90 DAT	-0.98^{NS}
Amino acid @45 DAT	0.97^{*}
Amino acid @90 DAT	0.99^{*}
Total soluble protein @45 DAT	-0.94^{NS}
Total soluble protein @90 DAT	-0.70^{NS}
Phenol content @45 DAT	-0.48^{*}
Phenol content @ 90 DAT	-0.65^{*}
Tannin content in leaves @45 DAT	-0.41^{NS}
Tannin content in leaves @90 DAT	-0.66^{*}
Tannin content in fruit	-0.46^{NS}
Total sugars @45 DAT	0.96^{*}
Total sugars @90 DAT	0.98*
Non reducing sugars @45 DAT	0.81^{NS}
Non reducing sugars @90 DAT	0.70^{NS}
Acyl sugar level	-0.89^{*}

*Indicates significance at p=0.05, NS= non significant

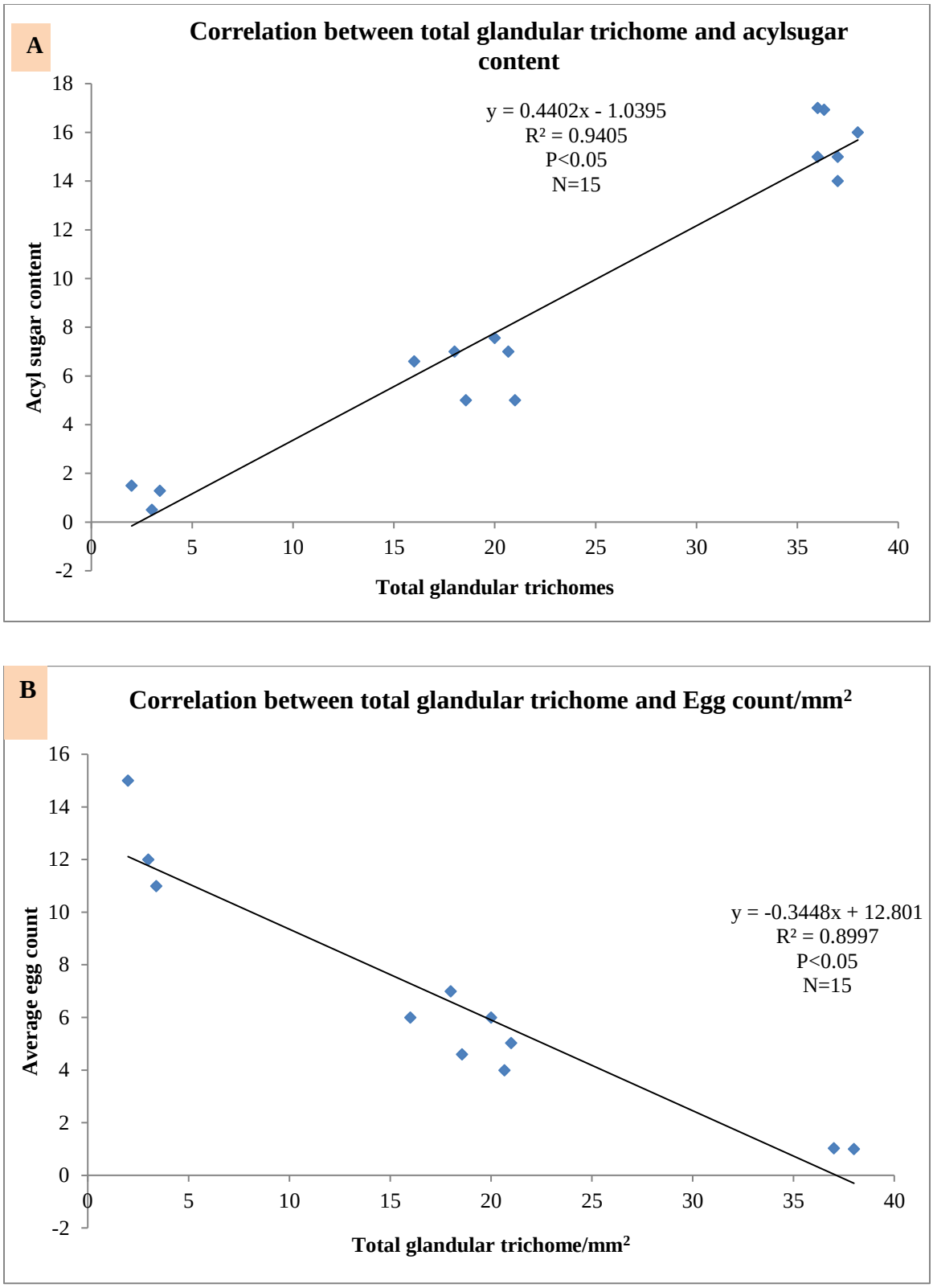


Fig. 10: Correlation between total glandular trichomes with acyl sugar content (A) and egg count (B)

Table 72: Correlation between *T. absoluta* damage and acylsugar content

Parameters	Correlation coefficients (r) for Acyl sugar content
No of leaf mines	**-0.714****
Leaf damage (%)	**-0.667****
Fruit damage (%)	**-0.599****
Egg loadper 20 leaves (under field conditions)	**-0.649****
Egg count in choice bioassay (under laboratory conditions)	**-0.69****

NB: ** indicates significance at P<0.001

interspecific crosses were made by crossing between highly resistant and susceptible genotype. Variation in their response towards insect damage was recorded. Field trial was carried out for F2, F1, P1 (*S. lycopersicum* CL5915) and P2 (*S. galapagense* VI037241) and the variation among them was recorded. Based on the damage and acylsugar content the plants grouped into four categories i.e resistant, moderately resistant, moderately susceptible and susceptible. From susceptible parent (P1), all the plants showed susceptibility and resistant parent (P2) showed resistance.

Among F2, 19 plants showed resistance, 27 plants showed moderate levels of resistance and 16 plants showed susceptibility towards *T. absoluta* or any other insect damage (Table 72). Further the plants were screened with 25 SNP markers and 7 of them showed polymorphism (Table 73) among resistant and susceptible parents. From 7 polymorphic SNP markers, **LGC_Tom_59159** (located on Chromosome 10) only showed significant difference with the resistant trait *i.e.* acylsugar content and resistance observed under field condition. This SNP marker can be associated with the trait of high acyl sugar content (Table 75) which can be used in further studies on host plant resistance against *T. absoluta.*

Table 73: Field observations on F2, F1, P1, P2 plants and their categorization based on acyl sugar content and foliar damage by *T.absoluta.*

No. of plants under each category					
Damage	**Category**	**F2**	**F1**	**P1 (susceptible parent)**	**P2 (Resistant parent)**
0-5% foliar damage	Resistant	19	32	0	10
5-10% foliar damage	Moderately resistant	27	0	0	0
10-15% foliar damage	Moderately susceptible	0	0	0	0
>15% foliar damage	Susceptible	16	0	10	0
	Total number of plants	62	32	10	10

Table 74: Number of polymorphic markers detected and per cent polymorphism between selected parents

Sl. No.	SNP Markers used	Markers showed polymorphism
1	LGC_Tom_ 61192	LGC_Tom_ 61192
2	LGC_Tom_ 12212	LGC_Tom_ 12212
3	LGC_Tom_ 62495	LGC_Tom_ 3112
4	LGC_Tom_ 3112	LGC_Tom_100197
5	LGC_Tom_ 4926	LGC_Tom_18443
6	LGC_Tom_100164	LGC_Tom_59159
7	LGC_Tom_100197	LGC_Tom_65964
8	LGC_Tom_13202	
9	LGC_Tom_17161	
10	LGC_Tom_17655	
11	LGC_Tom_18443	
12	LGC_Tom_3017	
13	LGC_Tom_33701	
14	LGC_Tom_33701 (R)	
15	LGC_Tom_36192	
16	LGC_Tom_50902	
17	LGC_Tom_5191	
18	LGC_Tom_55037	
19	LGC_Tom_59159	
20	LGC_Tom_61108	
21	LGC_Tom_65964	
22	LGC_Tom_9707	
23	1195-0007	
24	LGC_Tom_8223	
25	LGC_Tom_15058	
Total number of markers used	No of markers showed polymorphism	Polymorphism (%)
25	**7**	**28%**

Table 75: Frequency of polymorphism among resistant and susceptible F2 plants by using SNP markers

Frequency of showing polymorphism amongst resistant and susceptible F2 plants		
SNP polymorphic Markers	**P Value**	**Sig.**
LGC_Tom_ 61192	0.11	NS
LGC_Tom_ 12212	0.83	NS
LGC_Tom_ 3112	0.49	NS
LGC_Tom_100197	0.5	NS
LGC_Tom_18443	0.33	NS
LGC_Tom_59159	**0.007****	**S**
LGC_Tom_65964	0.53	NS

** indicates significance

Future line of work:

1. Utilization of the *T. absoluta* and *Thrips* resistant wild accessions identified during the present investigations in tomato field trials for breeding programmes for development of resistant hybrids.
2. Selection of high number of glandular trichomes especially type –IV for choosing as resistant trait against insect damage.
3. Acyl sugar content can be used as biochemical marker for developing insect resistant lines for future purpose.
4. The plants showing higher acyl sugar level in F2 can be taken forward for next generation.

V SUMMARY

Investigations on the morphological and biochemical factors imparting resistance against the invasive American pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) and thrips species in tomato was carried out at M/s I @B Seeds Pvt Ltd. Kengeri, Uttarahallii, Bengaluru and in the Department of Agricultural Entomology, University Agricultural Sciences, GKVK campus, Bengaluru during 2017-18 and 2018-19. The salient findings of these investigations are summarized in this chapter.

In seven cropping seasons (*rabi* 2017-18,summer 2018-19, *kharif* 2018-19), totally five genotypes and two commercial hybrids were screened for their reaction to *T. absoluta* and thrips damage.

The overall egg and larval load per 20 leaves were more during summer 2018 and 2019 followed by *rabi* 2017-18. During *kharif* the pest load was relatively less but differed significantly between genotypes. Four thrips species were recorded from the two season field trials *i.e. Gynaikothrips uzeli* Zimmermann, *Scirtothrips dorsalis* Hood, *Thrips palmi* Karny and *Thrips hawaiiensis* Morgan from the collected thrips samples. Only one vector species of TOSPO disease *i.e. Scirtothrips dorsalis* Hood was used for further laboratory screening studies. Correlation studies with weather parameters revealed that rainfall and relative humidity had significant negative correlation and temperature had a significant positive correlation with moth catch of *T. absoluta*.

All the field investigations revealed that *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) have high degree of resistance against *T. absoluta* and thrips with significantly lesser egg and larval load, besides lower per cent foliar and fruit damage in all the seasons, followed by *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) whereas commercial hybrid TM 308, PT 4208 and *S. lycopersicum* (CL5915) showed higher susceptibility towards *T. absoluta* with upto 30.00-57.00 per cent foliar and 20-50 per cent fruit damage during different season field trials. Overall thrips countper tap was 0.00-0.5 no.per tap in resistant wild accessions but ranges between 1.5-5 no.per tap in susceptible genotypes.

Pest population and damage was very low during *kharif* 2018 and 2019. Therefore, artificial screening was taken up for intensive screening under laboratory conditions under high pest pressure by conducting choice and no-choice experiments for both *T. absoluta* and *Scirtothrips dorsalis.*

Laboratory bioassays showed significantly higher egg load in susceptible genotypes than in the resistant wild accessions. Egg load was significantly highest in *S. lycopersicum* (CL 5915), followed by TM 308 and PT4208 and lowest in *S. cheesmaniae* (VI037240). Proportion of egg load was more in susceptible genotypes when choice was given to *T. absoluta* gravid females.

Significantly higher egg load was observed in abaxial surface and lesser number of eggs were observed on the stalks in case of susceptible genotype *i.e. S. lycopersicum* (CL 5915). These findings showed differential preference of leaf surface in different genotypes may have a significant role in the ovipositional preference of *T. absoluta*. No-choice bioassay revealed strong negative impact on *T. absoluta* larvae and on its biology when fed with the leaves of resistant wild accessions. High larval mortality was recorded in *S. cheesmaniae* (VI037240), followed by *S. galapagense* (VI037241). *T. absoluta* larvae can mine lesser leaf area in resistant wild accessions and thus gained very less pupal weight. Pupae attained highest weight which when they were fed on susceptible genotype *S. lycopersicum* (CL 5915) followed by other wild accessions. Pupal weight of 2.08<2.44<2.88<3.50<4.56 was recorded on *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites var. glabratum* (VIO30462), *S. habrochaites* (LA1777) and *S. lycopersicum* (CL 5915) respectively.

Choice bioassay of *Scirtothrips dorsalis* showed significantly highest egg load in *S. lycopersicum* (Cl5915), followed by *S. habrochaites var glabratum* (VI030462) and no egg load was observed in the three wild accessions *i.e. S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) and *S. habrochaites* (LA1777). In no choice assay, wild accessions showed higher resistance by causing higher per cent larval mortality of thrips. Per cent larval mortality in *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), *S. lycopersicum*

(Cl5915) was 82.60, 83.60, 40.60, 46.00 and 15.00 per cent respectively. Even adult emergence rate was significantly low in resistant accessions.

Morphological traits varied significantly between resistant wild accessions and susceptible genotypes. Total number of non-glandular type of trichomes varied significantly among different genotypes and was highest in *S. lycopersicum* (CL5915) whereas glandular trichomes were to be found more in wild accessions. Trichome type and density varied significantly between susceptible and resistant genotypes. Higher density of type I and IV trichomes on the leaves imparted greater degree of resistance against insect damage.

Resistant wild accessions have high total no. of leaves per plant but lesser leaf area (cm^2). Correlation studies showed that total no. of leaves per plant at 45 DAT and 65 DAT is significantly negatively correlated with foliar damage (r=-0.73* and r=-0.77*, respectively). Stem thickness at 45 and 90 DAT was positively correlated with susceptibility or higher foliar damage (r=0.88* and r=0.85*, respectively). Leaf thickness at 45 and 90 DAT was found to be significantly positively correlated with pest damage (r= 0.92* and 0.95*, respectively). Total no. of non-glandular trichomes were found to be positively correlated with the foliar damage but statistically non-significant whereas total glandular trichomes showed high significant negative correlation with the foliar damage (r=-0.92*). Total glandular trichomes showed highly significant positive correlation (R^2=0.94*) with acyl sugar content and total glandular trichomes showed significant negative correlation with egg load of *T.absoluta* (R^2=0.89)

Among biochemical parameters, acyl sugar, tannin content and phenol content were found at a significantly higher range in resistant wild accessions as compared to that in susceptible genotypes or commercial hybrids. Acyl sugar from upper, middle and lower canopy leaves of *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462), *S. lycopersicum* (CL5915/CH45), TM 308 and PT 4208 was 14.00, 16.5, 8.25, 6.00, 1.25,0.75, 1.25 µmoles/g 13.50, 14.86, 6.41, 6.99, 1.16, 1.08, 0.93 and 12.21,13.57, 8.13, 6.39, 1.42, 1.01, 1.11 µmoles/g of leaf weight, respectively. Mean acyl sugar content was high in

upper canopy leaves than the middle and lower canopy though it is not statistically significant. Although acylsugar content reduced drastically during *kharif* season at different phenological stages. Total sugar was found to be significantly more in susceptible genotypes and less in resistant wild accessions.

PPO and PO content was found to be higher in *S. habrochaites* (LA1777) when the plants were infested with *T. absoluta* larvae, whereas it did not differ significantly in healthy plants of different genotypes. Infested leaf samples of *S. galapagense* (VI037241) showed the highest PO content (48.25 Unit/mg), followed by *S. cheesmaniae* (VI037240), *S. habrochaites* (LA1777), *S. habrochaites var glabratum* (VI030462) and *S. lycopersicum* (CL 5915) with a mean value of 43.00, 41.00, 38.00 and 21.00 units/mg, respectively. In susceptible genotype the PO content was found to be significantly less after pest infestation.

Resistant wild accessions showed stark differences in their green leaf volatile profile as compared to the susceptible genotypes. Olfactometer bioassay showed that gravid female of *T. absoluta* has more preference towards the volatile blends of susceptible genotype i.e. *S. lycopersicum* (CL5915) than other resistant wild accessions. There were significant differences in EAG response between volatile puffs of susceptible *S. lycopersicum* (CL5915) with resistant genotypes *S. cheesmaniae* (VI037240) and *S. habrochaites var glabratum* (VI030462). Dual choice in olfactometer bioassay with gravid female of *T. absoluta* also showed higher time spent (min) towards the susceptible arm than with the resistant wild accessions, except *S. galapagense* (VI037241). Entry frequency in dual choice assay was found to be significant when *S. habrochaites* (LA1777) and *S. habrochaites var. glabratum* (VI030462) were compared with *S. lycopersicum* (CL5915) but non-significant in entry frequency in case of *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240). Green leaf volatiles of different resistant wild accessions have some role in response level but the exact compounds behind the preference or rejection was not been clearly evident hence further investigation is necessary. In wild accessions, some elements were found at higher level than susceptible genotype. Some volatile *viz.*, Limonene, α-Pinene, δ-EIemene, β-Caryophyllene, (+)-4-Carene, β-Pinene, γ-elemene, β-Ocimene and α-Santalene were found relatively higher

in wild accessions, than in the susceptible check *S. lycopersicum* (CL5915). Grouping of chemicals revealed that monoterpenes and sesquiterpenes were found to be relatively higher in wild accessions and alcohols and alkenes were significantly higher in susceptible genotype. These finding suggests that all the wild accessions which showed resistant reaction might posess potential green leaf volatiles to either repel or deter *T. absoluta*.

Overall findings of the present investigation throws light about the morphological and biochemical parameters of wild accessions which has a major role in conferring resistance against *T. absoluta* and thrips damage either by deterring or repelling them from egg laying or causing deleterious impact on their lifecycle.

Based on the present findings, research was taken forward and F2 genotypes of susceptible (*S. lycopersicum* (CL5915) and resistant (*S. galapagense* VI037241) parent was screened further under field conditions. Plants with higher acyl sugar content from F2 were selected for future breeding trials. The wide variation present in different genotypes can be exploited in the resistance breeding programmes, particularly for *T. absoluta* and thrips spp. in tomato.

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APPENDIX I

Resistance level and acyl sugar content in leaves of individual plants of different genotypes and their resistance level under field conditions

Sl. No.	Entry	AS tube code	Acyl sugar in umoles/ gram weight	Fruit size	Presence of larval mines/ 20 leaves observed	leaf area damaged (%)	Resistance scale to *Tuta absoluta*
1	F2	P1	2.09	Cherry	3	20	Moderately resistance
2	F2	P2	1.56	Medium	8	40	Susceptible
3	F2	P3	1.79	Cherry	5	30	Resistant
4	F2	P4	**2.54**	Cherry	4	20	**Moderately resistance**
5	F2	P5	2.20	Cherry	4	24	Resistant
6	F2	P6	2.70	Medium	0	0	Resistant
7	F2	P7	1.45	Medium	0	0	Susceptible
8	F2	P8	2.62	Cherry	3	20	Moderately resistance
9	**F2**	**P10**	**6.44**	**Cherry**	**0**	**0**	**Resistant**
10	F2	P9	2.47	Big	3	5	**Moderately resistance**
11	F2	P11	2.92	Medium	10	30	Susceptible
12	F2	P12	2.02	Medium	3	10	Moderately resistance
13	F2	P13	1.54	Big	4	20	Moderately resistance
14	F2	P14	2.39	Big	5	20	Moderately resistance
15	F2	P15	1.46	Big	8	25	Susceptible
16	F2	P16	1.64	Big	9	40	Susceptible
17	**F2**	**P17**	**3.63**	**Cherry**	**3**	**20**	**Moderately resistance**
18	F2	P18	2.59	Cherry	4	20	Moderately resistance
19	F2	P19	2.48	Big	4	30	Moderately resistance
20	**F2**	**P20**	**3.61**	**Medium**	**1**	**5**	**Resistant**
21	F2	P21	2.34	Cherry	0	0	Resistant
22	F2	P22	2.09	Cherry	8	35	Susceptible
23	F2	P23	2.01	Cherry	8	30	Susceptible
24	F2	P24	1.32	Cherry	10	40	Susceptible
25	**F2**	**P25**	**3.16**	**Cherry**	**0**	**0**	**Resistant**
26	F2	P26	1.89	Cherry	2	5	Resistant
27	F2	P27	1.20	Cherry	3	8	Moderately resistance
28	F2	P28	2.21	Cherry	2	10	Moderately resistance
29	F2	P29	1.51	Medium	4	20	Moderately resistance
30	F2	P30	1.64	Big	0	0	Resistant
31	F2	P31	1.96	Cherry	3	5	Moderately resistance
32	F2	P32	1.84	Medium	4	20	Moderately resistance
33	F2	P33	1.71	Big	4	15	Moderately resistance
34	**F2**	**P34**	**5.09**	**Cherry**	**2**	**12**	**Resistant**
35	F2	P35	1.44	Cherry	4	20	Moderately resistance
36	F2	P36	2.87	Cherry	11	10	Susceptible

Sl. No.	Entry	AS tube code	Acyl sugar in umoles/ gram weight	Fruit size	Presence of larval mines/ 20 leaves observed	leaf area damaged (%)	Resistance scale to *Tuta absoluta*
37	**F2**	**P37**	**4.63**	**Cherry**	**2**	**10**	**Resistant**
38	**F2**	**P38**	**3.29**	**Cherry**	**1**	**5**	**Resistant**
39	F2	P39	1.25	Big	4	20	Moderately resistance
40	F2	P40	2.51	Cherry	2	10	Resistant
41	F2	P41	1.44	Cherry	8	30	Susceptible
42	**F2**	**P42**	**2.41**	**Cherry**	**1**	**4**	**Resistant**
43	F2	P43	2.53	Cherry	10	40	Susceptible
44	F2	P44	1.81	Big	2	10	Moderately resistance
45	F2	P45	1.16	Medium	0	0	Resistant
46	F2	P46	1.75	Big	0	0	Moderately resistance
47	F2	P47	1.68	Cherry	5	34	Susceptible
48	F2	P48	1.42	Big	8	40	Susceptible
49	F2	P49	2.85	Cherry	6	32	Susceptible
50	F2	P50	2.35	Cherry	0	0	Resistant
51	F2	P51	1.79	Cherry	2	12	Moderately resistance
52	F2	P52	1.84	Cherry	4	20	Moderately resistance
53	**F2**	**P53**	**3.17**	**Big**	**2**	**10**	**Resistant**
54	**F2**	**P54**	**3.84**	**Medium**	**0**	**0**	**Resistant**
55	F2	P55	1.67	Medium	0	0	Moderately resistance
56	F2	P56	1.01	Medium	5	5	Moderately resistance
57	F2	P57	1.73	Medium	6	2	Moderately resistance
58	F2	P58	2.48	Cherry	0	0	Resistant
59	F2	P59	2.08	Big	7	28	Susceptible
60	F2	P60	2.59	Cherry	5	20	Susceptible
61	F2	P61	1.96	Cherry	4	20	Moderately resistance
62	F2	P62	1.72	Cherry	3	10	Moderately resistance
63	F1	P1	2.98	Cherry	1	2	Resistant
64	F1	P2	2.24	Cherry	0	0	Resistant
65	F1	P3	1.66	Cherry	0	0	Resistant
66	F1	P4	2.57	Cherry	0	0	Resistant
67	F1	P5	1.85	Cherry	0	0	Resistant
68	F1	P6	2.73	Cherry	0	0	Resistant
69	F1	P7	1.75	Cherry	0	0	Resistant
70	F1	P8	1.68	Cherry	0	0	Resistant
71	F1	P9	1.35	Cherry	1	2	Resistant
72	F1	P10	1.72	Cherry	0	0	Resistant
73	F1	P11	2.01	Cherry	0	0	Resistant
74	F1	P12	2.84	Cherry	0	0	Resistant
75	F1	P13	2.14	Cherry	0	0	Resistant
76	F1	P14	1.56	Cherry	0	0	Resistant
77	F1	P15	1.68	Cherry	0	0	Resistant

Sl. No.	Entry	AS tube code	Acyl sugar in umoles/ gram weight	Fruit size	Presence of larval mines/ 20 leaves observed	leaf area damaged (%)	Resistance scale to *Tuta absoluta*
78	F1	P16	1.97	Cherry	1	3	Resistant
79	F1	P17	2.19	Cherry	0	0	Resistant
80	F1	P18	1.81	Cherry	0	0	Resistant
81	F1	P19	1.26	Cherry	0	0	Resistant
82	F1	P20	2.54	Cherry	0	0	Resistant
83	F1	P21	2.83	Cherry	0	0	Resistant
84	F1	P22	2.96	Cherry	0	0	Resistant
85	F1	P23	1.89	Cherry	0	0	Resistant
86	F1	P24	1.65	Cherry	0	0	Resistant
87	F1	P25	2.53	Cherry	0	0	Resistant
88	F1	P26	2.23	Cherry	0	0	Resistant
89	F1	P27	3.03	Cherry	0	0	Resistant
90	F1	P28	2.66	Cherry	0	0	Resistant
91	F1	P29	3.09	Cherry	0	0	Resistant
92	F1	P30	2.99	Cherry	0	0	Resistant
93	*S. lycopersicum* (CL5915)	P1	2.02	Big	8	40	Susceptible
94	*S. lycopersicum* (CL5915)	P2	1.91	Big	9	30	Susceptible
95	*S. lycopersicum* (CL5915)	P3	2.27	Big	10	35	Susceptible
96	*S. lycopersicum* (CL5915)	P4	1.87	Big	8	40	Susceptible
97	*S. lycopersicum* (CL5915)	P5	1.23	Big	7	50	Susceptible
98	*S. lycopersicum* (CL5915)	P6	1.86	Big	9	70	Susceptible
99	*S. lycopersicum* (CL5915)	P7	2.36	Big	8	40	Susceptible
100	*S. lycopersicum* (CL5915)	P8	2.01	Big	8	45	Susceptible
101	*S. lycopersicum* (CL5915)	P9	1.72	Big	7	40	Susceptible
102	*S. lycopersicum* (CL5915)	P10	2.15	Cherry	8	30	Susceptible
103	*S. galapagense*(VI037241)	P1	13.13	Cherry	0	0	Resistant
104	*S. galapagense*(VI037241)	P2	14.25	Cherry	0	0	Resistant
105	*S. galapagense*(VI037241)	P3	10.67	Cherry	0	0	Resistant
106	*S. galapagense*(VI037241)	P4	13.03	Cherry	0	0	Resistant
107	*S. galapagense*(VI037241)	P5	15.18	Cherry	0	0	Resistant
108	*S. galapagense*(VI037241)	P6	14.55	Cherry	0	0	Resistant
109	*S. galapagense*(VI037241)	P7	12.51	Cherry	0	0	Resistant
110	*S. galapagense*(VI037241)	P8	11.30	Cherry	0	0	Resistant
111	*S. galapagense*(VI037241)	P9	8.02	Cherry	0	0	Resistant
112	*S. galapagense*(VI037241)	P10	11.66	Cherry	0	0	Resistant
113	*S. galapagense*(VI037241)	P11	14.64	Cherry	0	0	Resistant
114	*S. galapagense*(VI037241)	P12	11.36	Cherry	0	0	Resistant

APPENDIX II

EAG response peak of *T. absoluta* against volatile puff of different genotypes

Response in millivolts							
	Air	**honey**	***S. lycopersicum* CL5915**	***S. cheesmaniae* VI037240**	***S. habrochaites var. glabratum* VI030462**	***S. habrochaites* LA1777**	***S. galapagense* VI037241**
1	-8.000E-06	-1.298E-03	-7.120E-04	-2.252E-04	-2.853E-04	-7.000E-04	-4.912E-04
2	-8.000E-06	-1.298E-03	-5.120E-04	-2.466E-04	-2.676E-04	-7.380E-04	-8.306E-04
3	-8.000E-06	-1.298E-03	-5.340E-04	-2.666E-04	-1.876E-04	-9.160E-04	-3.854E-04
4	-8.000E-06	-1.298E-03	-8.340E-04	-1.116E-04	-3.328E-04	-3.800E-04	-1.174E-04
5	-8.000E-06	-1.298E-03	-6.820E-04	-2.140E-04	-1.166E-04	-6.400E-04	-3.806E-04
6	-8.000E-06	-1.298E-03	-1.346E-03	-2.706E-04	-2.696E-04	-5.800E-04	-1.116E-04
7	-8.000E-06	-1.298E-03	-6.220E-04	-1.340E-04	-1.788E-04	-5.520E-04	-9.360E-05
8	-8.000E-06	-1.298E-03	-7.420E-04	-1.946E-04	-1.906E-04	-6.400E-04	-4.120E-04
9	-8.000E-06	-1.298E-03	-6.220E-04	-1.340E-04	-1.788E-04	-5.520E-04	-9.360E-05
10	-8.000E-06	-1.298E-03	-7.420E-04	-1.946E-04	-1.906E-04	-6.400E-04	-4.120E-04

#10 biological replicates.

#Response peaks measured in millivolt

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Screening of Elite Genotypes of Tomato against Major TOSPO Vector- Thrips Complex

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A B S T R A C T

Tomato is the second most important vegetable grown in India. It faces heavy attack by pest and diseases in tropical countries. Biotic and abiotic stress is major challenge for higher production of tomatoes. Thrips complex are important sucking pests which also cause more damage as vector species for virus diseases. So controlling the vector by screening against thrips damage/preference is the major concern for screening and developing lines resistant to thrips. Five elite lines were procured from World Vegetable Centre, AVRDC, Taiwan. Field screening and lab screening was carried out for evaluating thrips resistance. Four different thrip species viz., *Thrips palmi, Scirtothrips dorsalis, Gynaikothrips uzeli and Thrips hawaiiensis* were recorded in two dry seasons from collected thrips complex. Thrips count/tap was significantly less or almost nill in two wild accessions *Solanum galapagense* (VI037241) *and S.cheesmaniae* (VI037240) than susceptible genotype *Solanum lycopersicum* (CL5915)/(CH45). Although total thrips count was more in *Solanum habrochaites* and *Solanum habrochaites var glabratum* but in lab assay it showed less preference for egg laying and also in terms of feeding. In vitro leaf disc assay has shown high mortality of larva and entrapped larvae died because of sticky exudates from high glandular trichomes. Field screening has shown high resistance to two of the wild accessions in terms of thrips catch/tap. Lab assay has shown less preference to all the four wild accessions for egg laying and feeding except *S.lycopersicum*(CL5915). These assays can help to get an insight about high glandular trichome density and thrips resistance which can help in developing TOSPO virus resistant lines for future.

Introduction

Tomato is the second most important vegetable crop in India just after potato. India is a great contributor for vegetable industries in terms of its production. Though a range of factors contribute to the low yields, insect pests and diseases have been found to be the most damaging (Kagezi *et al.,* 2001; Karungi *et al.,* 2009). The most important insect pests afflicting the crops are aphids, whiteflies, thrips, African bollworm, and mites (Defrancq, 1989; Mwaule, 1995; Kagezi *et al.,* 2001; Ssekyewa, 2006). Besides being important sucking pests, thrips also transmit the deadly tospo viruses in tomato in a persistent and propagative manner. The successful transmission of tospo virus by

thrips involves the acquisition of the virus followed by internalization within body and inoculation in a susceptible host. Multiplication of tospo virus has been shown in the epithelial cells of midgut, muscle cells surrounding the gut and salivary gland cells of thrips. Eleven thrips species are recorded to transmit twenty tospo viruses worldwide. In India, only six thrips species are reported to transmit six tospo viruses so far. However, the first study on thrips-tospo virus was reported in 1981.Though, the research on tospo viruses was initiated in India during 1960s very few reports are there about vector resistance.

Thrip species such as *Thripspalmi* and *Scirtothripsdorsalis* form another major group which is important as vectors of virus diseases of tomato. These pests destroy seedlings before they have a chance to become hardy. They can thrive on expanding plant tissue - the flower buds, tomato fruits, as well as growing stems and leaves. In addition, thrips can harbour tomato spotted wilt (TOSPO) virus, which can cause severe damage. Tospo virus infection is known to induce a suite of symptoms on its host plants including leaf speckling, mottling, chlorotic, and necrotic lesions of various shapes, sunken spots, etches, ring spots, stunting, yellowing, and wilting (David *et al.,* 2011). Both larval and adult stages of thrips vectors can actively feed on virus infected host plants, but only early larval instars can acquire the virus and later instar larvae and adults can transmit the virus after a latent period (Ullman *et al.,* 1997, Persley *et al.,* 2006). The major attention is because they cause direct and indirect damage. The direct injury and the virus disease result in discoloration of fruits, thus lowering the quality of the fruits which is almost 23.7% yield loss found by Kagezi *et al.,* (2001). Host plant resistance can be an important component of IPM programs. Resistant plants can help maintain pest populations below economic injury levels and are usually compatible with other control methods, in addition to being ecofriendly.

Information on insect resistance levels among a large number of accessions and their underlying resistance mechanisms would be very useful for tomato breeders worldwide. The objective of this study was to characterize all available wild accessions of AVRDC – The World Vegetable Center's genebank for trichome types, and to evaluate their resistance to thrips. Finding resistance source is the most important criteria to combat against different insect complex. As thrips can play more destructive role as a vector, getting vector resistance by field and lab screening was the interest of our study.

Materials and Methods

Field experimental design

The present investigation was carried out at M/S I@ B Seeds, Kengeri, Uttarahalli, Bengaluru, Karnataka and a monitoring survey was conducted for two consecutive growing seasons in 2017 dry season followed by 2018 dry season. Five wild accessions procured from AVRDC Taiwan were transplanted in a randomized block design with four replications. All the agronomic practices were followed except plant protection according to the package of practices. Five plants/plot and as a total twenty plants were randomly selected in each genotype for taking count and visually rated for thrips infestation based on upward leaf curl damage. The rating was used for recording the thrips infestation done at six different phonological intervals i.e. 3^{rd}, 6^{th}, 9^{th},12^{th} and 15^{th} weeks after transplanting with symptoms severity on a 0-3 scale as per the standard procedure given by Niles(1980) as Scoring category Symptoms 0 - No leaf curling (healthy plant) 1 < 25% (1-25%) low curling, 26-50% (26-50%) moderate curling, 51- 75% (51-75%) heavy curling.

Data were collected on thrips occurrence, from each selected plant, by counting and collecting thrips which were found on the underside of the three top-most, fully-expanded tomato leaflets. Thrips samples were collected in the late morning hours by gently tapping on the leaves, which dislodged the thrips from the leaves to white plastic trays placed under each plant. Using camel hair brushes, the thrips were transferred to vials containing 60% ethanol, glycerin, and acetyl glyceric acid (AGA) fluid in the ratio 10:1:1, respectively for preservation of futures (Palmer *et al.,* 1989; Palmer, 1990). The vials of thrips were then taken to the laboratory for counting and identification. Thrips were mounted and identified under a compound light microscope (manufactured by Leica), using the procedure described by Palmer (1990), at a magnification of 40x. Thrips complex were identified upto specis level from NBAII, Hebbal. Four major different species were recorded from two field trials. *Gynaikothrips uzelii, Scirtothrips dorsalis, Thrips palmi* and *Thrips hawaiiensis* were recorded from the collected thrips samples.

Among our identified thripspecis, two were reported as TOSPO vector till now in India *i.e. Thrips palmi* and *Scirtothrips dorsalis.* Only one vector species was further selected for screening the accessions under laboratory condition. *Scirtothrips dorsalis* was used for lab assay for screening those accessions. *S.dorsalis* culture was maintained in susceptible chilli cultivar planted in polybags by following no sprays and on capsicum fruits under laboratory condition at 16 light and 8 dark hours.

Leaf Disc Tests: *S. dorsalis* was collected from reared on susceptible Chilli (*Capsicum annum*) in an insect greenhouse at 25°C and 70% relative humidity (Koschier *et al.,* 2000). Adult female thrips were starved for 24 hours in a cage with only water (Murai and Loomans, 2001). Leaf discs (4 cm in diameter) were taken from fully opened leaves using a leaf punch and placed in Petri dishes on water agar (15g/l agar) with the lower (abaxial) side upward and placed in equidistance manner.

Ten starved female adult thrips and larvae were placed on each leaf disc using a wet brush separately. Dishes were closed using plastic cups having mesh attached for aeration and to prevent thrips from escaping and placed in a climate room at 24°C, 16 h light, 70% RH. There were six replicates for each accession. The extent of damage based on feeding scars (by larvae) and destruction by thrips (adults) feeding, oviposition and secretion were rated together using a relative scale from 0 (no damage) to 3 (severe damage) two days after inoculation. Per cent larval mortality was calculated by observing till 6 days regularly after release of second instar larvae onto the leaf disc.

Physiological trait (trichome type and density) analysis

Trichome types were identified by observing under Scanning electron microscope and classified according to Luckwill (1943) and determined the types present on both abaxial and adaxial sides. Density of trichome was carried out by counting the trichome numbers present in mm^2 area.

Presence of trichome type and density was further correlated with larval mortality, field thrips count/tap and egg laying preference by adult vector species i.e. *S. dorsalis.* Mean number of thrips count, egg count and leaf trichome count were subjected to statistical analysis using Analysis of Variance (ANOVA) after suitable transformation.

Results and Discussion

Among the thrips complex identified in 2018 summer season had more number of vector species rather than 2017 field data (Fig. 1) *Gynaikothrips uzeli* catch was more per tap during 2017 flowering stage whereas during 2018, other major tospo vector species were more.

Two season thrips count is represented in below (Table 1). Two accessions viz., *S. galapagense* (VI037241), *S. cheesmaniae* (VI037240) have shown high resistance to any of the thrips species with 0 to 1 thrips/tap where as in susceptible accession *S.lycopersicum* (CL5915) it was consistently more for both the season. In *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) the *Gynaikothri psuzeli* catch was more during its flowering stage in 2017 whereas very less in 2018. Although except *S.lycopersicum* (CL5915), all the other four wild accessions have shown resistance with no visual leaf curling. Lab choice bioassay has shown significant difference in egg laying preference than susceptible *S.lycopersicum* (CL5915), to all other four resistant accessions. No-choice lab assay has shown high larval mortality and less mobility and feeding preference to all four resistant accessions. More than 90 per cent larvae died in resistant wild accession especially in *S. galapagense* (VI037241), *S.cheesmaniae* (VI037240) followed by more than 60 per cent mortality in *S.habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) in laboratory bioassay (Fig. 2).

According to Fery and Schalk (1991) resistant cultivars support larval and adult thrips populations as large as those in susceptible cultivars, but with significantly less damage done. Our thrips catch per tap was not statistically significant for *S. habrochaites* (LA1777) and *S. habrochaites var glabratum* (VI030462) with susceptible *S. lycopersicum* (CL5915), although egg laying and mortality rate differed significantly among those two accessions and susceptible accession which are at a line with their findings.

One way ANOVA followed by Tukey HSD test showed that *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) are significantly differed than Susceptible *S.lycopersicum* (CH45) in terms of percent larval mortality $F(4,25)=75.49$, $p<.001$. Feeding scar on no choice assay was scored as scale 2 in susceptible accessions but 0 to almost nill in other four enties (Fig. 3).

The dense glandular trichomes (Fig. 4) conferred resistance by trapping the thrips adults and larvae and also have strong negative impact on its movement and feeding.

High glandular trichome density has shown resistance to other sucking pest like white flies, *Tetranychus* mite and also lepidopteran pests like *T.absoluta* (Rakha *et al.,* 2017, Sridhar *et al.,* 2019). Our field as well as lab studies shows high resistance of thrips population in case of *S. galapagense* (VI037241) and *S. cheesmaniae* (VI037240) which can be used as a resistant source for future breeding lines.

Wild accession from different province have some resistance trait like presence of glandular trichome "type iv" which shows high resistance against thrips by conferring hindrance in mobility causing less egg laying preference, less feeding and high mortality.

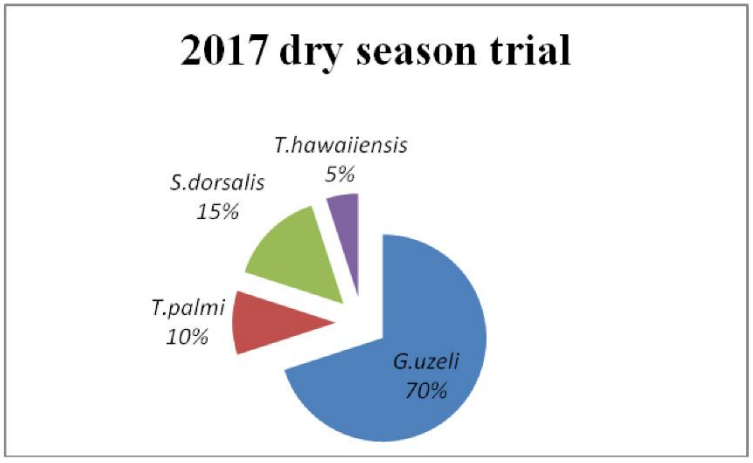
Finding any variety which can help to combat the vector thrips species can help in managing the damage caused by thrips and also by TOSPO disease (Table 2).

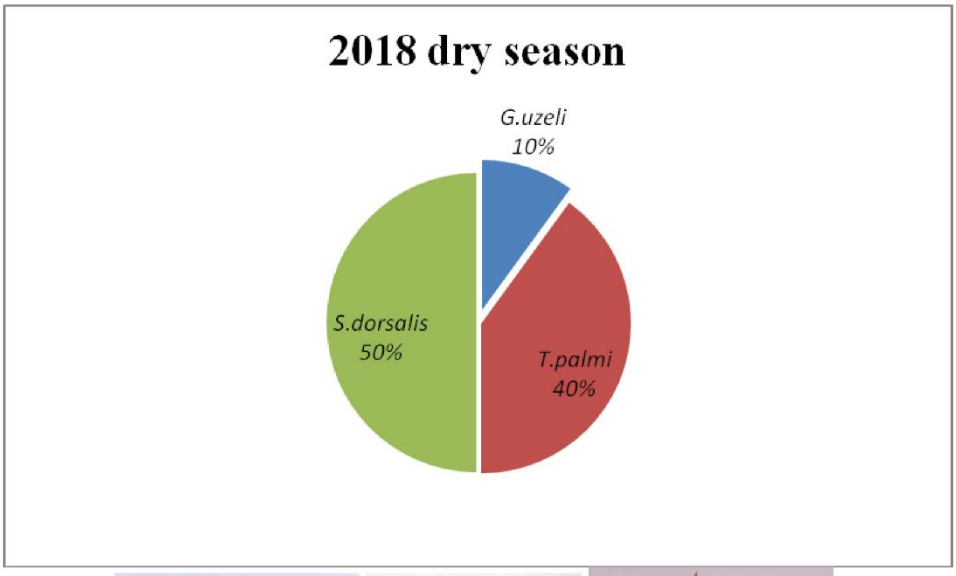
Table.1 Comparison of percent larval mortality of *Scirtothrips dorsalis*

Multiple comparisons							
Dependent Variable: percent mortality							
(I) wild accessions			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	*S.galapagense*	*S.cheesmaniae*	-3.55556	4.11804	.907	-15.6497	8.5386
		S.habrochaites	22.27778*	4.11804	.000	10.1836	34.3719
		S.habrochaitesvarglabratum	21.27778*	4.11804	.000	9.1836	33.3719
		S.lycopersicum	59.98611*	4.11804	.000	47.8920	72.0803
	S.cheesmaniae	*S.galapagense*	3.55556	4.11804	.907	-8.5386	15.6497
		S.habrochaites	25.83333*	4.11804	.000	13.7392	37.9275
		S.habrochaitesvarglabratum	24.83333*	4.11804	.000	12.7392	36.9275
		S.lycopersicum	63.54167*	4.11804	.000	51.4475	75.6358
	S.habrochaites	*S.galapagense*	-22.27778*	4.11804	.000	-34.3719	-10.1836
		S.cheesmaniae	-25.83333*	4.11804	.000	-37.9275	-13.7392
		S. habrochaites var glabratum	-1.00000	4.11804	.999	-13.0941	11.0941
		S.lycopersicum	37.70833*	4.11804	.000	25.6142	49.8025
	S.habrochaitesvarglabratum	*S.galapagense*	-21.27778*	4.11804	.000	-33.3719	-9.1836
		S.cheesmaniae	-24.83333*	4.11804	.000	-36.9275	-12.7392
		S.habrochaites	1.00000	4.11804	.999	-11.0941	13.0941
		S.lycopersicum	38.70833*	4.11804	.000	26.6142	50.8025
	S.lycopersicum	*S.galapagense*	-59.98611*	4.11804	.000	-72.0803	-47.8920
		S.cheesmaniae	-63.54167*	4.11804	.000	-75.6358	-51.4475
		S.habrochaites	-37.70833*	4.11804	.000	-49.8025	-25.6142
		S.habrochaitesvarglabratum	-38.70833*	4.11804	.000	-50.8025	-26.6142

*. The mean difference is significant at the 0.05 level.

Fig.1 Occurrence of Thrips species (in percentage) from collected samples





Thripshawaiiensi	*Scirtothripsdors*	*Thripspalmi*

Fig.2 No choice assay and larval mortality in (%)

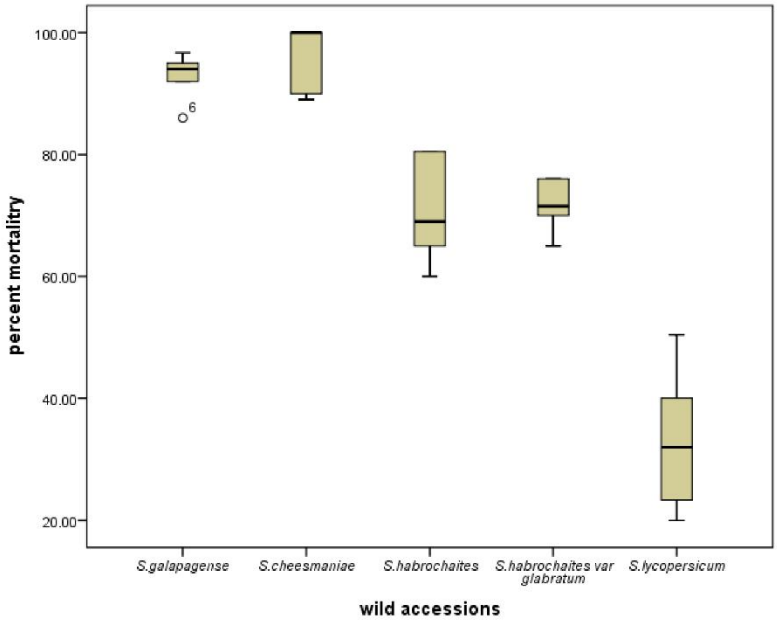


Fig.3 Egg laying assay of *Scirtothrips dorsalis* under laboratory condition

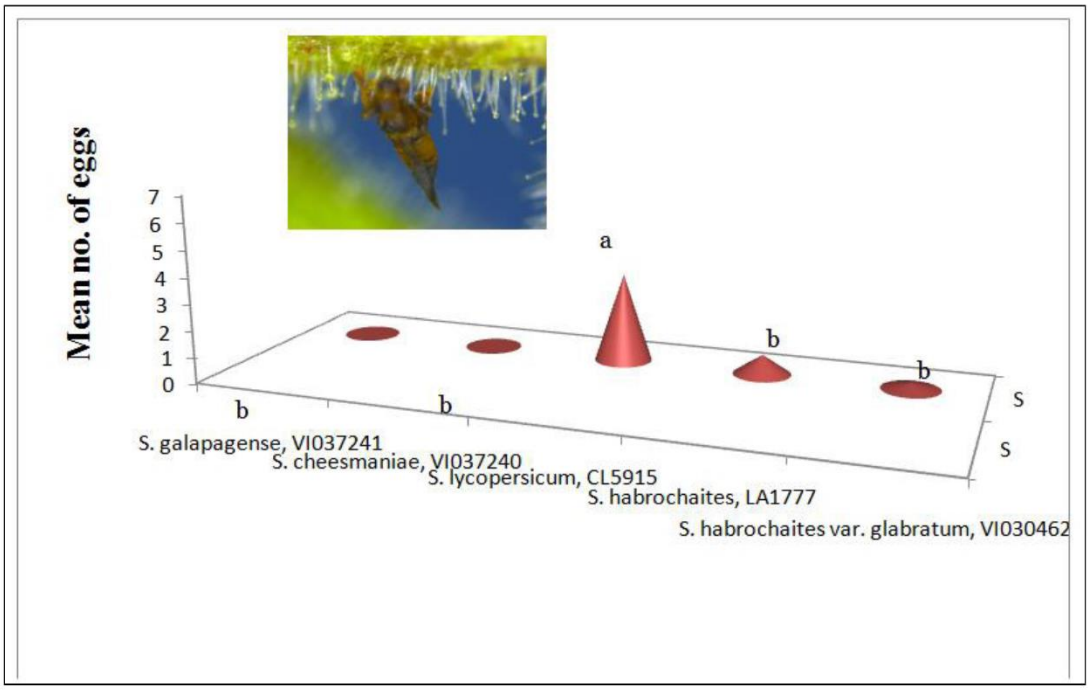


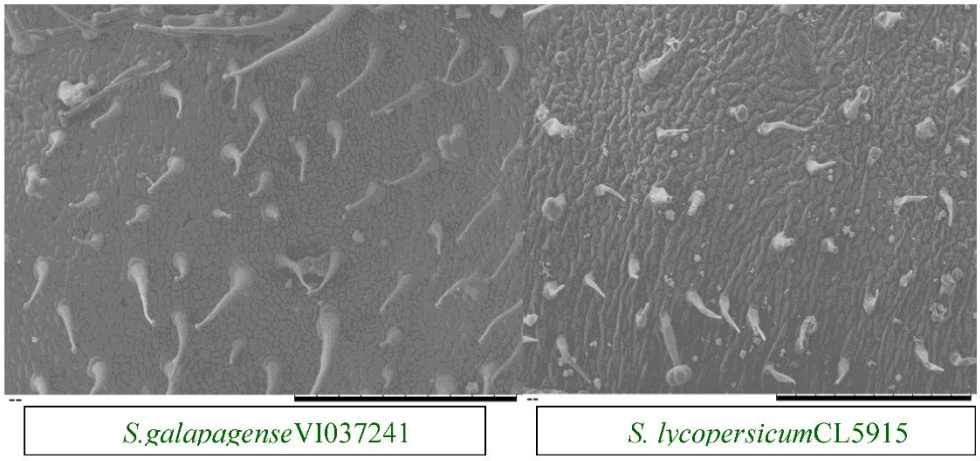
Table.2 Trichome density, laboratory egg laying assay and larval mortality assay

	total glandular	total non-glandular	Egg laid in choice assay	Per cent larval mortality
***S.galapagense*,VI037241**	22.12[a]	0.33[c]	0(0.70)[b]	92.94(74.98)[b]
***S.chesmaniae*,VI037240**	19.26[b]	0.27[c]	0(0.70)[b]	96.5(83.09)[a]
***S.habrochaites*,LA1777**	8.57[c]	17.42[b]	0.5 (0.9)[b]	70.66(57.40)[c]
***S. habrochaitesvar glabratum*,VI030462**	5.79[d]	23.96[b]	0.33(0.87)[b]	71.66(57.887)[c]
***S.lycopersicum*,CL5915**	2.02[e]	19.23[a]	3.33(1.86)[a]	29.16(34.806)[d]
SEM	0.48	0.5	0.02	6.14
CD(0.05)	2.262	2.32	0.429	9.77

Values in parenthesis are transformed values.

Fig.4 Thrips adult trapped in high glandular trichome

Fig.5 Trichome present in resistant and susceptible accession



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Acceptance letter

Dear Authors

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Population dynamics of Invasive insect pest *Tuta absoluta* in Tomato

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Abstract

Tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is serious pest infesting mainly Solanaceous plants worldwide. It became a problem on tomato crop since its invasion during 2014 in India. For enhancing the IPM control of this pest, very few studies have been conducted for assessing seasonal abundance and spatial distribution of this insect in India. This study aims to monitor the population fluctuation and infestation rate of *T. absoluta* on tomato crop under open field conditions. Different stages of *T. absoluta* were investigated in greenhouse during three cropping periods in 2018-2019. Different stages of *T. absoluta* were investigated under open fields during 2018 to 2019. At April 2018 the highest populations of *T. absoluta* per plant were recorded under both green house and open field condition. There was a peak in populations of *T. absoluta* per plant during October and March during 2018-2019. Low number of *T. absoluta* was recorded in the winter cropping cycle at December 2018 and Rainy 2018 *i.e.*, in July, August and September. The field study showed that *T. absoluta* population progress is increasing during tomato phenologic cycle. The peak load of *T. absoluta* starts from vegetative time with flowering and early fruit setting stages of the crop which leads to higher yield loss. Among weather parameters, rainfall and relative humidity showed negative impact on pheromone trap catches whereas temperature found to be positively correlated. Weather parameter has strong impact on population dynamics and thus these understanding will help to formulate IPM strategies to control *T. absoluta* management practices.

Keywords: *Tuta absoluta* ; invasive; Monitoring; Phenology; population dynamics

Introduction:

Tomato *Solanum lycopersicon* L., is one of the most important vegetable crops of India. It is grown in 0.760 M ha area, with an annual production of 18399 mt production (2015-16) [1]. The major tomato producing states are Bihar, Karnataka, Uttar Pradesh,

Orissa, Andhra Pradesh, Maharashtra, Madhya Pradesh and West Bengal. This crop is however attacked by multiple pests.

Among wide range of pests, the tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is one of the major pests of tomatoes, *Solanum lycopersicon* L., in South America. It was introduced to Europe via Spain and now it has spread all over the continent. Recently it has been found in Africa and Asia, where heavy damage occurred due to this pest. Larvae of *T. absoluta* can injure both the leaves and fruits of tomatoes, ultimately leading to reduction in yield [2]. Inspite of our country's strong quarantine measures, *T. absoluta* has invaded the country through wind and trade. It was first reported in Maharashtra during 2014. It can cause upto 90 per cent loss of yield and fruit quality under greenhouse and field conditions. Apart from the major host tomato, they also attack potato (*Solanum tuberosum*), eggplant (*S. melongena*), Jimson weed (*Datura stramonium*) broad bean (*Vicia faba*) and alfalfa (*Medicago sativa*) of the family Fabaceae and members of some of the Cucurbitaceae, Euphorbiaceae, Asteraceae etc., [3]. This invasive pest, *T. absoluta* is considered a serious problem to tomato production worldwide [4]. Thousands of tomato farmers are suffering from serious production losses due to devastating pest that destroying their valuable crop [5]. This pest can cause losses of 80 to 100% in tomato farms in greenhouse or in open fields if control measures are not properly implemented [6]. The climatic condition plays a major role in *T. absoluta* population buildup and thus causes high damage in the field.

The current status of *Tuta absoluta* is alarming as it can feed and attack several solanaceous host plants and the effective control measures are also not well known. The production loss of USD 59.3 and 8.5 million was reported in Kenya and Zambia, respectively (CABI 2019) [7]. Thus understanding the relationship of weather parameters and population buildup is necessary. The main focus of this study was to evaluate the population density of *T. absoluta* and finding the major environmental conditions which are congenial for their growth. Taking this factor into consideration, it is utmost essential to manage this pest in an eco-friendly manner, before it turns into a major bottleneck for successful tomato production. Our interest of this study was to investigate the influence

of weather factors on *T. absoluta* density and population dynamics of the pest under greenhouse and open field condition.

Materials and methods:

The experiments were laid out at the plots of M/s. I&B Seeds, Kengeri, Uttarahalli, Bengaluru which is situated in the Karnataka (India), located at an altitude of 930 MSL (12.90º N, 77.50º E) .The annual rainfall varies from 530 mm to 1200 mm, with a mean of 865 mm. All other agronomic management practices except plant protection for the field experiments were followed as per the recommended package and practices. Pheromone traps were installed to count the male adult density of the pest. Trap catches were recorded by using Pheromone trap (Koppert) which was installed for monitoring purpose, and correlated with the environment factors which may have impact on the density. Egg and larval load per 20 leaflets were recorded and per cent foliar were recorded for different seasons under open field and also under greenhouse condition. Potted plants were evaluated under greenhouse conditions. Observations were recorded for egg load, larval load and per cent foliar damage by considering random 20 leaflets from every canopy and average was taken. Observation was taken every week starting from transplanting to harvesting and the damage was correlated with weather parameters of previous week. Three seasonal periods were considered for recording the incidence level. Summer season from March-June, *kharif*/rainy season initiated from June-September and winter season started from October to February.

Results and Discussions:

Influence of meteorological variables on *T. absoluta* damage

There was higher egg and larval load during summer season starting from March to May. Highest population build up were recorded in the month of April for both open field and greenhouse observations. Per cent foliar damage due to highest larval load was observed in the month of April though it declined during July and August. The population of *T. absoluta* and mean weather parameters were subjected to multiple linear regression (MLR) analysis. The correlation matrix and regression co-efficient indicating

relationships between the insect population and meteorological variables are presented here under.

Table 1: Correlation coefficient and regression equation for *T. absoluta* and weather parameters

Summer 2019	**Rainfall (X_1)**	**Temperature**		**Relative humidity (%)(X_4)**	**R^2**	**Regression equation**
		Maximum (X_2)	**Minimum (X_3)**			
Pheromone trap catches of *T.absoluta*	-0.356	0.76*	0.81*	-0.61*	0.37	**$Y=-123.027-1.392X_1+4.410X_2-0.322X_3-0.20X_4+13.586$**
Mean no. of larvae per 20 leaves	0.10	-0.06	-0.29	0.05	0.13	**$Y= 0.453-0.033X_1+0.038X_2-0.227X_3+0.048X_4+0.636$**
***Kharif* 2019**						
Pheromone trap catches of *T. absoluta*	-0.36	0.51*	0.01	-0.53*	0.73	**$Y=-83.114-0.12X_1+1.325X_2-0.036X_3-0.806X_4+0.721$**
Mean no. of larvae per 20 leaves	0.01	-0.27	-0.37	0.15	0.21	**$Y= 15.393 -0.013X_1+0.190X_2-0.227X_3+0.048X_4+0.636$**

N=15 weeks,*indicates significance at $p<0.05$, X_1= rainfall (mm), X_2 = maximum temperature(°),X_3 = minimum temperature(°),X_4 = relative humidity (%)

During summer 2019, the trap catches of *T. absoluta* moth showed a negative correlation with rainfall (r = -0.35), positive correlation with maximum temperature (r = 0.76*) and minimum temperature (r =0.81*) and negative correlation with morning relative humidity (r = -0.61*) (Table 1). However the mean no. of larvae showed positive correlation with rainfall (r = 0.10), but the correlation coefficient was statistically non-significant. During *kharif* season, trap count (r = -0.36) was negatively associated with rainfall (Table 1) but it was statistically non-significant. Pheromone trap catches were found positively correlated with maximum temperature (r=0.51*) (Table 1).

When the data was subjected to multiple linear regression (MLR) analysis, results revealed that pheromone trap catches (R^2 = 0.37) was influenced to an extent of 37 per cent by rainfall, maximum temperature, minimum temperature and relative humidity

(Table 1). The multiple linear regression equation fitted with weather parameters and *T. absoluta* trap catch was as follows in summer season.

$$\mathbf{Y = -123.027 -1.392\ X_1+4.41X_2-0.32\ X_3-0.209X_4+13.586}$$

The results indicated that with an increase of one per cent rainfall, minimum temperature and relative humidity would lead to a decrease of 1.392 per cent,0.32 per cent 0.209 per cent moth catches, respectively and increase of one per cent of maximum temperature would lead to an increase of 4.41 per cent of *T. absoluta* moth catches.

Mean larvae/20 leaves and weather data showed that to an extent of 13 per cent of larval population (R^2 = 0.13) was influenced by the weather parameters. The multiple linear regression equation fitted with weather parameters and *T. absoluta* mean larval population was as follows.

$$\mathbf{Y= 0.453-0.033\ X_1+0.038X_2-0.036X_3+0.806X_4+0.721}$$

The results indicated that with an increase of one per cent rainfall, minimum temperature and relative humidity would lead to a decrease of 0.033 per cent, increase of 0.038 per cent, respectively and increase of one per cent of maximum temperature and relative humidity would lead to an increase of 0.036 and 0.806 per cent of mean no. of larvae per 20 leaves, respectively. Similar studies [8] reported that the maximum (r= -0.027 and -0.210) and minimum temperatures (r= -0.138 and -0.283) and minimum relative humidity (r= -0.191 and -0.031) were found to exert unfavourable influence on population development of whitefly and aphid species and showed negative correlation whereas maximum relative humidity (r=0.225 and 0.428) and sunshine hour (r=0.547 and 0.387) favoured the population build up which which are in line with our findings in case of field population of *T. absoluta.*

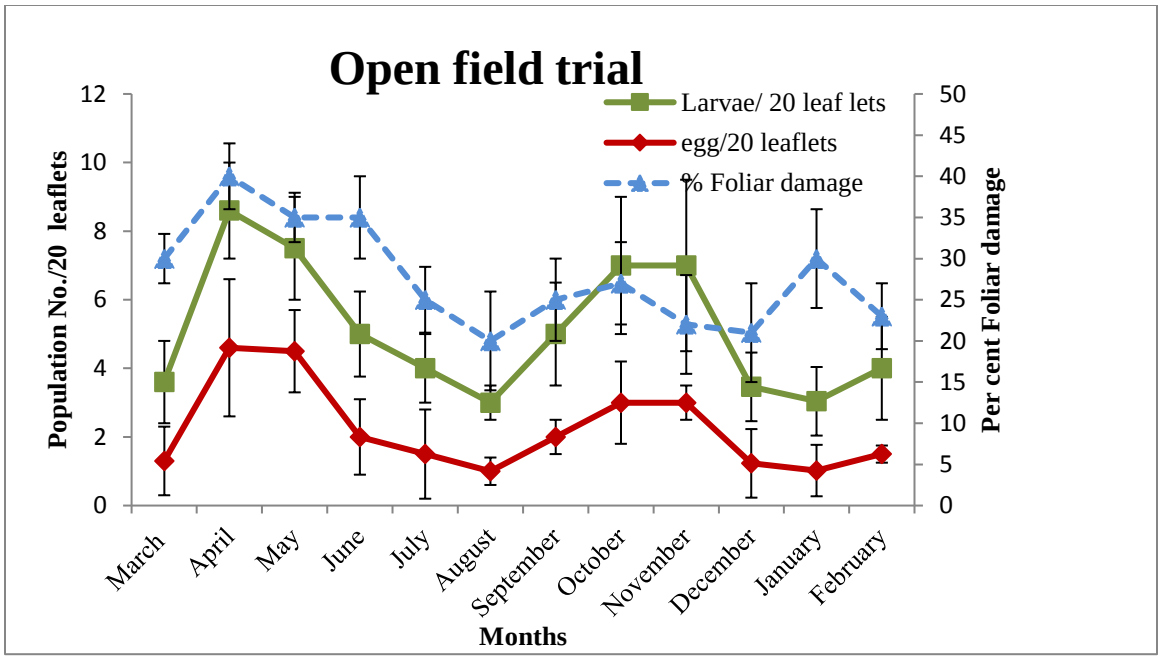

Fig 1: Monthly average population dynamics of *T. absoluta* on different stages per 20 leaf lets under open field conditions during 2018-2019.

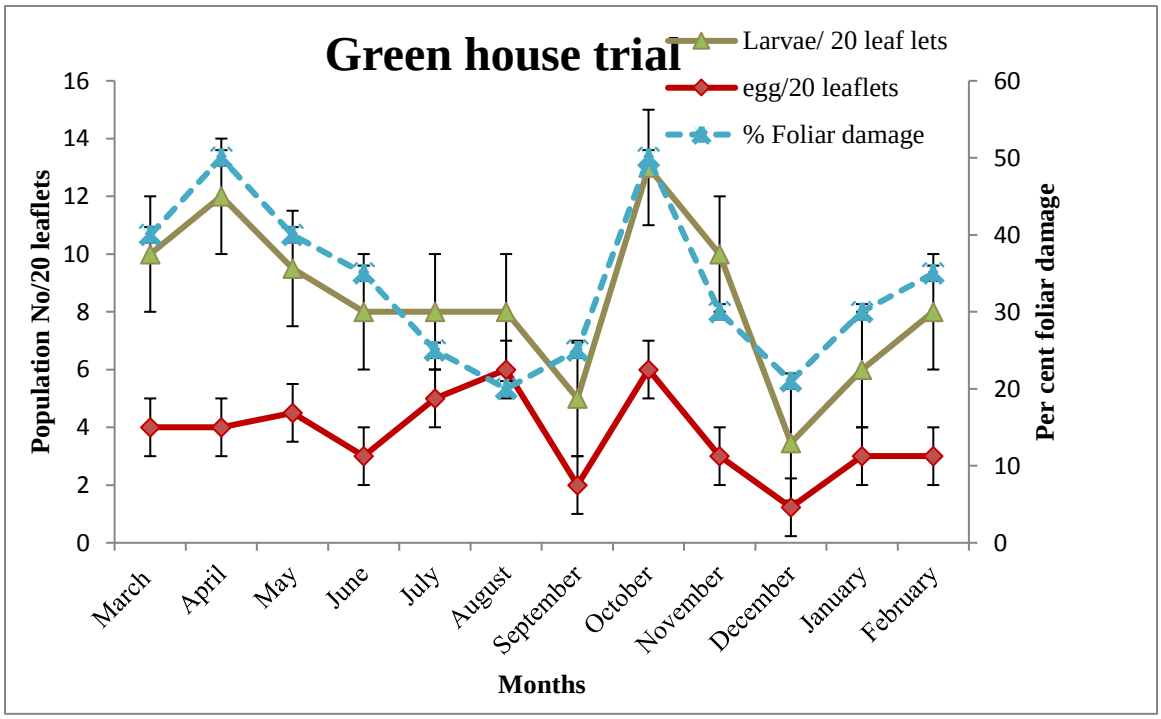

Fig 2: Monthly average population dynamics of *T. absoluta* on different stages per 20 leaflets under greenhouse conditions during 2018-2019.

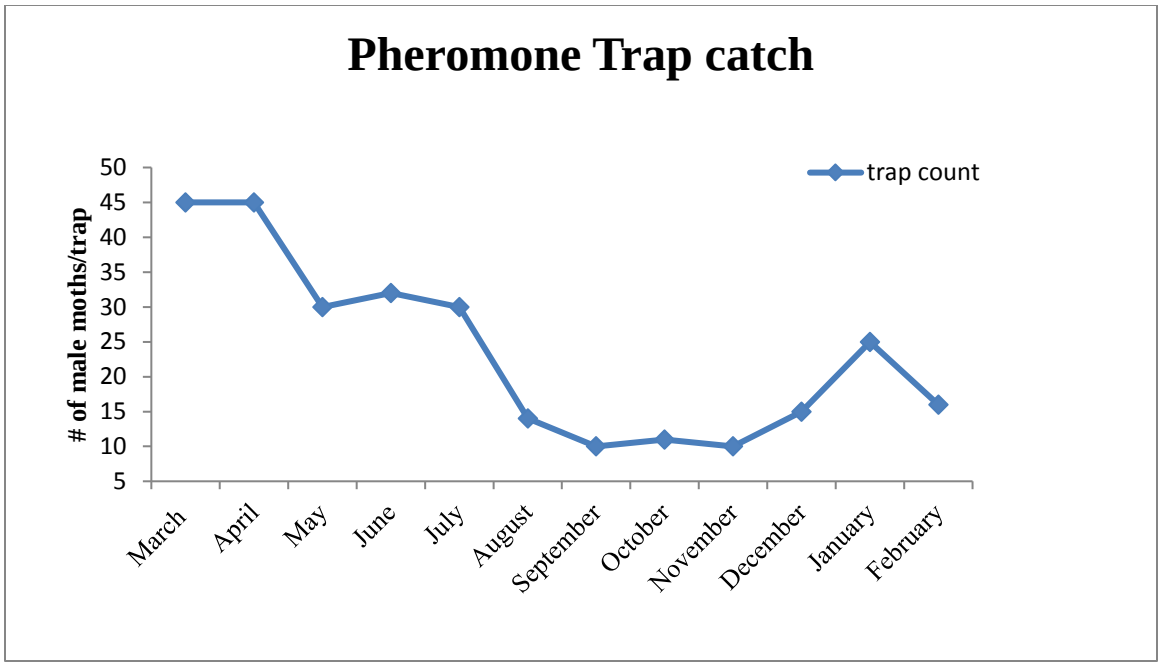

Fig 3: Pheromone trap catch of *T. absoluta* male moths in open field trial.

Trap catch was found highest during April month whereas it drastically reduced during rainy season *i.e.*, during end of July to August month. Although no significant correlation was observed with trap catch and egg and larval population in the open field trial. There were no significant (R^2=0.11) correlation between larval no. and foliar damage under greenhouse condition. *T. absoluta* is a key pest of tomato crops causing high losses. The knowledge of its population dynamics under greenhouse and open field conditions is considered as major step to plan effective management strategies. The present results showed that *T. absoluta* eggs and larval population number evolving at greenhouse was larger than that of the field studies. This number was influenced perhaps by abiotic factors like temperature, faulty agronomic practices, absence of natural enemies etc. Our results confirmed the previous studies of Miranda *et al.*, they reported that during the first phonologic stages of the crop, tomato plants are free from attack of *Tuta absoluta* .The average temperature recorded at this period was approximately 22-26°C. Their number became relatively high, as their attack became intense towards at vegetative stage of crop cycle. These results matched with those found by several authors [9]. Other findings underlined the occurrence and increase in *T. absoluta* captures during the crop season. Allache and Demnati mentioned that in Algeria, during the first

phenologic stages of the crop, tomato plants are free from attack of *T. absoluta* [10]. Harizanova et al. pointed that the leaves were the most heavily damaged plant parts [11]. Leite et al. found that the attack of *T. absoluta* was severe at the end of growing season, these authors suggested removal of crop residues and rotating with crops that were not suitable host for this pest [12]. *T. absoluta* females deposited their eggs on all plant-parts, they prefer laying eggs on leaves [13, 14]. Natural enemies present under field condition may also play role in reduced no. of egg load [15]. The tomato leaf miner, *T. absoluta* eggs number evolution in the greenhouse study was different from that of field studies. To manage this problem, using integrated pest management (IPM) and other alternative approaches, reducing pesticides use and preserving natural enemies by growers might be a solution. In summary, this study highlighted that the three field study areas and one glasshouse study lodged all *T. absoluta* developmental stages. Moreover, it was present during all tomato vegetative cycle and on all plant parts.

Conclusion

Damaged of tomatoes were high in the summer season, apart from damage on tomatoes in the rainy season. The maximum and most evident damages were on the leaves during vegetative stage. It is important to emphasize that heavy foliar damage leads to heavy fruit damage once the crop attains its fruiting stage. The level of *T. absoluta* was exist throughout the year if host is available and mostly depends on phenological stages. From this study, damages of tomatoes from the second cropping cycle, damages on all parts of the plant were visible but specifically the leaf parts totally invaded before fruit setting particularly under the glasshouse conditions. Hence, to manage *T. absoluta* this information can be utilized to know when to begin monitoring and control measures to be implemented which can be helpful for IPM practices.

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