Hexapoda (*Insecta indica*)
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Invasion by South American tomato moth, *Tuta absoluta* (meyrick) into India and R & D for its local management: A Review

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ABSTRACT: South American tomato moth, *Tuta absoluta* (Meyrick) (Gelechiidae: Lepidoptera), a serious pest of tomato (*Solanum lycopersicum*) in tropics and subtropics. It was first reported from India during 2014 and spread to all the major tomato regions in the country. Its occurrence and research developments for its management from India both for open and polyhouse conditions has been discussed in this paper. Various IPM tactics used like biological control, use of light and pheromone traps, initiatives for host plant resistance studies, use of insecticides *etc*. is reviewed in this paper.

Key words: *Tuta absoluta, Invasive* pest, management R&D, India

Introduction

The South American tomato moth, *Tuta absoluta* is a native of South America and it was first described from the specimens collected in Peru in 1917. It belongs to the family Gelechiidae under the order Lepidoptera which includes several other important agricultural pests such as the potato tuber moth (*Phthorimaea operculella*), pink bollworm (*Pectinosphora gossypiella*), tomato pinworm (*Keiferia lycopersicella*) and Guatemalan potato moth (*Tecia solanivora*). In 2006, *T. absoluta* was accidentally introduced to Spain from Chile and by 2009 it had spread to most of the European countries and crossed the Mediterranean Sea, reaching North African countries. By 2011, it had invaded countries in the Middle East. By 2014, it had crossed the Arabian Sea and established in India. Following its first report in India during 2014, it has now reached all major tomato growing areas in the country causing

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significant yield loss ranging from 50 to 100%, both under open and polyhouse conditions (Sridhar *et al.,* 2014; Sridhar *et al.,* 2020). The larvae of *T. absoluta* can destroy the tomato canopy by excavating the leaves, stems and buds and also burrow into fruits causing the quality decline of fresh tomato resulting in significant yield loss, if timely management interventions are not followed. The multiple generations of the pest coupled with its concealed habit while damaging the different parts of the plant, besides occurring at all stages of the crop, make it a difficult to control pest. The species has wide host range from Solanaceae family, an oligophagous pest (Nitin *et al.,* 2019) and is mainly associated with tomato among solanaceous plants. However, recent studies revealed that it can oviposit and develop on a wider range of cultivated and wild plant species.

This pest *is* known by different common names like tomato leaf miner, South American tomato moth, tomato borer or South American tomato pinworm. Detailed review about the worldwide occurrence, host plants and management aspects of *T. absoluta* are available from different authors (Illakwahhi and Lal Srivastava, 2017; Biondi *et al.,* 2018; Tarisikirwa *et al.,* 2020).

The present review is focused mainly on the R&D works carried out in India for the management of *T. absoluta* since its first report in 2014 from Karnataka and various initiatives undertaken for its local management in the country.

Occurrence in Indian states:

During 2014, *T. absoluta* was first reported in India from Karnataka infesting tomato and potato, with tomato being the primary host (Sridhar *et al.,* 2014). Soon thereafter it was also reported to cause significant damage in Maharashtra (Shashank *et al.*, 2015). Then on, it seems to have rapidly invaded other south Indian states *viz*. Telangana (Kumari *et al.*, 2015), Tamil Nadu (Shanmugam *et al.,* 2015, Balaji *et al.,* 2018), Kerala, Andhra Pradesh (Kumar *et al.,* 2015, 2018). The pest was subsequently also reported from other states like Gujarat (Chavan *et al.*, 2016, Patel *et al., 2020*), Chhattisgarh (Taram *et al.,* 2016), New Delhi (Shashank *et al.,* 2016), Madhya Pradesh (Swathi *et al.,* 2017), Punjab (Sidhu *et al.,* 2017), Meghalaya (Sankar Ganesh *et al.,* 2017), Himachal Pradesh (Sharma and Gavkare, 2017), Uttarakhand (Singh and Panchbhaiya, 2018), Uttar Pradesh (Halder *et al.,* 2019), Odisha (Sridhar and Srinivas, 2019), Rajasthan (Gaurang *et al.*, 2020) and Sikkim (Rajesh Kumar, 2020).

Biology of *Tuta absoluta*

Tuta absoluta is a multivoltine micro=lepidopteran moth with a high reproductive potential, capable of completing up to 12 generations per year under optimal conditions. Its life-cycle comprises of four developmental stages, *i.e.*, egg, larva, pupa and adult which are completed within 24 days at 27°C. There is need to monitor this pest for successful IPM because of its wide host range and concealed feeding habit with potential of causing 50 % to 100 % yield loss in either greenhouses or open fields. Brief account of biology has been given by different authors (Sridhar *et al.*, 2014, Ballal *et al.,* 2016, Nitin *et al.,* 2018).

Impact of temperature and elevated CO_2 on biology of *T. absoluta*

Nitin *et al.,* (2018) studied the effects of different temperatures (26, 28, 30, and 32°C) and CO_2 concentrations (380 and 550 ppm) on the life table of *T. absoluta at ICAR-IIHR, Bengaluru.* Age-stage, two-sex life tables were constructed using life history raw data of *T. absoluta*. The increase in temperature reduced the larval developmental time of *T. absoluta*, whereas the elevated CO_2 concentration (eCO_2) extended the larval developmental time. Highest fecundity rate was recorded at 30°C at ambient CO_2 (aCO_2) condition (88.10 eggs). Total fecundity significantly reduced under eCO_2 at 28°C and 30°C. There was 5 - 10% higher mortality observed under eCO_2 than aCO_2 condition. With rise in temperature from 26 to 30°C, *T. absoluta* reared under eCO_2 condition showed lower net reproductive rate, intrinsic and finite rate of increase in comparison to aCO_2. However, these parameters started decreasing at 32°C under both eCO_2 and aCO_2 conditions.

Alternate hosts and spread pathways

Under field conditions tomato is being preferred for egg laying and larval feeding when compared to other alternate hosts like potato, brinjal, chili, datura, capsicum, tobacco, black berry nightshade, tropical soda apple *etc.* (Nitin *et al.*, 2019, Salman *et al.*, 2020).

T. absoluta can *spread* through different pathways, such as through transport of infested seedlings, fruit packaging and transportation from different wholesale and retail markets and also through vehicles.

Nature of damage:

The larvae mine into the apical buds, tender new leaflets, flowers and also bore into the stems and green fruits. The larval mining is less in newly transplanted tomato and increases with the age and branches of the plant and the mines are more at the flowering stage of the plant (Dilip Sundar *et al.*, 2020). The characteristic large galleries caused by the larvae in the leaves, blisters caused by the galleries and the faecal matter within the mines could be observed in the infested fields. The feeding leads to necrosis and drying of plant parts, and drying of entire fields in case of severe infestation. Fruits infested by *T. absoluta* could be identified by presence of characteristic pin holes. The damage also attracts secondary pathogens leading to fruit rot (Sridhar *et al.* 2014; Ballal *et al.*, 2016, Sridhar *et al.*, 2020). As the crop damage can be starting from nursery itself, timely management of *T. absoluta* is of utmost importance.

Management of *T. absoluta*-Indian research, a case study

Studies and observations from different authors for the effective management of *T. absoluta* in India is presented below. For the effective management of the pest, it is critical to combine all available control measures including physical methods, cultural methods, use biological control agents and the correct use of registered pesticides. *T. absoluta* management studies carried out in India are briefly reviewed here.

Cultural control

Cultural control strategies for *T. absoluta* involve raising of pest free nursery and clean cultivation (IIHR annual report, 2020). Raising of border crops (Shanmugam *et al.*, 2020) and hand picking and destruction of *T. absoluta* infested leaves helps in minimizing the population build-up of the pest (Sridhar *et al.*, 2019b).

Physical / Mechanical control

The physical and mechanical control mainly involves traps and lures. The yellow incandescent bulb traps were found effective in attracting *T. absoluta followed by* blue light traps and captured both males and females (Sridhar *et al.,* 2019b). Under polyhouse conditions 60 W incandescent bulb traps @ one/ 150m^2 was found effective in attracting the adults of *T. absoluta* (Sridhar and Senthil Kumaran, 2018). Use of Light traps along with pheromone traps/ 300m^2 was found effective under polyhouse conditions (Sridhar *et al.,* 2020).

Indian farmers are using pheromone traps for the early detection, monitoring and mass trapping of *T. absoluta* in their fields (Bhanu *et al.,* 2017). Sex pheromone traps are used for mass trapping and disruption of mating activities which are considered as promising techniques to control this invading pest (Kumari *et al.,* 2018).

Nanoporous materials are a novel carrier/dispenser for the volatile signaling molecules with controlled spatio-temporal release rates. Dispensers are made of mesoporous sieves with ordered pore channels for loading the *T. absoluta* pheromone. Pheromone when loaded in nanomatrix has delayed dissipation as compared to pheromone alone when assayed by Thermal gravity analysis (TGA). Fourier transform infrared (FT-IR) measurements confirmed the presence of pheromone in the nanomatrix. Entrapped pheromone in the nanomatrix has controlled release of pheromone when compared to release from rubber septa (Subaharan *et al.,* 2020). Along with the pheromone traps, solar light traps have also given better results by trapping female *T. absoluta along with males* (Sridhar *et al.,* 2019b; Nitin and Chakravarthy, 2021).

Biological control of *Tuta absoluta*

Biological control involves parasitoids, predators and entomopathogens. There are various predators and parasitoids that have been demonstrated to suppress populations of *T. absoluta*. Natural incidence of predatory mirid bug, *Nesidiocoris tenuis* (Reuter) (Hemiptera: Miridae) was found to cause predation on eggs and early instars of *T. absoluta* under field conditions in tomato (Sridhar *et al.* 2014). Ballal *et al.,* (2016) evaluated the Tuta-adapted strains of Trichogrammatid egg parasitoid species against Tuta eggs under laboratory conditions. The respective egg parasitisation rates by the three species, *Trichogramma achaeae* Nagaraja and Nagarkatti, *Trichogramma pretiosum* Riley and *Trichogrammatoidea bactrae* Nagaraja on *T. absoluta* eggs were 5.0%, 51.1% and 68.2%. Successful emergence of adults from the parasitized *T. absoluta* eggs were 4.8%, 97.5% and 90.0%, respectively. The authors have also observed four 'hymenopteran' parasitoids, *viz. T. achaeae, Neochrysocharis formosa* (Westwood), *Habrobracon* sp. and *Goniozus* sp. to be associated with *T. absoluta* in the fields during the surveys undertaken in southern India.

Release of egg parasitoid, *Trichogramma pretiosum has shown promising results (Sridhar et al.,* 2020) against *T. absoluta* under field conditions. *Other studies showed that T. absoluta* can be effectively managed by *T. achaeae* followed by *T. chilonis* and *T. japonicum (Balaji et al., 2020; Singh et al., 2020).*

Other natural enemies reported include *Blaptostethus pallescens* Poppius which is a predator

(Jamwal *et al.,* 2021) and *Neochrysocharis formosa* (Westwood) being a parasitoid (Jour *et al.,* 2020) were reckoned as potential biocontrol agents of *T. absoluta.* Another parasitoid, *Avga choaspes* showed promising results in controlling *T. abosluta* by producing more number of progenies on fourth instar and is considered to be useful in augmentative biological control (Murugasridevi *et al.*, 2020).

Nagaraju *et al.,* (2020) evaluated ten *Bt.* strains and among them HD-1, Bt oa1, Bt 247 and Bt 257 isolates gave higher mortality on second instar larvae of *T. absoluta.* Sandeep Kumar et *al.,* (2020a) studied the effect of different Bt. strains on *T. absoluta* and recorded that HD1 strain of *Bt* is effective on 2nd, 3rd and 4th instars at the doses 6.0µg/ml, 6.62 µg/ml and 8.18 µg/ml, respectively. The gram-negative symbiotic bacterium *Xenorhabdus nematophyllus* (MK977603) was found to be effective against larval stages of *T. absoluta* (Sandeep Kumar *et al., 2020b).*

Sridhar *et al.* (2018) evaluated various entomopathogens against *T. absoluta and* Bacillus *thuringiensis, Metarhizium anisopliae, M. rileyi* and *Beauveria bassiana were identified as* eco-friendly and effective options both under polyhouse and open field conditions.

Host Plant Resistance against *T. absoluta* in India:

Studies were initiated at ICAR-IIHR, Bengaluru for identifying host plant resistance sources against *T. abosluta.* Twenty-one wild/cultivated/advanced breeding lines of tomato were screened for resistance to *T. absoluta* under greenhouse conditions (choice bioassay) during 2017-18. From these screening trials, promising genotypes were evaluated further for their antibiosis activity through no choice bioassay under in-vitro conditions. From 21 genotypes screened, six wild accessions viz., *S. pennellii* (LA 1940); S. chilense (LA 1963); *S. arcanum* (LA2157); *S. lycopersicum* (LA1257) and *S. corneliomulleri* (LA 1292, LA1274) were found relatively resistant to *T. absoluta* based on mean per cent damage. Among these six genotypes, *S. pennellii* (LA-1940) showed resistance both under choice and no choice bioassays with a higher number of type IV trichomes, highest total flavonoids and phenols (Sridhar *et al.,* 2019a). In addition, *S. pennellii* had the highest total phenols (2200 mg/100 g dry weight). In general, glandular trichomes (GTs) (type I, IV, VII) showed negative correlation in different genotypes of tomato with reference to larval number/plant, percent damage and adult activity, whereas type V (non-GTs) showed a negative correlation with number of larvae/plant (Sridhar *et al.,* 2019a, Sadashiva *et al.,* 2020). Trichomes, besides acting as chemical barriers, can also act as physical barriers, limiting pest insect access to the plant surface, due to trichome density and length. An interspecific hybrid (F1) between, cultivated line *S. lycopersicum* (TLBER-38-7) and wild genotype identified as resistant to *T. absoluta viz.*, *S. pennellii* (LA 1940) was successfully developed by introgressing genes resistant to *T. absoluta.* The evaluation of F1 progeny revealed clear difference in terms of resistance to the target pest. F1 progeny has recorded a total phenols of 1637 mg/100 g dry weight and total flavonoids of 1160 mg/100 g dry weight. On F1, *T. absoluta* took additional time for completing the larval and pupal stages coupled with higher larval mortality, which may be attributed to the antibiosis of the host against *T. absoluta.* On F1, developmental time for larvae and pupae was recorded as 12.33 days and 7.33 days, respectively, as against 9.33 days and 5.33 days, respectively on check cv. Shivam. When *T. absoluta* was reared on F1 progeny, only 18 per cent could reach the adult stage. BC1F1 and F2 progenies of SH-3 are being further advanced to study the resistance/tolerance of the lines against

T. absoluta. The present attempt to introgress *Tuta* resistance genes to the cultivated tomato lines is very challenging, as the resistance to *T. absoluta* is observed only in wild genotypes and needs different breeding approaches to successfully introduce the resistant genes into the cultivated lines.

Sterile Insect Technique

Sterile insect technique is an environmentally friendly control option aiming to suppress pest populations through F_1 generation which is by release of sterile males that mate with wild females, thereby producing non-viable offspring. Sterile insect technique (SIT) can be employed for the management in a mass region as it is species-specific, environmentally friendly, and can be combined with other management options (Nitin and Chakravarthy, 2021). ICAR-IIHR, Bengaluru has initiated studies in this direction entitled "Investigations on feasibility and potential of SIT in the management of South American tomato moth" with funding from the Department of Atomic Energy, Board of Research in Nuclear Sciences, Government of India since 2020.

Chemical control

Despite their limitations when used indiscriminately, chemical pesticides continue to be an essential component of integrated pest management (IPM) and can be an important part in *T. absoluta* management.

After the first report of *T. absoluta* in India, as a proactive measure, the registration committee of Central Insecticide Board, GoI (Minutes of 355th of registration committee held on 29.04.2015) made adhoc recommendation to use the following insecticides (for a period of two years provisionally) i.e., Chlorrantraniliprole (Rynaxypyr) 10.26 % OD @ 0.3 m l/l, Cyantraniliprole (Cyaxypyr) 18.5 SC @ 1.8 ml/l, Flubendiamide 20 WG @ 0.3 g/l, Indoxacarb 14.5 SC @ 0.5 ml/l, imidacloprid 17.8 SL @ 0.2 ml/l and Aradirachtin 1 or 5 % (2-3 ml/l).

Evaluation of different insecticides for their efficacy was also carried out by various researchers from India. Spray of indoxacarb 14.8 EC@ 1ml/l, Spinosad 45 SC @ 0.25 ml/l, spinetoram 12 SC @ 1.8 ml/l or Flubendiamide @ 480 SC @ 0.2m/l, Cyantraniliprole 10.26 OD @ 0.3 ml/l and spraying of Deltamethrin 2.5 EC @ 1ml/l at peak emergence of adults were found effective against *T. absoluta* (Sridhar *et al.* 2016; Sridhar *et al*, 2020; Bhat *et al.* 2017) It was observed that insecticides *viz.*, cyazypyr @ 1.8 ml/L, rynaxypyr @ 0.3 ml/L and indoxacarb @ 1 ml/L recorded least fruit damage (0.54, 0.76 and 0.95 per cent, respectively, compared to other insecticides. The highest healthy fruit yield was recorded in cyazypyr @ 1.8 ml/L (111.33 tonnes/ha) followed by rynaxypyr @ 0.3 ml/L (108 tonnes/ha) and indoxacarb @ 1 ml/L (99.98 tonnes/ha).

Sandeep Kumar *et al.* (2020c) evaluated several insecticides against various populations of *T. absoluta* under laboratory conditions. The LC_{50} values ranged from 0.27 to 2.0 ppm for chlorantraniliprole, 1.01 to 2.25 ppm for flubendiamide, 0.32 to 0.90 ppm for spinosad, 0.98 to 6.52 ppm for imidacloprid, 0.82 to 6.38 ppm for indoxacarb, 967.32 to 1911.98 ppm, for chlorpyriphos. The resistance ratios ranged from 1.1 to 7.7-folds for different insecticides. The results showed that chlorantraniliprole and spinosad were more toxic insecticides as compared to other chemicals. Continuous use of the chemical pesticides has apparently also led to resistance development. In India *T.*

absoluta has shown decreased susceptibility to certain commonly used insecticide which is due to cytochrome P450 monooxygenase and esterase enzymes which play a major role in the development of resistance in field population of *T. absoluta* (Prasanna Kumar *et al.,* 2020). Similarly, activity of cytochrome p-450, carboxylesterase and glutathione s-transferase were identified as responsible for detoxification of xenobiotics and have a key role in conferring resistance to insecticides (Linga *et al.,* 2020).

IPM strategies

Tuta absoluta has a wide host range to multiply and the ability to develop resistance to the insecticides besides completing many generations in a year, which make it difficult to be managed, which call for Integrated Pest Management strategies in controlling *T. absoluta.*

IPM strategies for *Tuta absoluta* involves raising of pest free nursery, clean cultivation, use of light cum suction traps @ 2/acre (60 W incandescent bulb), sex pheromone traps @ 15 /acre, release of egg parasitoid, *Trichogramma pretiosum* @ 75,000/ha (5 releases at weekly interval), need-based spraying of indoxacarb 14.5 SC @ 1 ml/l or spinosad 45 SC @ 0.25 ml/l and spraying of deltamethrin 2. 5 EC @ 1 ml/l during peak adult emergence and release of natural enemies like mirid bug, *Nesidiocoris tenuis* (IIHR annual report, 2020).IPM strategy of raising of border crops, installation of pheromone traps @ 50 nos/ha, release of egg parasitoid *Trichogramma chilonis* @ 1,00,000/ha is also considered effective (Shanmugam *et al.,* 2020).

ICAR-IIHR has developed IPM protocol for the effective management of *Tuta* under polyhouse conditions. The strategy includes the use of incandescent bulb @ one bulb/150 m^2 + 1 pheromone trap/300 m^2 + need based spray of indoxacarb 14.5 SC @ 0.75 ml/l or spinosad 45 SC @ 0.25 ml/l/flubendiamide @ 0.20 ml/l in rotation at 3 weeks interval. Light traps are kept before transplanting of the crop in the polyhouse. In polyhouse, when the IPM practices were followed, fruit damage was reduced to 6 per cent as against up to 56 per cent in control (Balakrishna and Hebbar, 2021).

Holistic options for keeping *T. absoluta* under check on tomato:

Cultural practices for the control of *T. absoluta* mainly includes crop rotation with non-solanaceous crops (preferably Cruciferous crops) and adequate fertilization, raising healthy nursery, collection and destruction of early infested plant parts, removal of alternate hosts in the field, using options of light and pheromone traps, biological control, destruction of crop residues, need based use of insecticides *etc.*

Conclusions: Since this pest has potential to cause 50% to 100% yield loss in both greenhouses or open fields on tomato, there is need to adopt IPM for the effective management of *T. absoluta more* so because of its wide host range and concealed feeding habit efforts need to be deployed in order to manage this pest by understanding its local host range and developing eco-friendly and safe management tools. Cultural practices, including crop rotation with non-Solanaceous plants as well as removing and destruction of infested plants and weeds, may facilitate adequate management of the pest and help to reduce insecticide applications. Development of resistant tomato cultivars, by the transfer of resistance factors to commercial tomato cultivars, will be useful in pest management programs. The use of RNAi technology by producing transgenic plants that express dsRNA molecules should be reinforced. Integration of cultural, physical and mechanical control, biological control, host plant resistance and need-based use of chemical insecticides may enhance the effectiveness of Integrated Pest Management tactics used to control *T. absoluta.* Efforts should be made in this direction to educate the farmers in adopting IPM practices for cost-effective and sustainable management of this invasive pest in India.

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