Efficacy of integrated pest management tools evaluated against *Tuta absoluta* (Meyrick) on tomato in India

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ABSTRACT: South American tomato moth, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is an invasive pest on tomato and other solanaceous crops. In general, 20 to 30 % yield loss is caused by this pest and sometimes it may result in 100% damage, if timely management interventions are not followed. Though the pest was reported in India during 2014, presently it has spread to several tomato growing states. In the present study various IPM tools have been evaluated against this pest. As a long-term strategy of resistance breeding, genotype screening was carried out for identification of resistance sources from wild and cultivated tomato genotypes showing resistance/tolerance against *T. absoluta*. Among the evaluated wild and cultivated tomato genotypes, *Solanum pennellii* (Accession, LA 1940) was identified as a resistant source against *T. absoluta* both under choice and no-choice bioassays and is being used for resistance breeding. Various entomopathogens (*Bacillus thuringiensis*, *Metarhizium anisopliae*, *Beauveria bassiana* and *M. rileyi*), egg parasitoids (*Trichogramma chilonis*, *T. pretiosum* and *Trichogrammatoidea bactrae*), light traps, pheromone traps, synthetic insecticides, botanical origin insecticides were also evaluated for their relative efficacy. Among the egg parasitoids *T. pretiosum* and among synthetic chemicals, spinetoram 12 SC@ 1.25ml/l were found very effective for the management of *T. absoluta*. Yellow light traps were found as an effective component for integrated management of *T. absoluta*. Azadirachtin 5% EC at the tested concentrations showed highest mean radial growth (24.67 mm) with relatively less inhibition (16.51%) of *M. anisopliae* indicating these combinations can be effectively utilised in the eco-friendly management of *T. absoluta*. We reported natural incidence of *M. anisopliae* on *T. absoluta* larvae, causing up to 35 per cent mortality during 2016-17.

KEY WORDS: Entomopathogens, host plant resistance, IPM, light traps, pheromone traps, *Tuta absoluta*

INTRODUCTION

South American tomato moth, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is a devastating pest of tomato that has undergone a rapid expansion since its first report from India and has the potential to occur throughout the year in the tomato ecosystem (Nitin *et al.*, 2017; Sridhar *et al.*, 2014). Presently, the pest has spread to other states like Maharashtra, Tamil Nadu, Andhra Pradesh, Telangana, Gujarat, Delhi, Chhattisgarh etc. Taram *et al.*, 2016). Application of chemical insecticides is the most commonly used practice for suppression of *T. absoluta* infestations. Though the pesticides used against this pest give satisfactory control, extensive use of insecticides may lead to the development of insecticide resistance (Siqueira *et al.*, 2000; Lietti *et al.*, 2005). In general, 20 to 30 % yield loss is caused by this pest and may result in 100% damage, if timely management interventions are not followed. Entomopathogens like *Bacillus thuringiensis*, *Metarhizium anisopliae*, *M. rileyi* and *Beauveria bassiana* are eco-friendly and effective options both under polyhouse and open field conditions. At ICAR-Indian Institute of Horticultural Research, Bengaluru some of the components of IPM including biocontrol agents were evaluated for identifying effective treatments for including in integrated management of *T. absoluta*.

MATERIALS AND METHODS

Various experiments carried out at ICAR-IIHR for the management of *Tuta absoluta* are briefly described below.

Screening of tomato genotypes for resistance against *Tuta absoluta*

Twenty one genotypes (11 wild and 10 cultivated) were evaluated in the green houses by using the methodology of Maluf *et al.* (1997) and Rakha *et al.* (2017). Within twenty plants of each genotype, five plants were screened for the
trichome density (both glandular and non glandular) on abaxial and adaxial surfaces of the tomato leaves by using scanning electron microscope (model: TM 3030 plus, Hitachi Co., Japan). Trichomes were grouped according to Luckwill (1943). T. absoluta damage parameter (larval numbers, per cent leaf damage and adult activity) were correlated with the trichome types to know whether any correlation exists between trichomes and level of resistance in the tomato genotypes.

**Traps for monitoring of adults of Tuta absoluta**

The solar light traps and pheromone traps were installed on 1st September 2016 at one and eight per acre, respectively for monitoring of the pest. The insects trapped were recorded on daily basis starting from installation of traps in the tomato field and data was cumulated on weekly basis for the entire cropping period. Different colour light traps were installed in poly houses of tomato to observe the best light source for T. absoluta attraction.

**Entomopathogens and egg parasitoids**

Four entomopathogens, viz., Bt (1 ml/l), Metarhizium anisopliae, M. rileyi and Beauveria bassiana @ 1 x 10^8 cfu/ml were evaluated for their efficacy under field conditions. Five replications were used for each treatment including control. Two sprays were given after noticing 1-2 mines/leaf. Mortality of T. absoluta larva was recorded at weekly interval.

Egg parasitoids of Trichogramma pretiosum, T. bactrae and T. chilonis were released at weekly interval at 50,000/ha for five weeks starting from first incidence of the T. absoluta observed in the light trap/pheromone trap. Each tomato plot for various treatments consisted of 8 m x 8 m measurement, each replicated five times. The observations on T. absoluta live mines/parasitism were recorded on 3, 7- and 10-days interval in each of the treatments.

**Bioefficacy of insecticides**

Eleven insecticides were evaluated against the pest during rabi (2016-17) under field conditions. The experiment was laid out in a randomised block design with 12 treatments including control, each replicated thrice. The seedlings (cv. Shivam) were transplanted during first week of October 2016. The tomato crop was raised as per the recommended package of practices, except plant protection protocols. A total of five sprays were given at fortnight interval. Per cent reduction in live mines of T. absoluta over control was assessed after each spray and healthy fruit yield was assessed at each harvest. Observations on live mines of T. absoluta were taken from five plants selected randomly from each plot (six leaves/plant). Observations were recorded on 3, 7, 10 and 14 days after the sprays. The per cent data on the incidence of T. absoluta was transformed to arcsine values before subjecting it to statistical analyses using ANOVA and DMRT. Being a newly invaded pest, baseline susceptibility of egg and larval stages of the pest were carried out with various groups of insecticides and data was assessed through LC50.

**Compatibility of pesticides with entomopathogenic fungi, Metarhizium anisopliae**

Earlier, we reported natural incidence of entomopathogenic fungus, Metarhizium anisopliae on T. absoluta in tomato causing up to 35% mortality of the larvae. As different pesticides are being used in tomato ecosystem, for knowing the antagonising or synergizing effect of these pesticides i.e., compatibility with the fungus, the present study was undertaken. The commonly used pesticides were tested against the entomopathogenic fungi, M. anisopliae by using poisoned food technique in Potato Dextrose Agar (PDA) medium (Moorhouse et al., 1992).

The experiment was carried out using a completely randomised design using seven pesticides at recommended (X) and double (2X) the recommended dose/concentration along with control (Table 1) each replicated thrice. Isolate of M. anisopliae obtained from cadavers of T. absoluta was used for the study. Hundred ml of PDA was sterilized and added with the target pesticides and 20 ml each was poured into 25 mm diameter sterile Petri dishes and were allowed to solidify under laminar flow cabinet. An agar disc of 5 mm mat of M. anisopliae was cut with cork-borer and was inoculated

| Treatments/ Pesticide formulations | Trade Names | Recommended dose (X) | Double the Recommended dose (2X) |
|-----------------------------------|-------------|-----------------------|---------------------------------|
| T1, Lamda cyhalothrin 5 EC        | Reeva       | 0.5 ml/l              | 1 ml/l                          |
| T2, Azadirachtin 5 EC             | Neemazal    | 2 ml/l                | 4 ml/l                          |
| T3, Indoxacarb 14.5 SC            | Kingdoxa    | 0.75 ml/l             | 1.5ml/l                         |
| T4, Thiometoxam 25 WP             | Actara      | 0.3 g/l               | 0.6g/l                          |
| T5, Chlorant-raniliprole 18.5 SC  | Coragen     | 0.3 ml/l              | 0.6ml/l                         |
| T6, Carbendazim 50 WP             | Bavistin    | 1 g/l                 | 2 g/l                           |
| T7, Mancozub 75 WP                | Tata M-45   | 2 g/l                 | 4 g/l                           |
| T8, Control                       | -           | -                     | -                               |
at the centre of the PDA plate. PDA with only mycelial disc, served as control. The Petri dishes were sealed with parafilm and incubated at room temperature for fungal growth. The diameter of growing culture, i.e., the radial growth in each Petri dish was measured on 10th day after inoculation (DAI). The data were expressed as percentage growth inhibition of *M. anisopliae* in pesticide treated PDA (Hokkanen and Kotiluoto, 1992).

**RESULTS AND DISCUSSION**

**Screening of tomato genotypes against *Tuta absoluta***

Among twenty-one genotypes screened against *Tuta absoluta*, six wild accessions, viz. *Solanum pennellii* (LA 1940); *S. chilense* (LA 1963); *S. arcanum* (LA 2157); *S. lycopersicum* (LA1257) and *S. corneliomulleri* (LA 1292, LA1274) were relatively resistant based on mean per cent damage and were further studied under *in vitro* conditions. Glandular trichomes (Type I, IV, VII) showed negative correlation in different genotypes of tomato with reference to larval number/plant, per cent damage and adult activity, while Type V (non-glandular) trichome showed negative correlation with larval number/plant Table 2, 3 and Fig. 2. Glandular (G) and non-glandular (NGT) play important role in host plant resistance by affecting the performance of herbivores (Bitew, 2018). *S. pennellii* showed highest resistance both under choice and no choice conditions, hence selected for breeding for *T. absoluta* resistance and the trials are in progress. Host-plant resistance was explored by developing tomato accessions with high zingiberene and/or acylsugar contents resulting on low oviposition rates and larval feeding of *T. absoluta* (Maluf et al., 2010). Rakha *et al.* (2017) observed the role of glandular trichomes in host plant resistance against *T. absoluta*.

**Traps**

Highest number of *Tuta. absoluta* adults were trapped in December 2016 i.e., 79 and 104 per trap in solar light and pheromone traps, respectively followed by November 2016 (70 and 95) and least were trapped in the month of February 2017 (50 and 47). Weekly traps of *T. absoluta* in solar light traps and pheromone traps are presented in Fig. 1. Sex pheromone traps attracted only males. Few females were also trapped in light traps along with males, indicating their potential utilisation in the IPM programme

| Table 2. Relative abundance of different types of trichomes in resistant lines of tomato against *Tuta absoluta* per 0.5 mm² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tomato wild genotypes | Accession no. | Abaxial surface | | | | | | | | |
| | | NG | G | NG | G | NG | G | NG | G | NG | G |
| | | V | III | Total | I | IV | VI | VII | Total | V | III | Total | I | IV | VI | VII | Total |
| *S. pennellii* | LA-1940 | 0.00 | 0.00 | 0.00 | 18.67 | 10.67 | 4.33 | 0.00 | 33.67 | 0.00 | 0.00 | 0.00 | 7.67 | 15.00 | 5.00 | 0.00 | 27.67 |
| *S. chilense* | LA-1963 | 79.33 | 147.67 | 227.00 | 0.33 | 0.00 | 0.00 | 0.00 | 40.00 | 20.33 | 60.33 | 0.00 | 0.00 | 0.67 | 2.00 | 2.67 |
| *S. corneliomulleri* | LA-1274 | 1.33 | 7.00 | 8.33 | 22.67 | 15.67 | 0.33 | 0.00 | 38.67 | 6.67 | 1.33 | 8.00 | 11.67 | 14.00 | 2.67 | 0.00 | 28.33 |
| | LA-1292 | 47.33 | 17.67 | 65.00 | 0.33 | 0.00 | 3.00 | 0.00 | 3.33 | 13.33 | 1.00 | 14.33 | 0.00 | 0.00 | 10.00 | 1.67 | 11.67 |
| *S. lycopersicum* | LA-1257 | 37.67 | 193.33 | 231.00 | 0.00 | 1.33 | 9.00 | 0.00 | 10.33 | 112.00 | 1.33 | 113.33 | 0.00 | 0.00 | 5.67 | 13.33 | 19.00 |
| *S. arcanum* | LA-2157 | 7.33 | 0.00 | 7.33 | 0.00 | 0.00 | 0.67 | 4.00 | 4.67 | 2.33 | 0.00 | 2.33 | 0.00 | 0.00 | 1.00 | 5.67 | 6.67 |

G-Glandular; NG-Non glandular

| Table 3. Correlation matrix of different parameters of *Tuta absoluta* damage v/s trichomes* |
|---|---|---|---|---|---|---|
| Parameters of *T. absoluta* | Leaf surface | Non- Glandular Trichomes | Glandular Trichomes |
| | | V | III | Total | I | IV | VI | VII | Total |
| Larval nos. | Abaxial | -0.005 | 0.13 | 0.10 | -0.46 | -0.49 | 0.38 | -0.15 | -0.15 |
| | Adaxial | -0.05 | 0.06 | -0.01 | -0.46 | -0.46 | 0.51 | -0.05 | 0.35 |
| | Cumulative | -0.04 | 0.14 | 0.07 | -0.47 | -0.47 | 0.50 | -0.09 | 0.22 |
| % leaf Damage | Abaxial | 0.11 | 0.22 | 0.22 | -0.33 | -0.31 | 0.03 | -0.20 | -0.31 |
| | Adaxial | 0.27 | 0.53 | 0.44 | -0.29 | -0.35 | 0.10 | -0.19 | -0.06 |
| | Cumulative | 0.23 | 0.33 | 0.32 | -0.32 | -0.34 | 0.09 | -0.23 | -0.17 |
| Adult activity | Abaxial | 0.12 | 0.05 | 0.09 | -0.29 | -0.27 | 0.54 | -0.13 | 0.02 |
| | Adaxial | 0.02 | 0.05 | 0.03 | -0.25 | -0.30 | 0.70 | -0.01 | 0.54 |
| | Cumulative | 0.08 | 0.06 | 0.08 | -0.29 | -0.31 | 0.52 | -0.15 | 0.22 |

*Correlation coefficient values
of this pest. Yellow incandescent bulb traps were found very effective in attracting *T. absoluta* followed by bluish white light traps. The pest has the potential to occur throughout the year in the tomato ecosystem (Nitin et al., 2017).

**Entomopathogens and egg parasitoids**

Various entomopathogens have resulted in 70-81 % reduction in larvae of *Tuta absoluta* on tomato. Among them Bt was found most effective with 81.93% reduction in *T. absoluta* (Table 4). Among the egg parasitoids evaluated, *T. pretiosum* was found promising (45% parasitisation) followed by *T. chilonis* and *T. bactrae* (Table 5). Several biocontrol agents are used to control *T. absoluta* in open field and greenhouse tomato cultivation. *Bacillus thuringiensis* (Bt)-based insecticide formulations have been used to control *T. absoluta* in its native and invaded regions. Several studies have demonstrated the efficacy of Bt in controlling *T. absoluta* particularly first-instar larvae without any side effects on beneficial arthropods (Mollà et al., 2011). Several fungal species including *Metarhizium anisopliae* and *Beauveria bassiana* are reported to attack the eggs, larvae and adults of *T. absoluta*. Studies have revealed up to 54% mortality of *T. absoluta* adults by *M. anisopliae* (Pires et al., 2010). Faria et al., (2007) studied the efficacy of egg parasitoid, *T. pretiosum* against *T. absoluta* on tomato and observed up to 28% parasitisation.

### Table 4. Efficacy of entomopathogens on *Tuta absoluta*

| Treatment details | Trade name and Accession number | Dose | Mean reduction of *T. absouta* |
|-------------------|---------------------------------|------|------------------------------|
| *Bacillus thuringiensis* | Lipel (NCIM-2514)** | 1g/l | 81.93* (64.82) |
| *Beauveria bassiana* (1 X 10^8 spores/ml) | Racer (NCIM-1216)** | 3ml/l | 75.11b (60.05) |
| *Metarhizium anisopliae* (1 X 10^8 spores/ml) | Pacer (NCIM-311)** | 3ml/l | 70.59* (57.14) |
| *M. rileyi* (1 X 10^8 spores/ml) IIHR strain | - | 3ml/l | 77.36* (61.77) |
| Control | - | - | 0.00 |

*Average of 2 sprays, three observations at 10 days interval  ** Ajay Agro Tech Pvt. Ltd., Rajasthan

**Efficacy of insecticides against *Tuta absoluta***

Among the different insecticides, spinetoram 12 SC @ 1.25g/L, (88.59 %), cyantraniliprole 10 OD @ 1. 8 ml/L (83.45 %), flubendiamide 480 SC @ 0.3ml/L (80.80 %), spinosad 45 SC @ 0.25 ml/L (78.99 %), indoxacarb 14.5 SC @ 0.75 ml/l (74.36 %) and chlorantraniliprole 18.5 SC @ 0.3 ml/L (74.26 %) were found effective against *T. absoluta* (Sridhar et al., 2016). Baseline toxicity against *T. absoluta* egg and larval stages, spinetoram followed by spinosad, chlorantraniliprole, indoxacarb and flubendiamide were toxic in the descending order. Botanical based Azadirachitin 5% EC at 2 ml/L was effective against *T. absoluta* resulting in 69.87 % reduction in live mines of *T. absoluta* and is relatively safe to the natural enemies also (Sridhar et al., 2016). Studies from others conducted elsewhere revealed that different insecticides were found effective against *T. absoluta* like spinosad (Bratu et al., 2015; Abdelgaleil et al., 2015), azadirachtin, emamectin benzoate, spinosad, chlorantraniliprole (Eleonora and Vili, 2014) chlorantraniliprole + abamectin (Ali et al., 2014), cyantraniliprole (Patricia et al., 2014), indoxacarb and...
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Compatibility of pesticides with *Metarhizium anisopliae* radial growth and growth inhibition

Among the insecticides (T₁ to T₅) tested, at recommended dose (x), azadirachtin 5% EC followed by chlorantraniliprole, showed maximum radial growth of 31.33 mm and 28.33 mm with least growth inhibition of *M. Anisopliae*, i.e., 10.28% and 18.71%, respectively. Similar results were obtained with these insecticides even at double the recommended dose (2x) with radial growth of 27 mm and 21 mm with growth inhibition of 22.75% and 40.34%, respectively. Among the fungicides (T₆ and T₇) tested at X and 2X doses, carbendazim showed radial growth of 14 mm and 9.67 mm (*M. anisopliae*) with growth inhibition of 60.20% and 72.49%, respectively (Table 6). Thus, among the pesticides, Azadirachtin was relatively less toxic to *M. anisopliae* at the concentrations tested.

### Spore count

Data on sporulation of *M. anisopliae* in relation to pesticides treated media are presented in Table 2. Among the various pesticides tested at two concentrations, the highest mean spore count was recorded in control (T₈)

### Table 5. Per cent egg parasitisation of *Tuta absoluta* by *Trichogramma* species

| Species of egg parasitoid | Percent parasitisation after release of egg parasitoids | Mean* |
|--------------------------|--------------------------------------------------------|-------|
|                          | I Week | II Week | III Week | IV Week | V Week |       |
| *Trichogramma chilonis*  | 40.00  | 44.00   | 35.00    | 31.00   | 40.00  | 38.00* |
| *Trichogrammatoidea bactrae* | 35.00 | 44.00 | 50.00 | 40.00 | 36.00 | 41.00ab |
| *Trichogramma pretiosum* | 48.00  | 55.00   | 48.00    | 44.00   | 48.00  | 48.00* |

Cumulative mean analysis results: SEM: 2.35; CD (p = 0.05) = 7.20 and cv = 12.35
*Means with the different letters are significant (p > 0.05) as analysed by Duncan Multiple Range Test (DMRT).

### Table 6. Compatibility of various pesticides with *Metarhizium anisopliae*

| Treatment/ Pesticide formulations | Performance of *M. anisopliae* in different pesticides | Mean spore count (1x10⁸ spores/ml) # |
|-----------------------------------|------------------------------------------------------|-------------------------------------|
| X                                 | 2X                                                   | Mean                                |
| Radial growth (mm)                | Growth inhibition (%) *                               |                                      |
|                                   | X                      | 2X                         | Mean          | X                      | 2X                     | Mean          |                                      |
| T₁, Lamda cyhalothrin 5 EC        | 16.67                  | 14.67                      | 15.67         | 52.11 (46.22)          | 58.16 (49.71)          | 55.14 (47.95) | 2.70 (1.79)  | 2.20 (1.64)  | 2.45 (1.72)  |
| T₂, Azadirachtin 5 EC             | 31.33                  | 27.00                      | 29.17         | 10.28 (17.93)          | 22.75 (28.44)          | 16.51 (23.86) | 4.40 (2.21)  | 3.90 (2.10)  | 4.15 (2.16)  |
| T₃, Indoxacarb14.5 SC              | 27.33                  | 22.00                      | 24.67         | 21.57 (27.33)          | 36.56 (36.79)          | 29.07 (32.21) | 2.11 (1.61)  | 1.79 (1.51)  | 1.95 (1.56)  |
| T₄, Thiometoxam 25 WP              | 22.67                  | 19.33                      | 21.00         | 34.88 (36.08)          | 44.75 (41.99)          | 39.82 (39.10) | 2.62 (1.76)  | 2.16 (1.63)  | 2.39 (1.70)  |
| T₅, Chlorantraniliprole 18.5 SC    | 28.33                  | 21.00                      | 24.67         | 18.71 (25.21)          | 40.34 (39.12)          | 29.53 (32.83) | 3.27 (1.94)  | 2.63 (1.77)  | 2.95 (1.86)  |
| T₆, Carbendazim 50 WP              | 14.00                  | 9.67                       | 11.83         | 60.20 (50.96)          | 72.49 (58.38)          | 66.34 (54.59) | 1.77 (1.50)  | 1.56 (1.43)  | 1.67 (1.47)  |
| T₇, Mancozeb 75 WP                 | 10.67                  | 4.00                       | 7.33          | 69.68 (56.65)          | 88.44 (70.57)          | 79.06 (62.84) | 0.91 (1.15)  | 0.33 (0.88)  | 0.62 (1.03)  |
| T₈, Control                        | 35.00                  | 35.00                      | 35.00         | -                      | -                      | -               | 5.00 (2.34)  | 5.00 (2.34)  | 5.00 (2.34)  |

SEM ± 0.73 1.14 0.65 1.90 2.12 1.43 0.06 0.04 0.04
CD at 5% 1.51 2.36 1.34 3.93 4.41 2.97 0.12 0.09 0.08

X: Recommended dose; 2X: Double the recommended dose; *Figures in parentheses are arcsine transformed values; # Figures in parentheses are square root transformed values
(5.00 x 10^8 spores ml⁻¹) followed by azadirachtin (T₄) (4.15 x 10^8 spores ml⁻¹) and chlorantraniliprole (T₅) (2.95 x 10^8 spores ml⁻¹) (Table 6). Possibility of combining botanicals with microbial for enhanced efficacy against insect pests was established earlier by (Antonio et al., 2001).

Thus from the present study, azadirachtin 5% EC at the tested concentrations showed highest mean radial growth (24.67 mm) with relatively less inhibition (16.51%) of M. anisopliae. These combinations can be effectively utilised in the eco-friendly management of T. absoluta.

Various IPM protocols for T. absoluta were worked out in other parts of the world (Goda et al., 2015) and needs to be standardised for indian conditions. The management options for T. absoluta should start from raising of healthy seedlings, as the pest causes the damage to the crop from seedling stage to final harvest of the crop. Hand picking and destruction of T. absoluta infested leaves and other plant parts, installation of light traps, pheromone traps minimises the population build-up of the pest. Though several management options are available for T. absoluta, there is a need for integrating them.

Being a newly invaded pest attacking major vegetable crops like tomato, these studies contributes for the development of effective IPM modules for T. absoluta by including effective treatments into the IPM modules which are environmentally friendly like light traps, pheromone traps, biocontrol agents like egg parasitoids, entomopathogens and eco-friendly insecticide molecules.

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