Toxicity of Insecticides to Tomato Pinworm, *Tuta absoluta* (Meyrick) Populations from Tamil Nadu

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**ABSTRACT**

Tomato pinworm, *Tuta absoluta* is a serious and notorious pest on tomato. Control mainly relies on insecticides because of their high infestation levels on all plant parts and life stages of the crop. This study, investigated the efficacy of different insecticides, against *Tuta absoluta* for different populations in laboratory conditions. The LC₅₀ ranged from 0.27 to 2.0 ppm for chlorantraniliprole, from 1.01 to 2.25 ppm for flubendiamide, from 0.32 to 0.90 ppm for spinosad, from 0.98 to 6.52 ppm for imidacloprid, from 0.82 to 6.38 ppm for indoxacarb, from 967.32 to 1911.98 ppm, for chlorpyriphos. The resistance ratios ranged from 1.1 to 7.7-fold difference in all six cases. The laboratory experimental results showed that chlorantraniliprole and spinosad were the most toxic insecticides as compared to other chemicals and showed homogenous response to them.

**Key words:** Baseline toxicity, Chlorantraniliprole, Chlorpyriphos, Flubendiamide, Imidacloprid, Indoxacarb, Spinosad, *Tuta absoluta*.

**INTRODUCTION**

Tomato (*Lycopersicon esculentum* Mill.) is a vegetable crop of major importance which is native to Western South America. It is cultivated in an area of 814 thousand hectares with an average annual production of 20515 (000 MT) (National Horticulture Board, 2018). The major producing States of tomato in the country are Andhra Pradesh, Madhya Pradesh, Karnataka, Gujarat, Odisha, West Bengal, Maharashtra, Chhattisgarh, Bihar, Telangana, Uttar Pradesh, Haryana and Tamil Nadu. These States account for 91% of the total tomato production of the country. Tomatoes are grown both under greenhouses and in open field. The tomato pinworm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is one of the global major destructive invasive pests. *Tuta absoluta* is an important pest of solanaceous crops which is native to South America and occurs in many parts of the world (Desneux et al. 2011). It has spread from South America to several parts of Europe, Africa and now it has spread to India. In Europe *T. absoluta* was initially reported in eastern Spain in the late 2006 (Urbaneka et al., 2007). In India, this pest was initially observed in Pune on tomato plants grown in polyhouse and field during October 2014 in Maharashtra (Shashank et al., 2015). In Tamil Nadu it was reported in Karimangalam block, Dharmapuri district on tomato (Hybrid Shivam), Shankumugam et al. (2015). *Tuta absoluta* has been observed for the first time on tomato at Vegetable Research Station, Rajendranagar, Telangana state during regular surveys from January to April 2015 by Anitha et al. (2015). Plant parts that are infested by pinworm are leaves, stems, buds, calyces, young fruits or ripe fruits and invasion of secondary pathogens which enter through the place of infestation made by the pest. It can cause up to 80 to 100% yield loss under protected and field conditions (Khanjani, 2013; Sandeep et al., 2019). This devastating tomato pest *T. absoluta* was recorded in Siberia (Ivo Tosevski, 2011). South American tomato pinworm, *T. absoluta* mostly prefers tomato, but it can also feed, develop and reproduce on other cultivated solanaceous crops. The pest is reported to cause damage to other solanaceous vegetables, including eggplant, potato and pepper as well as tobacco, solanaceous weeds and the garden bean *Non-solanaceous* host plants have also been reported, including *Chenopodium album* Linnaeus, *Convolvulus arvensis* Linnaeus and *Vicia faba* Linnaeus (Kalleshwaraswamy et al. 2015). It has maximum lifetime fecundity of 250 eggs per female and the whole life cycle of the *T. absoluta* from egg to adult emergence under laboratory conditions ranged from 21.0-27.50 days with an average of 24.5±2.15 days (Nayanal and Kalleshwaraswamy, 2015). *Tuta absoluta* attacks the tomato crop from seedling to harvesting stage. Tomato plants are damaged by feeding on leaves, stems,
flower buds and both green and ripe fruits by the invasion of secondary pathogens which enters through the wounds caused by the pest (Shasank et al., 2015). Management mainly relies on insecticides because of immediate effect. Establishing baseline susceptibility levels in pinworm is the first step in developing an insecticide resistance management program for this pest. Collecting baseline susceptibility data over a broad geographical range of populations provides information regarding natural variation in insecticide concentration-mortality and may aid in identifying those insecticides where resistance is more likely to develop. In this study we report the results of laboratory bioassays to determine the baseline susceptibility of pinworm to six insecticide chemistries.

**MATERIALS AND METHODS**

**Insect rearing**

Field populations of tomato pinworm were collected from five district locations of Tamil Nadu during 2017-2018 at infested greenhouse tomato crops and fields (Fig 1). A detailed record for each population is given in Table 1. From all sampling sites infested leaves with different instars were collected in polycovers and transferred in to a insect proof cages provided with fresh tomato seedlings to avoid stress and some samples were kept in a plastic tray lined with filter paper. When the leaves were fully mined fresh tomato leaves were provided to the larvae until pupation. The pupae were collected from the tray and placed them in a petri dish and kept in adult emergence cage. Newly emerged adults were provided with 10 per cent sugar solution fortified with multivitamin solution in petri dish with cotton swab. Fifteen days old tomato seedlings grown in pro-tray were kept in the adult emergence cage for oviposition. Fresh seedlings were provided for every 24 h until the completion of oviposition by the adults. The seedlings with eggs were kept in separate cages and observed for hatching. The hatched larvae maintained by providing fresh seedlings and the culture will be maintained continuously in lab and insect proof net house without any insecticide application. Rearing cages were maintained at 28 ± 1°C, 75% RH and a 12:12 h light:dark photoperiod. Tomato plants were grown in mud pots and seedlings were grown in pro-trays in insect proof net house. Field populations from different locations were reared separately for two generations and F$_2$ populations were used for baseline susceptibility studies. Second instar larvae were used for various laboratory experiments. Laboratory work was performed at the Horticultural College and Research Institute, Periyakulam, Tamil Nadu Agricultural University (TNAU).

**Bioassay method**

Baseline susceptibility data was collected for six insecticides (Table 2). Toxicological bioassay was conducted under Completely Randomized Design in laboratory conditions. Each treatment was replicated thrice. Leaf discs were dipped in insecticide solution for 30 seconds and shade dried for half an hour on pro-trays tied with rubber bands. These treated leaves were placed in a petri dish with filter paper moistened with 400 µl of distilled water to maintain turgidity of leaves. Larvae were starved for four hours in plastic containers and ten larvae were allowed for feeding on treated leaves in each petri dish. For untreated check larva allowed to feed on untreated leaves. The larvae were considered as dead after gentle stimuli with fine brush.

**Data analysis**

Mortality data from dose-response bioassays were subjected to probit analysis (Finney, 1971). Corrected mortality percentages were worked out using Abbott’s formula (Abbott, 1925) and most susceptible population were identified. The software tests the dose mortality response for linearity and provides the slope, lethal concentrations and the confidence limits (CL) of the lethal concentrations for each mortality line.

| Table 1: Collection sites (Fig 1) of Tuta absoluta populations in Tamil Nadu. |
|-----------------|-----------------|-----------------|-----------------|
| District        | Geographical position | Time of insect collection | Collected | Crop | Developmental stage |
|                 | Latitude (°NL) | Longitude (°EL) |                |       |                   |
| Theni (THENI)   | 9.96          | 77.65           | Nov, 2017    | Field | Tomato 2nd & 3rd Instar |
| Krishnagiri (KRI) | 12.48      | 78.21           | Jan, 2018    | Field | Tomato 3rd instar    |
| Dindigul (DGL)  | 9.51          | 78.13           | Jan, 2018    | Field | Tomato 3rd instar    |
| Coimbatore (CBE) | 11.01       | 77.93           | April, 2018  | Field | Tomato 1st instar    |
| Madurai (MDU)   | 10.08         | 78.39           | April, 2018  | Field | Tomato 2nd & 3rd Instar |
**RESULTS AND DISCUSSION**

The probit analysis results are summarized in Tables 3 to 8. Susceptibility to six chemicals of 5 pinworm populations collected during 2017-18 from different districts of Tamil Nadu and laboratory strains are presented in Table 1. The results indicated that tomato borer populations showed variable responses to different insecticide treatments. The highest ratios between minimum and maximum LC$_{50}$ of populations for these insecticides were 2–8 fold. The dose-response curves of tested populations exhibited high slopes in most cases. Curve slopes were variable but not very broad among populations of *T. absoluta*. The slopes for insecticides in all populations was higher than two in all cases, potentially suggesting higher homogeneity in all populations. The baseline study is extremely important to establish how variable the natural response of populations is for the insecticides and the way they are geographically homogeneous. Moderate variability in the LC$_{50}$ values were observed in the most cases resulting in no differences among the populations. Solid set of baseline data has been detected that can be used for the comparisons in the future. High variability in slopes were observed for spinosad (7.2) in Turkey populations (Dagli et al. 2012), Chlorantraniliprole (3.79) for Spain populations (Roditakis et al., 2012), flubendiamide (4.93) for Kuwait populations (Jallow et al., 2018) and indoxacarb (4.79) for Spain populations (Roditakis et al., 2012). These high slopes of concentration – mortality curves probably reflect a higher homogeneity of response to these insecticides in these populations (Finney, 1971).

**Diamides**

The tested populations exhibited high slopes in response to diamide exposure. The slope values generated from concentration mortality response to chlorantraniliprole (Table 3) varied widely among the populations of *T. absoluta* and ranged from 2.02 to 2.94 with an average of 2.44 (SE = 0.51), while for flubendiamide (Table 4) the slopes

| Insecticides          | Rate (ml/ha) | Dosage g a.i./ ha | Supplier          |
|-----------------------|--------------|-------------------|-------------------|
| Chlorantraniliprole   | 150 ml/ha    | 40                | DuPont            |
| Flubendiamide 480 SC  | 100 ml/ha    | 48                | Bayer             |
| Spinosad 45 SC        | 160 ml/ha    | 73                | Dow AgroSciences  |
| Indoxacarb 14.5 SC    | 500 ml/ha    | 75                | DuPont            |
| Imidacloprid 17.8 SL  | 125 ml/ha    | 30-35             | Bayer             |
| Chlorpyrphos 20 EC    | 450 ml/ha    | 100               | Dow AgroSciences  |

**Table 2**: Details of insecticides tested against *Tuta absoluta* on tomato.

| Population | Slope  | SE* | X²* | LC$_{50}$ | Confidence limits (95%) | LC$_{95}$ | Confidence limits (95%) | RR$_{50}$ | RR$_{95}$ |
|------------|--------|-----|-----|-----------|-------------------------|-----------|-------------------------|-----------|-----------|
|            | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit |
| Madurai    | 2.187  | 0.575 | 2.467 | 0.607 | 0.428 | 0.841 | 3.431 | 1.836 | 22.003 | 2.22 |
| Krishnagiri| 2.026  | 0.36  | 6.279 | 0.371 | 0.299 | 0.462 | 2.403 | 1.423 | 6.948 | 1.36 |
| Coimbatore | 2.945  | 0.488 | 5.573 | 0.608 | 0.484 | 0.727 | 2.199 | 1.615 | 3.865 | 2.23 |
| Theni      | 2.522  | 0.421 | 4.319 | 2.056 | 1.600 | 2.594 | 9.228 | 6.164 | 19.442 | 7.55 |
| Dindugul   | 2.069  | 0.404 | 2.835 | 0.301 | 0.206 | 0.403 | 1.879 | 1.135 | 5.350 | 1.10 |
| Lab population | 2.939  | 0.850 | 3.212 | 0.272 | 0.135 | 0.364 | 0.988 | 0.673 | 3.253 | 1.00 |

a-Standard Error, b-Chi Square, c- ppm, d- Resistant Ratio (RR estimated by dividing LC$_{50}$ of individual populations by LC$_{50}$ of most susceptible population).

**Table 3**: Log dose probit mortality data for *Tuta absoluta* populations from Tamil Nadu with Chlorantraniliprole.

| Population | Slope  | SE* | X²* | LC$_{50}$ | Confidence limits (95%) | LC$_{95}$ | Confidence limits (95%) | RR$_{50}$ | RR$_{95}$ |
|------------|--------|-----|-----|-----------|-------------------------|-----------|-------------------------|-----------|-----------|
|            | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit |
| Madurai    | 2.017  | 0.496 | 1.851 | 1.354 | 0.883 | 1.815 | 8.849 | 4.906 | 43.518 | 1.33 |
| Krishnagiri| 2.262  | 0.54  | 1.773 | 2.258 | 1.706 | 2.828 | 12.046 | 7.064 | 49.717 | 2.21 |
| Coimbatore | 3.151  | 0.512 | 3.906 | 1.097 | 0.900 | 1.298 | 3.649 | 2.709 | 6.263 | 1.07 |
| Theni      | 2.480  | 0.365 | 2.949 | 1.566 | 1.179 | 1.960 | 7.208 | 5.154 | 12.545 | 1.54 |
| Dindugul   | 2.914  | 0.585 | 1.743 | 1.541 | 1.219 | 1.911 | 5.650 | 3.810 | 13.243 | 1.51 |
| Lab population | 2.164  | 0.507 | 2.711 | 1.018 | 0.575 | 1.381 | 5.857 | 3.677 | 18.249 | 1.00 |

a-Standard Error, b-Chi Square, c- ppm, d- Resistant Ratio (RR estimated by dividing LC$_{50}$ of individual populations by LC$_{50}$ of most susceptible population).

**Table 4**: Log dose probit mortality data for *Tuta absoluta* populations from Tamil Nadu with Flubendiamide.
ranged from 2.01 to 3.15 with an average of 2.495 (SE = 0.50). The LC_{50} for chlorantraniliprole ranged from 0.27 to 0.608 ppm resulting eight-fold increase in resistance ratio could be considered to be within the natural variability range or developing low resistance. For flubendiamide the LC_{50} ranged from 1.01 to 2.25 ppm, three-fold difference was observed. In all cases the LC_{50} values were lower than the recommended label rate for both chlorantraniliprole and flubendiamide, suggesting that the particular diamide insecticides would provide the expected control of *T. absoluta* infestation. More specifically, the estimated mortality at the recommended rate was found to be 100% for chlorantraniliprole and 98.5-100% for flubendiamide. The current study showed that the susceptibility of *T. absoluta* populations from Tamil Nadu to flubendiamide and chlorantraniliprole was relatively similar when comparing the LC_{50} and resistance ratios of LC_{50} estimates. The magnitude of the variation was less than three-fold for flubendiamide and seven-fold for chlorantraniliprole resulting in no differences among the populations for the two insecticides. Similar variations in response to flubendiamide and chlorantraniliprole have also been reported in *Tuta absoluta* populations from Kuwait three-fold and four-fold difference for flubendiamide and chlorantraniliprole also showed high homogeneity of response among the populations and increase the resistance after 34 generations of selection with 750 and 860 fold (Jallow et al., 2018). Similarly resistance was also detected in Italian population with 2414 and 1742 fold for chlorantraniliprole and flubendiamide (Roditakis et al., 2015). Low resistance was found in Greece populations with four-fold difference for chlorantraniliprole and flubendiamide (Roditakis et al., 2012), two-fold to six-fold difference in chlorantraniliprole in Italy (Roditakis et al., 2012), but Brazilian populations were more susceptible than those populations. The LC_{50} values varied from 3.17 to 29.64 µg l^{-1} and 94 to 230 µg l^{-1} for chlorantraniliprole and flubendiamide with nine-fold and three-fold resistance ratios. It is worth mentioning that different adjuvants were used with diamides and this may be one reason why the Brazilian populations have showed lower LC_{50} values. The mechanisms involved in diamide resistance for pinworm was unknown (Campos et al., 2014). Nevertheless, with 10 to 12 generations per year, combined with wide spread and intensive use of flubendiamide and chlorantraniliprole to control *T. absoluta*, higher levels of resistance against these pesticides could occur in a relatively shorter period of time in the field where populations are large and selection pressures can be much higher than in the laboratory (Guillemaud et al., 2015). *Tuta absoluta* has proven to have potential ability to develop resistance to any insecticide sooner or later after extensive field use (Biondi et al., 2018; Guedes and Siqueira, 2012). The mechanism involved in diamide insecticides resistance in *T. Absoluta* is often linked to the specific target site mutations in the ryanodine receptors (RyX) transmembrane domain (Roditakis et al., 2017). However, it is also noted that detoxification enzymes

**Table 5:** Log dose probit mortality data for *Tuta absoluta* populations from Tamil Nadu with spinosad.

| Population       | Slope  | SE^{a} | X^{b} | LC_{50}^{c} | Confidence limits (95%) | LC_{95}^{d} | Confidence limits (95%) | RR_{95}^{e} |
|------------------|--------|--------|-------|-------------|-------------------------|-------------|-------------------------|-------------|
|                  |        |        |       |             | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit |
| Madurai          | 3.274  | 0.96   | 1.208 | 0.813       | 0.510       | 0.999       | 2.584       | 1.784       | 9.377       | 2.47        |
| Coimbatore       | 2.951  | 0.494  | 3.275 | 0.668       | 0.540       | 0.798       | 2.410       | 1.747       | 4.379       | 2.03        |
| Theni            | 3.243  | 0.561  | 5.180 | 0.571       | 0.465       | 0.682       | 1.837       | 1.349       | 3.292       | 1.74        |
| Dindugul         | 2.968  | 0.587  | 1.330 | 0.905       | 0.716       | 1.116       | 3.241       | 2.216       | 7.269       | 2.76        |
| Krishnagiri      | 2.769  | 0.57   | 2.190 | 0.635       | 0.433       | 0.800       | 2.494       | 1.766       | 5.238       | 1.94        |
| Lab population   | 1.457  | 0.271  | 0.691 | 0.328       | 0.228       | 0.447       | 4.410       | 2.189       | 18.750      | 1           |
|                   | a-Standard Error, b-Chi Square, c- ppm, d- Resistant Ratio (RR estimated by dividing LC_{95} of individual populations by LC_{50} of most susceptible population).

**Table 6:** Log dose probit mortality data for *Tuta absoluta* populations from Tamil Nadu with Imidacloprid.

| Population       | Slope  | SE^{a} | X^{b} | LC_{50}^{c} | Confidence limits (95%) | LC_{95}^{d} | Confidence limits (95%) | RR_{95}^{e} |
|------------------|--------|--------|-------|-------------|-------------------------|-------------|-------------------------|-------------|
|                  |        |        |       |             | Lower limit | Upper limit | Lower limit | Upper limit | Lower limit | Upper limit |
| Madurai          | 3.702  | 0.871  | 1.060 | 5.430       | 4.477       | 6.424       | 15.102      | 10.797      | 35.824      | 5.5         |
| Coimbatore       | 3.341  | 0.55   | 2.411 | 6.520       | 5.487       | 7.686       | 20.255      | 14.943      | 35.659      | 6.6         |
| Theni            | 1.521  | 0.308  | 0.828 | 3.534       | 2.460       | 5.542       | 42.573      | 18.534      | 270.497     | 3.6         |
| Dindugul         | 2.996  | 0.992  | 0.099 | 4.654       | 3.125       | 6.469       | 16.471      | 9.738       | 163.861     | 4.7         |
| Krishnagiri      | 3.243  | 0.850  | 0.789 | 3.033       | 1.911       | 3.816       | 9.751       | 6.928       | 25.127      | 3.1         |
| Lab population   | 1.245  | 0.27   | 2.976 | 0.989       | 0.504       | 1.549       | 20.696      | 8.886       | 147.688     |             |
|                   | a-Standard Error, b-Chi Square, c- ppm, d- Resistant Ratio (RR estimated by dividing LC_{95} of individual populations by LC_{50} of most susceptible population).
may also play a role in diamide resistance in *T. absoluta* (Campos et al., 2015; Karaagac, 2015). The resistant ratios ranged from 1 to 288995 fold for chlorantraniliprole and 1 to 80,413 fold for flubendiamide (Silva et al. 2016).

**Spinosyn**

High slopes of the response line to spinosad were observed, ranging from 1.45 to 3.27 and resulting in an average of 2.77 (SE = 0.57), which is similar to that observed for the diamide insecticides (Tables 3 and 4). The LC$_{50}$ ranged from 0.32 to 0.9 ppm resulting in a three-fold difference. The LC$_{95}$ ranged from 1.83 to 4.41 ppm (Table 5). Similar variations in response to spinosad have also been reported in Turkey populations showed LC$_{50}$ (0.3-1.6) and LC$_{95}$ (1.5-7.7) values less than that of the field recommended doses with five-fold difference, resulted in 100% mortality with minimal or no feeding in all populations (Dagli et al., 2012). Very high levels of spinosad resistance has been reported from Brazilian populations, spinosad resistant strain achieved within seven generations of selection with 1,80,000 fold difference with LC$_{95}$ of 1717.13 µg a.i m$^{-1}$. The quick development of spinosad resistance in this region is suggestive of a highly inheritable (monogenic) trait (Campos et al., 2014). The LC$_{50}$ of 2.26 µg a.i m$^{-1}$ with five-fold difference were observed in Brazil (Savannah) by (Silva et al., 2011). Resistance development against indoxacarb in resistant populations than the susceptible populations and resistance is positively correlated and favoured by high temperatures (Silva et al., 2011).

**Neonicotinoids**

The slopes of the response line to imidacloprid exhibited high variability ranging from 1.24 to 3.7 and resulting in an average of 2.67 (SE = 0.64). The LC$_{50}$ ranged from 0.98 to 6.52 ppm, resulting in a sevenfold difference lower than the recommended label rate. The LC$_{95}$ ranged from 9.75 to 42.57 ppm (Table 6). Although imidacloprid have not been registered for *T. absoluta* control in India, our group was investigated for its potency against this new pest. High variability in the LC$_{50}$ values was observed for Imidacloprid. When compared with the recommended field rate, very low toxicity levels were detected. Plots treated with imidacloprid suffered greater damage by the pests with low marketable and total yield. Poor performance by reportedly effective insecticides for controlling *T. absoluta* with imidacloprid suggest that the *T. absoluta* population which invaded Ethiopia is not resistant only to the older group of insecticides such as organophosphates (e.g. profenofos), but also relatively to the new molecules (Ayalew, 2015). Ramesh and Ukey (2007) and Kay (2006) found that imidacloprid were weak and ineffective insecticide against tomato leaf miner.

**Oxadiazine**

The slopes of the response line to indoxacarb, variability ranging from 1.70 to 3.01 and resulting in an average of 2.26 (SE = 0.5). The LC$_{50}$ ranged from 0.82 to 6.38 ppm resulting in a eight-fold difference. The LC$_{95}$ ranged from 7.67 to 34.14 ppm (Table 7). Indoxacarb, this chemical has been used to curb the pests for several years. Resistance

| Population       | Slope  | SE$^a$ | X$^b$ | LC$_{50}$ | Confidence limits (95%) | LC$_{95}$ | Confidence limits (95%) | RR$_{50}$ | RR$_{95}$ |
|------------------|--------|--------|-------|-----------|--------------------------|-----------|--------------------------|----------|----------|
| Madurai          | 3.016  | 0.798  | 2.474 | 2.918     | 1.885 - 3.635            | 10.239    | 7.048 - 30.179           | 3.53     |
| Coimbatore       | 2.091  | 0.368  | 2.164 | 4.595     | 3.545 - 6.000            | 28.106    | 16.736 - 77.211          | 5.6      |
| Theni            | 2.599  | 0.519  | 2.881 | 6.385     | 5.073 - 8.000            | 27.413    | 17.574 - 72.271          | 7.72     |
| Dindugul         | 2.062  | 0.532  | 1.945 | 5.439     | 4.061 - 7.894            | 34.140    | 17.041 - 262.136         | 6.6      |
| Krishnagiri      | 2.098  | 0.543  | 2.375 | 3.361     | 1.740 - 4.685            | 20.428    | 12.097 - 87.031          | 4.1      |
| Lab population   | 1.700  | 0.219  | 0.821 | 0.827     | 0.628 - 1.072            | 7.670     | 4.707 - 16.738           | 1        |

**Table 8:** Log dose probit mortality data for *Tuta absoluta* populations from Tamil Nadu with chloripyriphos.

| Population       | Slope  | SE$^a$ | X$^b$ | LC$_{50}$ | Confidence limits (95%) | LC$_{95}$ | Confidence limits (95%) | RR$_{50}$ | RR$_{95}$ |
|------------------|--------|--------|-------|-----------|--------------------------|-----------|--------------------------|----------|----------|
| Madurai          | 2.23   | 0.53   | 1.18  | 1911.98   | 1434.54 - 2605.52        | 10375.87  | 5729.81 - 49682.36       | 1.23     |
| Krishnagiri      | 2.81   | 0.51   | 5.12  | 1041.81   | 860.447 - 1274.85        | 3993.96   | 2685.27 - 8924.24        | 1.07     |
| Coimbatore       | 2.66   | 0.50   | 2.33  | 1548.06   | 1193.70 - 1904.72        | 6403.14   | 4360.06 - 14067.47       | 1.6      |
| Theni            | 2.57   | 0.56   | 0.58  | 1656.55   | 1291.41 - 2140.44        | 7206.81   | 4431.76 - 22947.75       | 1.71     |
| Dindugul         | 2.85   | 0.74   | 2.76  | 1671.90   | 990.24 - 2157.23         | 6290.15   | 4302.28 - 17943.91       | 1.72     |
| Lab population   | 1.93   | 0.44   | 4.19  | 967.32    | 651.49 - 1379.50         | 6830.12   | 3589.11 - 33204.164      | 1        |

*Note: a-Standard Error, b-Chi Square, c- ppm, d- Resistant Ratio (RR estimated by dividing LC$_{50}$ of individual populations by LC$_{50}$ of most susceptible population).*
development to indoxacarb in Lepidoptera species was expected, as this molecule is mainly known for controlling the moths in various crops. Similar variations in response to indoxacarb have also been reported in Brazil, where indoxacarb exhibited moderate levels of resistance (up to 27.5-fold) (Silva et al., 2010). Variability in the responses to indoxacarb have also been reported by Silva et al. (2011), in the populations from Brazil (27-fold) and by (Roditakis et al., 2012) in populations from Italy (3-fold) and 12-fold) and Greece (10-fold) and 2-fold difference in Italy, 20-fold difference in Italy (Dagli et al., 2012). Silva et al. (2011) also reported cases of potential control failure with indoxacarb, but this has not detected in this study. These results might indicate genetic potential of this pest to develop resistance to indoxacarb. Indoxacarb resistance is also a concern in the Brazilian savannah and Atlantic forest. Although the resistance levels are lower than those of chitin synthesis inhibitors up to 222-fold. Natural variability due to genetic polymorphisms is possibly one parameter.

Organophosphate

The slopes of the response line to chlorpyriphos variability ranging from 1.93 to 2.81 and resulting in an average of 2.51 (SE = 0.55). The LC₅₀ ranged from 967.32 to 1911.98 ppm, resulting in a twofold difference. The LC₅₀ ranged from 3993.9 to 10375 ppm, was always higher than the of the recommended label rate (Table 8). To date, the toxicity of chlorpyriphos investigated only in Greece. In that, moderate variability in the responses to chlorpyriphos was reported (fourfold) by Roditakis et al., 2012, where twofold difference was found in our studies. LC₅₀ values are more than recommended field dose. It is suspected that the tested populations exhibited high tolerance to chlorpyriphos. Subsequently, probit analysis revealed that doses higher than the recommended field rate were required to achieve 80 per cent of pest control.

CONCLUSION

These findings suggest the feasibility of chlorantraniliprole and spinosad for the control of tomato pinworm effectively under field conditions. All possible tools need to be exploited to suppress further spread of insecciticide resistance to the resistant prone pest Tuta absoluta. Insecticides with different mode of action are the best option to control the pest. More importantly, rotating the insecticides with other compounds belonging to different classes and MoA as an insecticide resistance management (IRM) strategy must be encouraged. The reliance of growers solely on insecticides to manage T. absoluta will not provide the flexibility that is required for a rational resistance management strategy of the pest. Therefore, the successful integration of diverse strategies, involving both preventive and corrective control measures will remain crucial for the sustainable management of the pest globally. This invasive species is difficult to control, thus the use of insecticides remains the key strategy for keeping it under control, which is an immediate threat to tomato production with the lack of alternative management strategies in the invaded countries. Intensive use of pesticides favours the evolution of insecticide resistance and consequent insecticide control failure. Insecticides which are in use for this pest in introduced areas should be carefully monitored to prevent rapid selection for high levels of resistance and its potential for its spread to other new areas.

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