

## Susceptibility of Four Trichogrammatid Parasitoids to some Bio-rational Insecticides Used to Control Tomato Leaf Miner *Tuta absoluta* (Lepidoptera, Gelechiidae)

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**Abstract:** Laboratory bioassays were performed to evaluate the susceptibility of four species of trichogrammatid egg parasitoids to the toxicity of five bio-rational insecticides used widely to control tomato leaf miner, (TLM) *Tuta absoluta* (Lepidoptera: Gelechiidae). The selected parasitoids were *Trichogramma evanescens* (West.), *T. cacoeciae* (Brun), *T. pretiosum* (Riley), and *Trichogrammatoidea bactrae* (Nagaraja). Insecticides tested were coragen 20% SC, dipel2× 6.4%, match 50% EC, proclaim 5% EC and spintor 24% SC. Susceptibility of parasitoids to field rate of the tested insecticides were evaluated using three bioassay tests: 1) exposing parasitoid females to TLM eggs treated pre-exposure, 2) exposing parasitoid females to TLM eggs treated post-exposure, and 3) exposing parasitoid females to dry insecticide residue on filter paper. Results revealed that the tested insecticides showed various degree of adverse impact on all tested parasitoid species, including reduction in rates of parasitism and adult emergence when exposing parasitoids adults to host eggs treated pre or post exposure. Spintor and proclaim were the most toxic to tested parasitoids, while dipel 2× and match were slightly toxic. *T. bactrae* was the most tolerant parasitoid species, while *T. pretiosum* was the most susceptible one. Data of exposing parasitoid adults to insecticide residues indicated that proclaim had the highest toxicity against *T. pretiosum* at 92.5% adults' mortality, followed by spintor against the same species at 85%. *T. evanescens* was more susceptible to coragen and spintor at 70 and 62.5% mortality, respectively. Meanwhile, match caused moderate toxicity, as the mortality ranged from 17.50% in *T. evanescens* to 37.50% in *T. pretiosum*.

**Keywords:** Bio-rational insecticides, Parasitism, Parasitoid emergence, Toxicity, Trichogrammatidae, *Tuta absoluta*

### INTRODUCTION

The tomato leafminer (TLM), *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is one of the most destructive invasive insect pests attacking tomato crop in Mediterranean basin countries (Desneux *et al.*, 2010; Desneux *et al.*, 2011; Tropea Garzia *et al.*, 2012). In Egypt, it was first recorded infesting tomato crop in Western desert in the late of 2009 (Temerak, 2011). Since its detection in Egypt, it spread rapidly to become a key insect pest on tomato crop in both open field and protected greenhouse. This pest is capable of causing major economic losses in tomatoes of up to 80-100% (EPPO 2005; Picanco *et al.*, 2007; Desneux *et al.*, 2010). Thus, developing and implementing effective control tactics of this pest are rather essential in order to prevent possible potential damage caused by this pest.

Integrated pest management (IPM) strategies emphasize the use of multiple tactics based on economically and ecologically sound manner. Beneficial insects play a vital role in the agro-ecosystem and are a realistic management tool in integrated pest management. Egg parasitoid species of the family Trichogrammatidae are considered efficient biological control agents and are commercially used for the suppression and control of various lepidopterous pests on many crops (Caltagirone and Huffaker, 1980), including TLM on tomato crop (Pratissoli and Parra, 2001).

In spite the vital role of the biological control agents for controlling agricultural pests, the use of chemical insecticides is still inevitable. Unfortunately, the commonly used insecticides are toxic to many non-target organisms particularly hymenopterans parasitoids, and greatly reduce their potential as

biocontrol agents (Desneux *et al.*, 2007; Stark and Banks, 2003). Selective pesticides that can be used to control pests without adversely affecting natural enemies are urgently needed for integrated control programs (Hafez *et al.*, 1999).

Recently, great attention has been given to maintain environment and keep natural balance, which might be achieved in the field for pest control by using bio-rational insecticides and natural enemies. However, it is very important to study the adverse effects of these bio-rational insecticides on the natural enemies to exclude the ones that have detrimental effect on such natural enemies. A range of harmful effects of insecticides on *Trichogramma* spp. have been reported by several researches (Hewa-Kapuge *et al.*, 2003; Desneux *et al.*, 2007; Vianna *et al.*, 2009).

Therefore, the current research aimed to verify the adverse effect of five bio-rational insecticides, which are widely used to control TLM in tomato fields, on the parasitism efficiency, adult emergence, as well as their direct toxicity on the adult stage of four trichogrammatid egg parasitoids under laboratory conditions.

### MATERIALS AND METHODS

#### Source and maintenance of parasitoid species:

Four trichogrammatid egg parasitoid species (Hymenoptera: Trichogrammatidae) were investigated; i.e., *Trichogramma evanescens* (West.), *T. cacoeciae* (Brun), *T. pretiosum* (Riley), and *Trichogrammatoidea bactrae* (Nagaraja). The source of *T. evanescens* (West.) was obtained from the mother colony kept in the laboratory of Biological Control Center (BCC), Suez Canal University (SCU). As for *T. cacoeciae* (Brun) and

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*Tr. bactrae* (Nagaraja), wasps were kindly provided by Prof. Essam Agamy (Faculty of Agriculture, Cairo University) and Prof. Ahmad El-Heneidy (Agricultural Research Center), respectively. In case of *T. pretiosum* (Riley), the wasp was imported from Berkely, California University, USA. All parasitoids were maintained on the Angoumois grain moth, *Sitotroga cerealella* (Lepidoptera: Gelichiidae) eggs for several generations under laboratory conditions.

#### Maintenance of target pest and preparing egg cards:

Tomato leaf miner (TLM) was reared on tomato seedlings placed in a rearing cage (40×60×80 cm) under laboratory conditions of 25±2°C; 60±10% RH and photoperiod of 14: 10 (L: D) h. This pest was reared and maintained for at least 3 generations before being used in this experiment. Newly laid TLM eggs (less than 24 h old) were glued onto small cartoon cards, each containing 10 eggs. These egg cards were prepared one hour prior to assay and placed into glass tubes.

#### Tested bio-rational insecticides:

Commercial formulations of the bio-rational insecticides tested in this study were coragen 20% SC (chlorantraniliprole), dipel 2× 6.4% (*Bacillus thuringiensis* var. kurstaki 32000 IU/mg), match 50% EC (lufenuron), proclaim 5% SG (emamectin benzoate), and spintor 24% SC (spinosyns A and D, *Saccharopolyspora spinosa*). Solutions of all tested compounds were prepared in distilled water at the recommended field rate (FR), (coragen 60 mg/l a.i., dipel 2× 128 mg/l a.i., match 200 mg/l a.i., proclaim 30 mg/l a.i. and spintor 60 mg/l a.i.). The tested concentration of each compound was freshly prepared one hour prior to assay.

#### Bioassay toxicity assessment tests:

The susceptibility of the four tested oophagous parasitoids to the tested bio-rational insecticides was conducted in the laboratory using their field rates. Fresh solutions of the tested bio-rational insecticides were prepared one hour prior to use. To ascertain the toxicity of spraying bio-rational insecticides on the four tested trichogrammatid species, three groups of assessment tests were conducted. These groups included a) exposing parasitoid adult females to treated TLM eggs, b) exposing parasitoid adult females to TLM eggs prior to treatment and c) exposing parasitoid adult females to treated filter paper in Petri dishes.

#### a. Exposing parasitoid females to treated host eggs:

Small egg cards, each containing 10 unparasitized eggs of TLM, were dipped for 5 seconds in freshly prepared solution of the recommended rates of the tested bio-rational insecticides. Each treatment of bio-rational insecticide was replicated four times (four cards) for each parasitoid species. Distilled water was used in the untreated control. The treated egg cards were left to dry out for one hour. After that, each treated TLM egg card was exposed to 5 adult females of each tested parasitoid species for a period of 2 hours. Then these cards were placed in Petri dishes and kept in an incubator at 25°C till emergence. The rate of parasitized host eggs and emerging parasitoid adults were counted using the following equations;

$$\text{Parasitism (\%)} = \frac{\text{No. of parasitized eggs (Black eggs)}}{\text{Total No. of exposed host eggs}} \times 100$$

$$\text{Emergence (\%)} = \frac{\text{No. of parasitized eggs with emergence hole}}{\text{Total No. of parasitized eggs}} \times 100$$

#### b. Exposing parasitoid females to host eggs prior to treatment:

In this experiment, the above mentioned methodology, including experimental setup and number of replicates for each treatment were used. However, newly emerged parasitoid females were offered untreated TLM eggs for parasitization. After that, these parasitized host egg cards were treated with the tested bio-rational insecticides as indicated earlier.

#### c. Exposing parasitoid females to treated filter paper in Petri dishes:

The toxicity of the tested bio-rational insecticides were assessed against the trichogrammatid species by exposing the adult parasitoids to residues of a fresh dry pesticide film applied on filter papers inside glass Petri dishes. The recommended field rate of each bio-rational insecticide was directly sprayed on the filter papers (7 cm diameter) and left to dry out. The treated filter papers were placed inside the Petri dish (7 cm diameter). Ten newly emerged females of each parasitoid species were released into Petri dish with treated filter paper and rapidly covered with fine plastic sheet. Small holes were made in the plastic covers to ease ventilation. One hour later, these females were collected and transferred to other clean Petri dish and kept in an incubator at 25°C, 70% R.H. Each treatment of bio-rational insecticide was replicated four times for each parasitoid species. Distilled water was used in the untreated control. The number of dead and survived parasitoids was counted 24h post of treatment.

#### Statistical analysis:

Normality of data was tested by the Shapiro-Wilks test before further analysis. When a Shapiro-Wilk test indicated that data were normally distributed, data were analyzed by parametric analysis of variance (ANOVA) and then the Holm-Sidak or Student-Newman-Keuls methods were used for all pair wise multiple comparisons. When data were not normally distributed, a nonparametric Kruskal-Wallis ANOVA on ranks (H test) was used and Tukey's or Dunn's tests were used to compare treatment means at a 0.05 level of significance. Data were analyzed using SigmaPlot 12.3 (Systat Software Inc., 2011).

## RESULTS AND DISCUSSION

#### a. Exposing parasitoid adult females to treated TLM eggs:

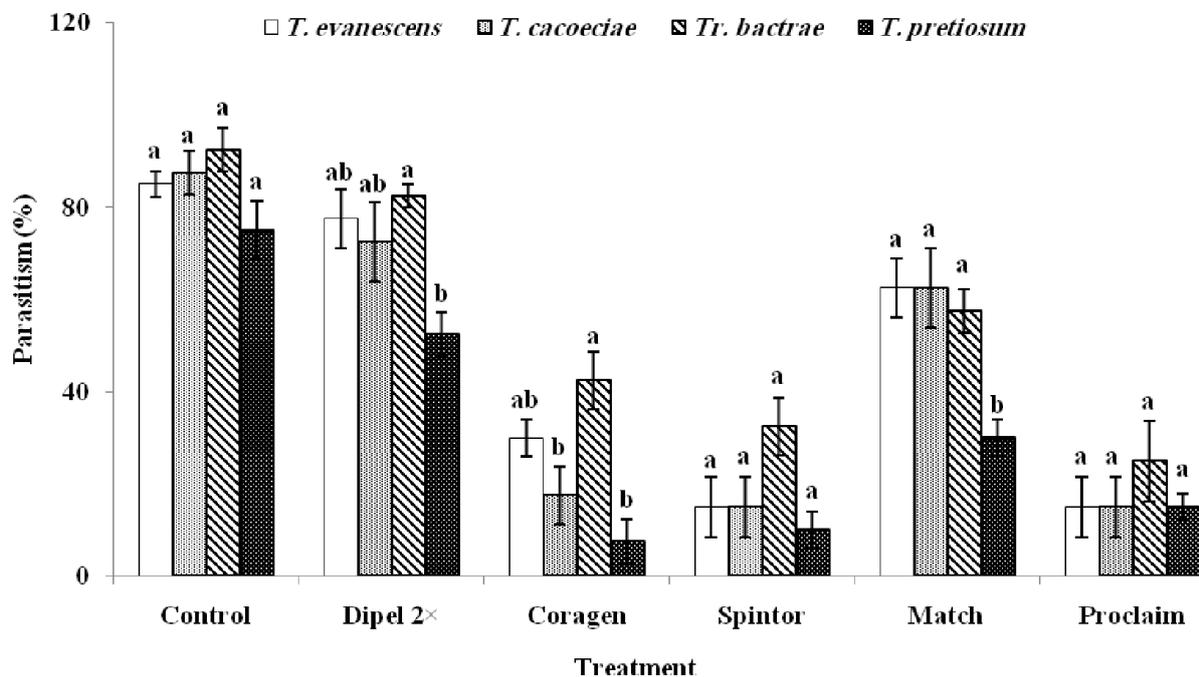
##### Effects on parasitism percentage:

As shown in Figure (1), all tested bio-rational insecticides have reduced percentages of parasitism irrespective of tested parasitoid species. Percentages of parasitism in control treatment reached 85, 87.50, 92.50 and 75% in *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and

*T. pretiosum*, respectively. Data revealed that the tested insecticides significantly affected the number of parasitized TLM eggs. Spintor, proclain and coragen severely affected the number of parasitized eggs that were treated before exposing to parasitoids. The lowest percentage of parasitism in treated TLM eggs exposed to *T. pretiosum* was recorded with coragen at 7.50%. Spintor showed its highest toxic effect on the percentage of parasitism; being 10, 15 and 15% for *T. pretiosum*, *T. evanescens* and *T. cacoeciae*, respectively. The highest toxic effect of proclain was observed in *T. evanescens*, *T. pretiosum* and *T. cacoeciae* at parasitism rate of 15% to all of them. Moreover, proclain treatment has not caused significant differences between the four parasitoid species. Match had moderate toxic effect where the percentage of parasitism ranged between 3% for *T. pretiosum* to 62.50% for *T. evanescens* and *T.*

*cacoeciae*. Dipel 2× had less toxic effect, where the rate of parasitism ranged between 52.50% for *T. pretiosum* and 82.50% for *Tr. bactrae* (Figure 1). Statistical analyses indicated that percentages of parasitism by the four parasitoids differed significantly in dipel 2× ( $F_{3,12}=4.88$ ;  $P=0.019$ ), coragen ( $F_{3,12}=7.77$ ;  $P=0.004$ ) and match ( $F_{3,12}=6.40$ ;  $P=0.008$ ). However, no significant differences existed in control ( $F_{3,12}=2.26$ ;  $P=0.134$ ), spintor ( $F_{3,12}=2.79$ ;  $P=0.086$ ) and proclain treatment ( $F_{3,12}=0.60$ ;  $P=0.627$ ).

Statistical analyses further proved that there were significant differences among rates of parasitism in TLM eggs treated with the tested bio-rational insecticides in *T. evanescens* ( $F_{5,12}=31.68$ ;  $P=0.001$ ), *T. cacoeciae* ( $F_{5,12}=22.32$ ;  $P=0.001$ ), *Tr. bactrae* ( $F_{5,12}=21.70$ ;  $P=0.001$ ) and *T. pretiosum* ( $F_{5,12}=33.87$ ;  $P=0.001$ ).



**Figure (1):** Mean percentages of parasitism ( $\pm$ SE) by four trichogrammatid species in TLM eggs treated one hour pre-exposure to parasitoid with field rates of certain bio-rational insecticides. Bars with different letters in the same treatment indicate significant differences ( $P < 0.05$ )

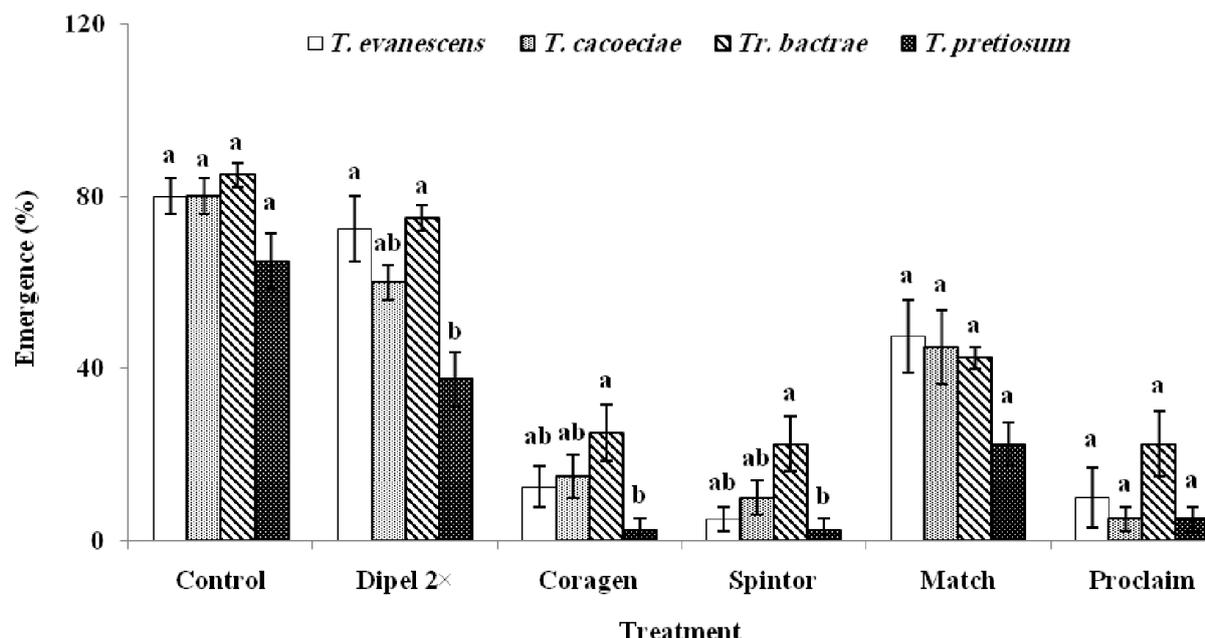
#### Effects on percentage of adult emergence:

As shown in Figure (2), all tested bio-rational insecticides reduced adult emergence rates, irrespective of parasitoid species. Rates of emergence in control treatment reached 80, 80, 85 and 65% in *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively. Based on the reduction in adult emergence rates, the toxicity of the tested bio-rational insecticides was in the order of spintor > proclain > coragen > match > dipel2×. Clearly, *Tr. bactrae* was the least affected parasitoids with the tested insecticides at percentages of emergence of 75, 25, 22.50, 42.50 and 22.50% in dipel 2×, coragen, spintor, match and proclain treatments, respectively. On the other hand, *T. pretiosum* was the most affected parasitoid with pesticide treatment at percentages of adult emergence of 37.50, 2.50, 2.50,

22.50 and 5% in the respective bio-rational insecticide treatments (Figure 2).

Statistical analysis showed significant differences in rates of adult emergence between the studied bio-rational insecticides, i.e., dipel 2× ( $F_{3,12}=9.72$ ;  $P=0.002$ ), coragen ( $F_{3,12}=3.57$ ;  $P=0.047$ ) and spintor ( $F_{3,12}=4.47$ ;  $P=0.025$ ). However, no significant differences were observed in control ( $F_{3,12}=3.60$ ;  $P=0.046$ ), match ( $F_{3,12}=2.95$ ;  $P=0.076$ ) and proclain treatment ( $F_{3,12}=2.22$ ;  $P=0.138$ ).

Statistical analyses also revealed that significant differences existed in percentages of adult emergence in *T. evanescens* ( $F_{5,12}=29.42$ ;  $P=0.001$ ), *T. cacoeciae* ( $F_{5,12}=35.40$ ;  $P=0.001$ ), *Tr. bactrae* ( $F_{5,12}=29.31$ ;  $P=0.001$ ) and *T. pretiosum* ( $F_{5,12}=30.12$ ;  $P=0.001$ ).



**Figure (2):** Mean percentages of adult emergence ( $\pm$ SE) of four trichogrammatid species in TLM eggs treated one hour pre-exposure to parasitoids with field rates of certain bio-rational insecticides. Bars with different letters in the same treatment indicate significant differences ( $P < 0.05$ )

#### b. Exposure of parasitoid females to TLM eggs prior to treatment:

##### *Effects on percentage of parasitism:*

As shown in Figure (3), all tested bio-rational insecticides reduced rates of parasitism irrespective of parasitoid species. Rates of parasitism in control treatment reached 92.50, 95, 97.50 and 82.50% in *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively. The lowest percentages of parasitism in treated host eggs after being exposed to *T. pretiosum* were recorded with spintor and coragen at 10 and 25.50%, respectively. Proclaim caused high toxicity for all tested parasitoid species with no significant differences, where the parasitism percentage ranged between 27.50% in *T. pretiosum* and 37.50% in *T. evanescens*. Match was less toxic and the percentage of parasitism ranged between 57.50% for *T. pretiosum* to 82.5% for *T. evanescens*. Dipel 2x didn't display noticeable effects, where the percentages of parasitism ranged between 70% for *T. pretiosum* and 85% for *T. evanescens* (Figure 3).

Treatment of TLM parasitized eggs by bio-rational insecticides caused significant differences in terms of successful rates of parasitism among tested parasitoids in coragen ( $F_{3,12} = 7.71$ ;  $P = 0.004$ ), spintor ( $F_{3,12} = 13.68$ ;  $P = 0.001$ ) and match ( $F_{3,12} = 3.56$ ;  $P = 0.047$ ). However, no significant differences were observed in case of control ( $F_{3,12} = 2.86$ ;  $P = 0.081$ ), dipel 2x ( $F_{3,12} = 1.54$ ;  $P = 0.254$ ) and proclaim treatment ( $F_{3,12} = 0.58$ ;  $P = 0.640$ ).

Similarly, statistical analyses also showed that the rates of parasitism in TLM treated with certain bio-rational insecticides differed significantly in *T. evanescens* ( $F_{5,12} = 21.58$ ;  $P = 0.001$ ), *T. cacoeciae* ( $F_{5,12} = 16.71$ ;  $P = 0.001$ ), *Tr. bactrae* ( $H_5 = 19.87$ ;  $P = 0.001$ ) and *T. pretiosum* ( $F_{5,12} = 26.45$ ;  $P = 0.001$ ).

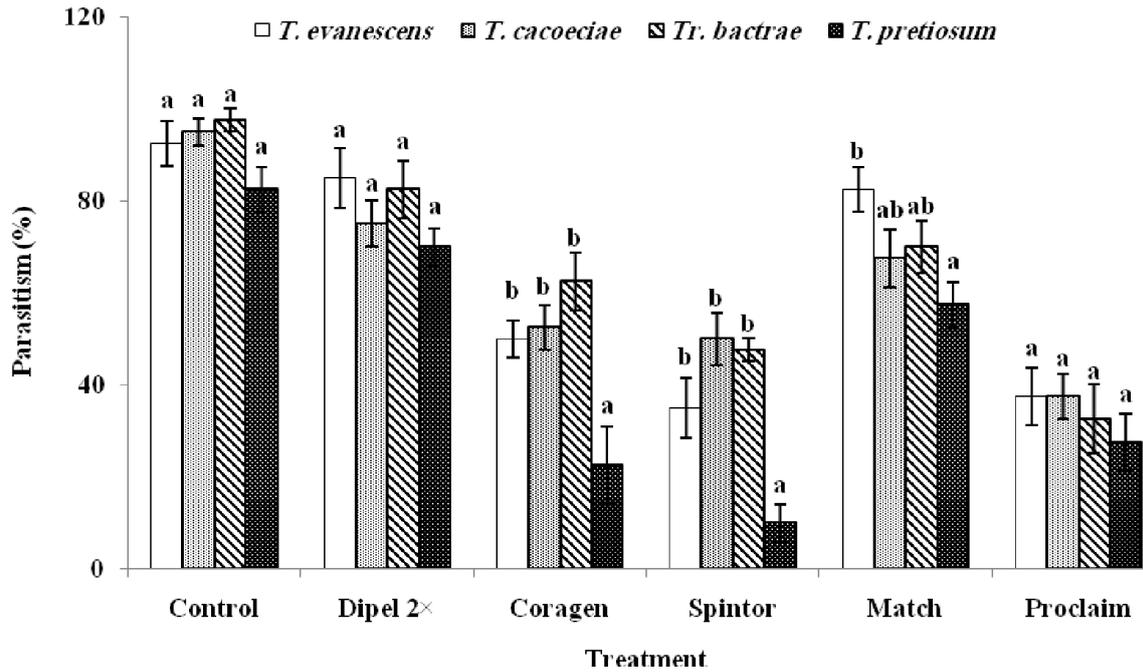
##### *Effects on percentages of adult emergence:*

As shown in Figure (4), all tested bio-rational insecticides reduced percentages of adult emergence irrespective of parasitoid species. Rates of parasitoid emergence in control treatment reached 87.50, 90, 95 and 75.50% in *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively. Data revealed that exposing parasitoid females to TLM treated eggs with spintor resulted in the lowest percentages of emergence for all tested parasitoids at 17.50, 35, 30 and 5% in *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively. Proclaim came second after spintor in its toxic effect at percentages of parasitoid emergence of 10, 15, 25 and 10% for the respective parasitoids (Figure 4).

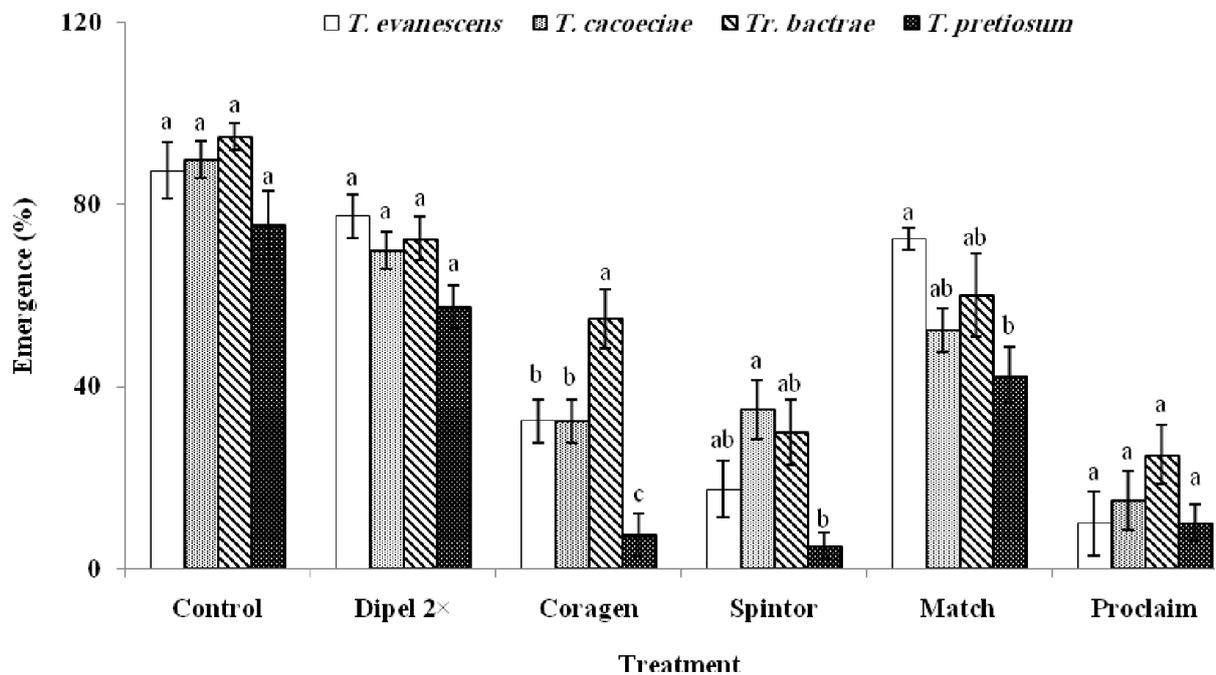
The respective percentages of adult emergence for coragen were 32.50, 32.50, 55 and 7.50%, and those for match was 72.50, 52.50, 60 and 42.50. Moreover, dipel2x treatment showed the highest percentages of emergence at 77.50, 70, 72.50 and 57.50% for *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively.

Statistical analyses showed significant differences in rates of adult emergence in TLM-treated-eggs for *T. evanescens* ( $F_{5,12} = 37.28$ ;  $P = 0.001$ ), *T. cacoeciae* ( $F_{5,12} = 27.75$ ;  $P = 0.001$ ), *Tr. bactrae* ( $F_{5,12} = 16.68$ ;  $P = 0.001$ ) and *T. pretiosum* ( $F_{5,12} = 30.33$ ;  $P = 0.001$ ).

Based on the tested bio-rational insecticides, statistical analyses proved a significant differences between coragen ( $F_{3,12} = 13.64$ ;  $P = 0.001$ ), spintor ( $F_{3,12} = 5.18$ ;  $P = 0.016$ ) and match ( $F_{3,12} = 4.21$ ;  $P = 0.030$ ). On the other hand, no significant difference existed in terms of rates of emergence in control ( $F_{3,12} = 3.10$ ;  $P = 0.067$ ), proclaim ( $F_{3,12} = 1.33$ ;  $P = 0.310$ ) and dipel 2x ( $F_{3,12} = 3.39$ ;  $P = 0.054$ ).



**Figure (3):** Mean percentages of parasitism ( $\pm$ SE) by four trichogrammatid species in TLM eggs treated one hour post-exposure to parasitoids with field rates of certain bio-rational insecticides. Bars with different letters in the same treatment indicate significant differences ( $P < 0.05$ )



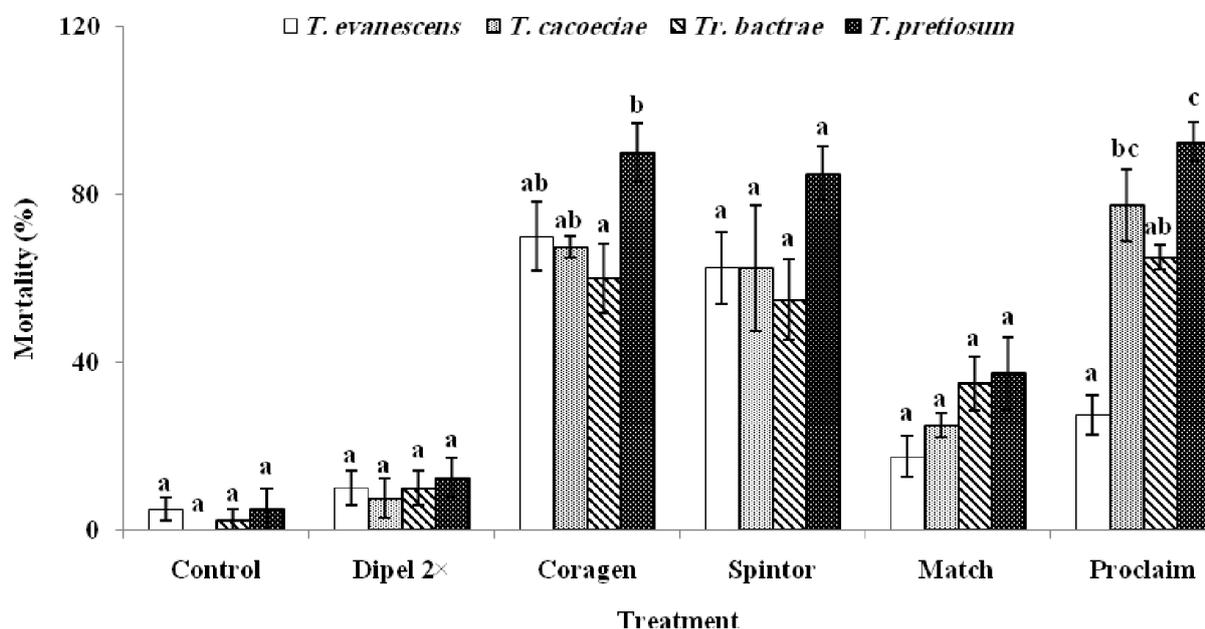
**Figure (4):** Mean Percentages of adult emergence ( $\pm$ SE) of four trichogrammatid species in TLM eggs treated one hour post-exposure to parasitoids with field rates of certain bio-rational insecticides. Bars with different letters in the same treatment indicate significant differences ( $P < 0.05$ )

### c. Exposure of parasitoid adult females to insecticide residues:

The obtained data revealed that the mortality percentages of parasitoid females exposed to different bio-rational insecticide residues on a filter paper differed significantly among tested parasitoids (Figure 5). Exposing adults of parasitoids to residues of coragen caused the highest percentages of mortality at 70, 67.50, 60 and 90% for *T. evanescens*, *T. cacoeciae*, *Tr. bactrae* and *T. pretiosum*, respectively. Spintor came second in its effect on adult mortality at mortality percentages of 62.50, 62.50, 55 and 85% for the respective parasitoids. Proclaim also caused higher percentages of mortality at 27.50, 77.50, 65 and 92.50% for the respective parasitoids. Match was moderately toxic to the parasitoids at respective mortality percentages of 17.50, 25, 35 and 37.50%. Meanwhile, dipel 2 $\times$  proved to be slightly toxic at respective mortality percentages of 10, 7.50, 10 and 12.50% (Figure 5).

Statistical analysis showed high significant differences of the parasitoid mortality rates between the tested bio-rational insecticides. There were significant differences in mortality percentages in proclaim treatment ( $F_{3,12}= 24.31$ ;  $P= 0.001$ ). However, no significant difference was found among rates of mortality in all tested parasitoids in control ( $H_3= 2.22$ ;  $P= 0.528$ ), dipel 2 $\times$  ( $F_{3,12}= 0.21$ ;  $P= 0.887$ ), coragen ( $F_{3,12}= 3.46$ ;  $P= 0.051$ ), match ( $F_{3,12}= 2.34$ ;  $P= 0.125$ ) and spintor treatment ( $F_{3,12}= 1.57$ ;  $P= 0.247$ ).

Moreover, statistical analyses revealed that significant differences mortality percentages when parasitoid adults exposed to bio-rational insecticides residues in *T. evanescens* ( $F_{5,12}= 21.77$ ;  $P= 0.001$ ), *T. cacoeciae* ( $H_5= 19.75$ ;  $P= 0.001$ ), *Tr. bactrae* ( $F_{5,12}= 18.45$ ;  $P= 0.001$ ) and *T. pretiosum* treatment ( $F_{5,12}= 41.464$ ;  $P= 0.001$ ).



**Figure (5):** Mean ( $\pm$ SE) of adult mortality of four trichogrammatid parasitoids exposed to residues of certain bio-rational insecticides, on a filter paper. Bars with different letters in the same treatment indicate significant differences ( $P < 0.05$ )

## DISCUSSION

Despite the success of biological control in pest control, chemical insecticides are still an important control tool, indispensable for the control of TLM in tomato fields. The integration of chemical and biological control is often critical to the success of an integrated pest management program (El-Wakeil *et al.*, 2013). However, modern integrated plant protection strategy has recommended, optimal use of selective insecticides that are less harmful to natural enemies (Tillman and Mulrooney, 2000; Stark *et al.*, 2007), which requires more about their adverse effects on the behavioural and biological attributes of these organisms (Tillman and Mulrooney, 2000; Stark *et al.*, 2007). Bio-rational insecticides are a distinct group, having selective toxicity and different modes of action as

compared to commonly used conventional insecticides. However, no pesticide is 100% safe and non-toxic toward non target organisms, particularly parasitoids (Desneux *et al.*, 2007; Stark and Banks, 2003). Fortunately, in Egypt, several new products of the bio-rational pesticides are available and commercially used against TLM. Among the most novel bio-rational insecticides with selective properties are emamectin benzoate (proclaim<sup>®</sup>), chlorantraniliprole (coragen<sup>®</sup>) and spinosad (spintor<sup>®</sup>). Lufenuron (match<sup>®</sup>) is an acylurea insect growth regulator belonging to the group of benzoyl-phenyl-ureas (BPUs) and is classified as an insect development inhibitor (IDI) (Whiting *et al.*, 2000). Dipel<sup>®</sup> is a biological insecticide containing the naturally occurring microorganism *Bacillus thuringiensis v. kurstaki* (Btk) (Lambert and Peferoen, 1992).

In this study, results of the assessment of the selected bio-rational insecticides showed various degree of susceptibility of the four trichogrammatid species to the tested insecticides commonly used in tomato fields against TLM. Spinosad (spintor) came first in terms of reducing parasitism and adult emergence followed by emamectin benzoate (proclaim), chlorantraniliprole (coragen<sup>®</sup>), lufenuron (match), and *B. thuringiensis* (dipel 2×<sup>®</sup>) either when TLM eggs treated before or after exposure to the parasitoid. The high toxicity of spinosad to the four tested trichogrammatid species in the current study is in agreement with those reported earlier for other species of *Trichogramma* e.g. *T. galloi* (Consoli *et al.*, 2001), *T. exiguum* (Suh *et al.*, 2000), *T. pretiosum* (Bueno *et al.*, 2008) and *T. platneri* (Jay *et al.*, 2001). Emamectin benzoate (proclaim<sup>®</sup>) showed high toxicity to the tested parasitoids. These results are also in line with those reported for *T. chilonis* (Sattar *et al.*, 2011; Dilbar *et al.*, 2012). However, Hew-Kapuge *et al.* (2003) reported moderate toxic effect of emamectin benzoate to *T. brassicae* with mortality rate of 23-64%. Regarding the toxicity of chlorantraniliprole, the present findings agreed with the work of Preetha *et al.* (2010) and Dilbar *et al.* (2012) who reported that chlorantraniliprole had less knockdown effect to *T. chilonis* as compared to other insecticides. Concerning the slightly harmful effect of lufenuron, the present findings agree with those of Vianna *et al.* (2009) who found that lufenuron had lowest negative impacts on parasitism and populations of *T. pretiosum*. Also, Sattar *et al.* (2011) recorded that lufenuron had low negative effects on *T. chilonis* adult survival, but it significantly decreased parasitization capacity. Lufenuron caused 61.80% reduction in the parasitism capacity of *T. pretiosum* under laboratory conditions (Carvalho *et al.*, 2005). As for *B. thuringiensis*, the obtained results are consistent to those of Vianna *et al.* (2009) who concluded that *B. thuringiensis* had the lowest negative effects on parasitism of *T. pretiosum*. Shoeb (2005) also found that protecto (*B. thuringiensis*) had the least deleterious effect on *T. evanescens*.

The obtained data also confirmed high susceptibility of the tested parasitoid wasps to spintor, proclaim and coragen and demonstrated that dipel 2× is more compatible and/or suitable to conserve natural or released populations of *Trichogramma* wasps. Nevertheless, as in the case of using other insecticides, it is useful to bear in mind that under field conditions, eggs would receive a much lower dose, and many eggs such as those deposited on the underside of leaves might not even be exposed to the insecticides (Suh *et al.*, 2000).

### CONCLUSION

The conclusion drawn from the above results indicated that all tested bio-rational insecticides caused various toxicity effects against the four Trichogrammatid egg parasitoid species. They have already induced significant inhibition in parasitism efficiency, adult emergence, beside their toxicity to adult parasitoids, indicating that parasitoid species had varying degree of susceptibility. The tested insecticides were either harmful (spintor, coragen and proclaim) or

moderately harmful (match) or slightly harmful (dipel 2x). Despite the effectiveness of these insecticides in controlling TLM under field conditions (Abd El-Hady *et al.*, 2013), unfortunately, they would also cause significant reduction in the population of the coexistence parasitoids. In this respect, the obtained results support the idea that the use of different bio-tactics such as bio-rational insecticides in conjunction with the release of egg parasitoids could offer great opportunity to control of TLM, with timely manner and avoiding the time of insecticide application for a sufficient period as much as possible.

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