Research Article

Evaluation of toxicity of some biocompatible insecticides on Trichogramma brassicae and T. evanescens under laboratory and semi-field conditions

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Abstract: The effects of four insecticides, abamectin (1500 and 750mg l⁻¹), emamectin benzoate (1000 and 500mg l⁻¹), acetamiprid (500 and 250mg l⁻¹), and flubendiamide (500 and 250mg l⁻¹), were studied on different preimaginal stages of T. brassicae and T. evanescens, the egg parasitoids of tomato leaf miner Tuta absoluta (Lepidoptera: Gelechiidae). Parasitized eggs of the Angoumois grain moth Sitotroga cerealella (Lepidoptera: Gelechiidae) were treated by the dipping method at the larval, prepupal, and pupal stages of the parasitoid. For persistence evaluation, the insecticides were applied at the recommended concentration on tomato plants by a hand sprayer till runoff point. Plants were maintained under a transparent polyethylene rain cover in the field. Leaves of the treated tomato plants were sampled and transferred to the laboratory at time intervals of 3, 5, 16, and 31 days after application. Based on our study, abamectin was the most harmful insecticide for immature stages of both parasitoids T. brassicae and T. evanescens. Treatment by abamectin at the pupal stage had more adverse effects compared to prepupal or larval stages. Acetamiprid with 30.5% and 31.6% mortality in less than five days was classified as the short-lived insecticide for T. brassicae and T. evanescens, respectively. The same result was obtained in flubendiamide treatment which caused 27.2% and 26.1% mortality to the parasitoids, respectively. Abamectin with 16.1% and 13.8% mortality in less than 16 days was slightly persistent. However, emamectin benzoate with 13.3% and 15.5% mortality in less than 30 days was classified as moderately persistent for those two species, respectively. Therefore, flubendiamide and acetamiprid were non-harmful to both T. brassicae and T. evanescence wasps and are good candidates to be incorporated into IPM programs in combination with biological agents for the control of tomato leaf miner T. absoluta. By contrast, emamectin and abamectin should be used with greater care as a part of an IPM procedure.

Keywords: Tuta absoluta, egg parasitoids, insecticides, persistency, IPM

Introduction

The tomato leaf miner moth Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) is one of the most important pests of the tomato plant. The pest can produce between 10 and 12 generations in a year, and each female can lay 250-300 eggs in its lifetime (Barrientos et al., 1998). Excess use of insecticides to control the tomato leaf miner has led to the appearance of resistant genotypes against different groups of insecticides, contamination of the environment, and increased pesticide residues on the produce (Siqueira et al., 2010).
Biocompatible insecticides for Trichogramma spp. J. Crop Prot.

2001). These issues have encouraged the use of biocompatible insecticides alongside biological agents for pest control. The pest is attacked by various biological control agents including egg parasitoids Trichogramma species which are the most prevalent parasitoids in the world (Knutson, 2005). According to Pratissoli and Parra (2001) family Trichogrammatidae has significantly contributed to reducing the populations of lepidopteran pests as well as the number of insecticide applications on tomato crops. However, nonselective insecticides can reduce the control potential of these biological agents (Desneux et al., 2007; Vianna et al., 2009; Croft, 1990; Bartlett, 1964). Many of these chemicals can maintain their deleterious effects for a long period of time after application (Zappala et al., 2012). Due to the wide range effects of pesticides on natural enemies, it is necessary to study their side effects in order to adopt chemical and biological control for minimizing their negative impacts (Souza et al., 2014). Insecticides have both lethal and sublethal effects on arthropods, thus in addition to death, they can adversely affect life parameters such as developmental rate, sex ratios, parasitism, and emergence rate (Poorjavad et al., 2014). Acute toxicity is usually assessed after the organism is exposed to a chemical for a short period of time (e.g. a few hours to a few days), and the endpoint is the death of the organism (Stark and Banks, 2003). The estimated lethal concentration during acute toxicity tests may only be a partial measure of the deleterious effects. Sublethal effects are defined as effects, either physiological or behavioral, on individuals that survive exposure to a pesticide (Desneux et al., 2007). Therefore, it is necessary to evaluate the lethal and sublethal effects of insecticides on the natural enemies. This evaluation provides a better understanding of the interaction of chemicals and the biological control agents in the system (Stark and Banks, 2003). Integrating biological control agents with pesticides should regulate arthropod pest populations without directly or indirectly affecting their natural enemies (Ruberson et al., 1998). In some cases, the use of short-lived insecticides that only interfere slightly with biological control agents should be a solution for effective pest control. Some studies have revealed the effects of many insecticides on different Trichogramma species (Hassan, 1998; Hewa-Kapuge et al. 2003; Jiusheng et al., 2009).

Abamectin is a chemical originally isolated from the soil bacterium Streptomyces avermitilis or generated through semisynthetic modifications. Abamectin stimulates the chloride channels that are regulated by the neurotransmitter glutamate causing paralysis in arthropods (Fisher and Mrozek, 1989). Emamectin benzoate has a strong effect against Lepidopteran pests. Similar to abamectin, emamectin belongs to the avermectin family of compounds, all of which exhibit toxicity to several pests. The benzoate salt of emamectin is widely used as an insecticide (Mistretta and Durkin, 2010). Acetamiprid, a neonicotinoid compound, is a synthetic “nicotine-like” chemical that binds tightly to the acetylcholine receptor site on the post-synapse nerve cell and causes nerve overstimulation. It is highly effective against Lepidoptera, and the insecticide is applicable for controlling pests of vegetables (Yamada et al., 1999). Flubendiamide acts as a stomach poison and oral intoxicant. It belongs to a new class, phthalic acid diamide. Flubendiamide has the novel biochemical action of affecting calcium ion balance, which is an effective control of lepidopteran pests (Das et al., 2017).

The present study was designed to evaluate T. brassicae and T. evanescence for their susceptibility to four insecticides: abamectin, emamectin benzoate, acetamiprid, and flubendiamide when applied at the insects’ immature stages.

In order to determine the most suitable insecticides for effective pest control, we also investigated the persistence rate of the insecticides at field conditions when applied at the recommended concentration according to IOBC procedure (Sterk et al., 1999).

Materials and Methods

Rearing

The experiments were carried out in the Laboratory of Plant Protection at the Agricultural
and Natural Resources Research and Education Center of Markazi Province, Arak, Iran. The egg parasitoids *T. brassicae* and *T. evanescens* (Hymenoptera: Trichogrammatidae) were provided from the Biological Control Department of Plant Protection Research Institute (Tehran, Iran). Parasitoids were reared on the Angoumois grain moth, *Sitotroga cerealella* (Lepidoptera: Gelechiidae) in the laboratory under the controlled conditions of 25 ± 1°C, 60 ± 10% RH, and a photoperiod of 16:8 h (L: D).

**Insecticides**
The insecticides used were: abamectin (EC 1.8% *Vertimec*, Golsam Co., Gorgan), emamectin benzoate (WG50% *Proclimfit*, Syngenta Co., Swiss), acetamiprid (SP20% *Mospilan*, Golsam Co., Gorgan), and flubendiamide (WG20% *Takumi*, Syngenta Co., Swiss). Field recommended concentrations (RC) and half RC of the insecticides were used (Table 1).

**Immature stages bioassay**
The effect of insecticides was studied on different preimaginal stages of *T. brassicae* and *T. evanescens*. Parasitized eggs of Angoumois grain moth *Sitotroga cerealella* (Lepidoptera: Gelechiidae) were treated by the dipping method at different intervals suggested by the IOBC working group (Costa et al., 2014; Sterk et al., 1999). The experiment was repeated six times. The control was treated with distilled water. Randomly selected egg cards, having 140 parasitized eggs were dipped into the solution of RC or half RC of each insecticide for 10 seconds on the 3rd, 6th, and 9th day after the eggs were parasitized. These days corresponded to the developmental stages of *Trichogramma* larvae (3 d), prepupae (6 d), and pupae (9 d). When the dipped eggs were dried, they were placed in glass tubes at the laboratory under the controlled conditions of 25 ± 1°C, 60 ± 10% RH, and a photoperiod of 16:8 h (L: D). The parameter evaluated was adult emergence rate of parasitoids from each of the three stages and then divided by the control for calculation of emergence reduction. The insecticides were classified into the toxicity categories proposed by the IOBC working group for semi-field trials on beneficial arthropods: Class 1: harmless (<30% mortality or effect), Class 2: slightly harmful (30%-79%), Class 3: moderately harmful (80%-99%), and Class 4: harmful (>99%) (Costa et al., 2014; Sterk et al., 1999).

**Persistence rate evaluation**
The insecticides were applied at RC on tomato plants by a hand sprayer till runoff point. Plants were maintained under a transparent polyethylene rain cover in the field. Leaves of the treated tomato plant were sampled and transferred to the laboratory at time intervals of 3, 5, 16 and 31 days after application. These intervals were proposed by the IOBC/WPRS Working Group (Costa et al., 2014; Sterk et al., 1999). The samples were placed in ventilated plastic Petri dishes for exposure to the adult parasitoids. The experiment was repeated six times on 30 adult individuals of each species. Assessment of mortality was made on the basis of 24h post-exposure time. Persistence rate of each insecticide was evaluated according to IOBC/WPRS Working Group. The categories under laboratory conditions included: A, short-lived (<5 days); B, slightly persistent (5-15 days); C, moderately persistent (16-30 days); D, Persistent (>30 days) (Costa et al., 2014; Sterk et al., 1999).

### Table 1 Names, doses and manufacturers of the insecticides that were tested in the study.

<table>
<thead>
<tr>
<th>Name of insecticides</th>
<th>Trade name</th>
<th>Recommended Concentration (ml/ha)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin EC 1.8%</td>
<td><em>Vertimec</em></td>
<td>1500</td>
<td>Golsam, Gorgan</td>
</tr>
<tr>
<td>Emamectinbenzoate WG50 5%</td>
<td><em>Proclimfit</em></td>
<td>1000</td>
<td>Syngenta, Swiss</td>
</tr>
<tr>
<td>Acetamiprid SP20 20%</td>
<td><em>Mospilan</em></td>
<td>500</td>
<td>Golsam, Gorgan</td>
</tr>
<tr>
<td>Flubendiamide WG20 20%</td>
<td><em>Takumi</em></td>
<td>500</td>
<td>Syngenta, Swiss</td>
</tr>
</tbody>
</table>
Statistical analysis

These experiments were carried out in a completely randomized design (CRD) with six replications. Data on percent efficacy were arcsine-square root transformed to normalize them and were subjected to one-way analyses of variance using SPSS software (SPSS Inc. 2007). Abbott’s formula (Abbott, 1925) was used to correct mortality. The means were separated using least significant difference (LSD) test at 5% level of significance.

Results

Emergence rate

Parasitoid emergence rate after treatment at larval, prepupal and pupal stages was reduced when treated by the recommended concentration of each insecticide. Maximum and minimum reduction of emergence for abamectin was 52.23%, 47.34% and 59.49%, and for flubendiamide was 25.44%, 13.27% and 20.25%, respectively (Table 2). The data for half RD of abamectin was 47.32%, 43.36% and 54.85%, and for flubendiamide was 20.98%, 7.96%, and 14.34%. There were significant differences among insecticides for their effects on emergence rate of the parasitoid at the larval (F = 259.40; df = 4, 29; P = 0.0001), prepupal (F = 243.79; df = 4, 29; P = 0.0001) and pupal stages (F = 624.72; df = 4, 29; P = 0.0001) (Table 2).

Trichogramma evanescens

Reduction of T. evanescens emergence rate after treatment at the recommended concentration of abamectin was 50.68%, 45.49% and 53.78%, and for flubendiamide was 20.09%, 10.36% and 12.89% at the larval, prepupal and pupal stages, respectively (Table 3). These values for half RD of abamectin were 43.83, 40.99, 51.55%, and for flubendiamide were 16.43, 4.95 and 8.88%. There were significant differences among insecticides for their effects on emergence rate of the parasitoid at the larval (F = 202.50; df = 4, 29; P = 0.0001), prepupal (F = 162.96; df = 4, 29; P = 0.0001) and pupal stage (F = 256.18; df = 4, 29; P = 0.0001) (Table 3).

Persistence

Trichogramma brassicae

At three days post-treatment (= DPT), a significant difference was observed among various treatments for the rate of adult parasitoid mortality (F = 243.41; df = 4, 29; P = 0.0001). Abamectin caused 86.67 ± 2.58% mortality which was the most among all treatments, however, flubendiamide showed 27.22 ± 2.00% mortality which was the least. At five DPT, abamectin caused 63.33 ± 2.11% mortality which differed significantly from other treatments (F = 147.08; df = 4, 29; P = 0.0001). Acetamiprid and flubendiamide with mean mortality of 24.44 ± 1.65% and 21.67 ± 1.43%, respectively, showed less lethal effect than abamectin but were not significantly different from one another. At 16 DPT emamectin caused 41.11 ± 1.64% mortality which was the highest and significantly different from the other treatments (F = 63.83; df = 4, 29; P = 0.0001). Acetamiprid and flubendiamide with mean mortality of 11.11 ± 1.40% and 10.56 ± 1.34% showed less lethal effects. At 31 DPT emamectin caused 13.33 ± 1.22% mortality which still significantly differed from other treatments (F = 12.94; df = 4, 29; P = 0.0001). Acetamiprid and flubendiamide with mean mortality of 8.89 ± 1.11% and 7.78 ± 1.11%, respectively, showed less lethal effect than emamectin with no statistical difference between the two (Table 4).

Trichogramma evanescens

At three DPT the rate of mortality differed significantly among various treatments (F = 151.564; df = 4, 29; P = 0.0001). Abamectin caused 85.56 ± 2.94% mortality which was the most among all treatments, however, flubendiamide showed 26.11 ± 1.59% mortality which was the least. The mortality rates of emamectin, acetamiprid, and flubendiamide were 61.67 ± 2.54%, 31.67 ± 1.43% and 26.11 ± 1.59%, respectively. At five DPT, abamectin caused 60.55 ± 2.00% mortality which differed significantly from other treatments (F = 94.323; df = 4, 29; P = 0.0001). Acetamiprid and flubendiamide with mean mortality of 26.11 ± 1.59% and 20.56 ± 1.59%, respectively, showed less lethal effect than emamectin without any
statistical difference between them. At 16 DPT, emamectin was significantly different from other treatments ($F = 43.601; \text{df} = 4, 29; P = 0.0001$). Acetamiprid and flubendiamide with mean mortality of $12.22 \pm 1.11\%$ and $10.56 \pm 1.59\%$, respectively, showed less lethal effects than emamectin without any statistical difference between those two insecticides (Table 5).

Table 2: Effects of insecticide treatments on emergence of *Trichogramma brassicae* when treated at larval, prepupal and pupal stages inside its host egg under laboratory conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Larvae (% emergence)</th>
<th>% Reduction in emergence of larvae (Category)</th>
<th>Prepupae (% emergence)</th>
<th>% Reduction in emergence of prepupae (Category)</th>
<th>Pupae (% emergence)</th>
<th>% Reduction in emergence of pupae (Category)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>RC</td>
<td>$44.58 \pm 1.34a$</td>
<td>52.23 (2)</td>
<td>$49.58 \pm 1.19a$</td>
<td>47.34 (2)</td>
<td>$40.00 \pm 3.02a$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$49.17 \pm 2.24a$</td>
<td>47.32 (2)</td>
<td>$53.33 \pm 2.26a$</td>
<td>43.36 (2)</td>
<td>$44.58 \pm 1.98a$</td>
</tr>
<tr>
<td>Control</td>
<td>$93.33 \pm 1.26e$</td>
<td>0</td>
<td>$94.17 \pm 0.99d$</td>
<td>0</td>
<td>$98.75 \pm 0.72e$</td>
<td>0</td>
</tr>
<tr>
<td>Emamectin</td>
<td>RC</td>
<td>$50.00 \pm 1.35b$</td>
<td>46.43 (2)</td>
<td>$51.67 \pm 1.29a$</td>
<td>45.13 (2)</td>
<td>$61.25 \pm 1.57b$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$54.17 \pm 2.26b$</td>
<td>41.96 (2)</td>
<td>$56.67 \pm 1.43a$</td>
<td>39.81 (2)</td>
<td>$67.08 \pm 1.15b$</td>
</tr>
<tr>
<td>Control</td>
<td>$93.33 \pm 1.26e$</td>
<td>0</td>
<td>$94.17 \pm 0.99d$</td>
<td>0</td>
<td>$98.75 \pm 0.72e$</td>
<td>0</td>
</tr>
<tr>
<td>Acetamiprid</td>
<td>RC</td>
<td>$60.42 \pm 0.87c$</td>
<td>35.27 (2)</td>
<td>$65.42 \pm 1.36b$</td>
<td>30.52 (2)</td>
<td>$70.42 \pm 1.88c$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$65.00 \pm 1.89c$</td>
<td>30.35 (2)</td>
<td>$69.58 \pm 1.42b$</td>
<td>26.10 (1)</td>
<td>$73.75 \pm 2.02c$</td>
</tr>
<tr>
<td>Control</td>
<td>$93.33 \pm 1.26e$</td>
<td>0</td>
<td>$94.17 \pm 0.99d$</td>
<td>0</td>
<td>$98.75 \pm 0.73e$</td>
<td>0</td>
</tr>
<tr>
<td>Flubendiamide</td>
<td>RC</td>
<td>$69.58 \pm 1.07d$</td>
<td>25.44 (1)</td>
<td>$81.67 \pm 2.15c$</td>
<td>13.27 (1)</td>
<td>$78.75 \pm 2.20d$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$73.75 \pm 2.07d$</td>
<td>20.98 (1)</td>
<td>$86.67 \pm 2.64c$</td>
<td>7.96 (1)</td>
<td>$84.58 \pm 1.87d$</td>
</tr>
<tr>
<td>Control</td>
<td>$93.33 \pm 1.26e$</td>
<td>0</td>
<td>$94.17 \pm 0.99d$</td>
<td>0</td>
<td>$98.75 \pm 0.72e$</td>
<td>0</td>
</tr>
</tbody>
</table>

Means followed by the same letters are not significantly different (LSD test, $p < 0.05$).

Table 3: Effects of insecticide treatment on the adult emergence of *Trichogramma evanescens* when treated at larval, prepupal and pupal stages inside its host egg under laboratory conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Larvae (% emergence)</th>
<th>% Reduction in emergence of larvae (Category)</th>
<th>Prepupae (% emergence)</th>
<th>% Reduction in emergence of prepupae (Category)</th>
<th>Pupae (% emergence)</th>
<th>% Reduction in emergence of pupae (Category)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>RC</td>
<td>$45.00 \pm 1.06a$</td>
<td>50.68 (2)</td>
<td>$50.42 \pm 2.16a$</td>
<td>45.49 (2)</td>
<td>$43.33 \pm 1.07a$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$51.25 \pm 2.56a$</td>
<td>43.83 (2)</td>
<td>$54.58 \pm 1.42a$</td>
<td>40.99 (2)</td>
<td>$45.42 \pm 2.32a$</td>
</tr>
<tr>
<td>Control</td>
<td>$92.50 \pm 1.18d$</td>
<td>0</td>
<td>$92.50 \pm 1.18d$</td>
<td>0</td>
<td>$93.75 \pm 1.19e$</td>
<td>0</td>
</tr>
<tr>
<td>Emamectin</td>
<td>RC</td>
<td>$52.08 \pm 1.67b$</td>
<td>42.93 (2)</td>
<td>$51.25 \pm 1.38a$</td>
<td>44.59 (2)</td>
<td>$58.33 \pm 2.33b$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$57.50 \pm 1.44b$</td>
<td>36.99 (2)</td>
<td>$55.42 \pm 3.49a$</td>
<td>40.09 (2)</td>
<td>$64.17 \pm 1.31b$</td>
</tr>
<tr>
<td>Control</td>
<td>$91.25 \pm 1.48e$</td>
<td>0</td>
<td>$92.50 \pm 1.18d$</td>
<td>0</td>
<td>$93.75 \pm 1.19e$</td>
<td>0</td>
</tr>
<tr>
<td>Acetamiprid</td>
<td>RC</td>
<td>$60.00 \pm 1.97c$</td>
<td>34.24 (2)</td>
<td>$63.75 \pm 2.08b$</td>
<td>31.08 (2)</td>
<td>$67.50 \pm 3.16c$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$63.33 \pm 2.80e$</td>
<td>30.59 (2)</td>
<td>$67.92 \pm 1.40b$</td>
<td>26.57 (1)</td>
<td>$72.08 \pm 1.15c$</td>
</tr>
<tr>
<td>Control</td>
<td>$91.25 \pm 1.48e$</td>
<td>0</td>
<td>$92.50 \pm 1.18d$</td>
<td>0</td>
<td>$93.75 \pm 1.19e$</td>
<td>0</td>
</tr>
<tr>
<td>Flubendiamide</td>
<td>RC</td>
<td>$72.92 \pm 2.17d$</td>
<td>20.09 (1)</td>
<td>$82.92 \pm 2.29c$</td>
<td>10.36 (1)</td>
<td>$81.67 \pm 2.31d$</td>
</tr>
<tr>
<td></td>
<td>0.5RC</td>
<td>$76.25 \pm 1.18d$</td>
<td>16.43 (1)</td>
<td>$87.92 \pm 1.40c$</td>
<td>4.95 (1)</td>
<td>$85.42 \pm 1.22d$</td>
</tr>
<tr>
<td>Control</td>
<td>$91.25 \pm 1.48e$</td>
<td>0</td>
<td>$92.50 \pm 1.18d$</td>
<td>0</td>
<td>$93.75 \pm 1.19e$</td>
<td>0</td>
</tr>
</tbody>
</table>

Means followed by the same letters are not significantly different (LSD test, $p < 0.05$).
IOBC classification
Results regarding the effects of the insecticides on different developmental stages of *T. brassicae* and *T. evanescens* revealed that flubendiamide was the most selective compound among the tested insecticides. However, abamectin, emamectin benzoate, and acetamiprid were slightly harmful to both parasitoids (Tables 2 and 3). Persistence tests based on IOBC classification for more than 30% mortality at each period of time revealed that both flubendiamide and acetamiprid had less than five days persistence. This result classified them as short-lived insecticides (class A) for *T. brassicae* wasps. Abamectin which persisted for more than five days but less than 16 days was slightly persistent (class B). Emamectin with persistence of more than 16 days and less than 30 days was moderately persistent for the parasitoid (class C) (Table 4). For *T. evanescence* adult parasitoid, acetamiprid and flubendiamide with less than five days persistence were classified as short-lived insecticides (class A). Abamectin which persisted for more than five days but less than 16 days was slightly persistent (class B). Emamectin with persistence of more than 16 days and less than 30 days was moderately persistent for the parasitoid (class C) (Table 5).

### Table 4 Mortality of *Trichogramma brassicae* wasps after exposure to leaf residues of insecticides at 3, 5, 16 and 31 days post-treatment (DPT) at field conditions.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>3 d</th>
<th>5 d</th>
<th>16 d</th>
<th>31 d</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>86.67 ± 2.58a</td>
<td>63.33 ± 2.11a</td>
<td>16.11 ± 1.59a</td>
<td>12.22 ± 1.40a</td>
<td>B, Slightly persistent</td>
</tr>
<tr>
<td>Emamectin</td>
<td>60.56 ± 1.59b</td>
<td>51.11 ± 2.81b</td>
<td>41.11 ± 1.64b</td>
<td>13.33 ± 1.22a</td>
<td>C, Moderately persistent</td>
</tr>
<tr>
<td>Acetamiprid</td>
<td>30.56 ± 1.59c</td>
<td>24.44 ± 1.65c</td>
<td>11.11 ± 1.40b</td>
<td>8.89 ± 1.11ab</td>
<td>A, Short lived</td>
</tr>
<tr>
<td>Flubendiamide</td>
<td>27.22 ± 2.00c</td>
<td>21.67 ± 1.43c</td>
<td>10.56 ± 1.34b</td>
<td>7.78 ± 1.02b</td>
<td>A, Short lived</td>
</tr>
</tbody>
</table>

Means followed by the same letters are not significantly different (LSD test, p < 0.05).

### Table 5 Mortality of *Trichogramma evanescence* wasps after exposure to leaf residues of insecticides at 3, 5, 16 and 31 days post-treatment (DPT) at the field conditions.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>3 d</th>
<th>5 d</th>
<th>16 d</th>
<th>31 d</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>85.56 ± 2.94a</td>
<td>60.55 ± 2.00a</td>
<td>13.89 ± 1.34a</td>
<td>10.55 ± 1.59a</td>
<td>B, Slightly persistent</td>
</tr>
<tr>
<td>Emamectin</td>
<td>61.67 ± 2.54b</td>
<td>52.78 ± 2.00a</td>
<td>43.89 ± 1.02b</td>
<td>15.56 ± 1.65ab</td>
<td>C, Moderately persistent</td>
</tr>
<tr>
<td>Acetamiprid</td>
<td>31.67 ± 1.43c</td>
<td>26.11 ± 1.59b</td>
<td>12.22 ± 1.11b</td>
<td>9.44 ± 1.59ab</td>
<td>A, Short lived</td>
</tr>
<tr>
<td>Flubendiamide</td>
<td>26.11 ± 1.59c</td>
<td>20.56 ± 1.59b</td>
<td>10.56 ± 1.59b</td>
<td>7.22 ± 1.34b</td>
<td>A, Short lived</td>
</tr>
</tbody>
</table>

Means followed by the same letters are not significantly different (LSD test, p < 0.05).

**Discussion**

Our study revealed that abamectin was the most harmful insecticide for immature stages of both parasitoids. We also found that treatments with abamectin at the pupal stage had more adverse effects compared to prepupal or larval stages. In a similar study Jiu-Sheng *et al.* (2009) showed that field recommended concentration of abamectin (7.2mg/L) severely reduced the emergence rate of *T. pretiosum* from treated eggs of *Corcyra cephalonica* (Stainton). The effect of abamectin was also evaluated by Hussain *et al.* (2015) on *T. chilonis* under laboratory conditions which had adverse effects on the emergence rate of adults. Those results were the same as our findings. In a similar study, by examining the effect of the field
recommended concentration of abamectin (480ml/100L) on larval and pupal stages of *T. pretiosum*, Khan and Ruberson (2017) found that abamectin significantly decreased the emergence percent of adult parasitoids. Similar to other insects, immature stages of *Trichogramma* have been considered less susceptible to pesticides than adults, because the eggshell of the host could provide protection. However, preimaginal mortality of *Trichogramma* parasitoids may be related to a phenomenon called partial emergence. Consoli *et al.* (2001) who explained this phenomenon, reported that some chemicals might be unable to penetrate through the host eggshell, but the parasitoid might ingest the product during the opening of the emergence hole. When the parasitoid is cutting a small area of the host eggshell with its mandibles, a small quantity of the eggshell surface could be swallowed as well as the product residues that exist on the host surface. This phenomenon also explains why treatment at the pupal stage resulted in less emergence than the treatment at the larval stage because the first produces fresher residues at the time of parasitoid emergence. We also found RD of abamectin on tomato plants in the field was slightly persistent (5-15 days) for both parasitoids when exposed to the residues. This result is the same as those of Hassan (1998) who classified abamectin as slightly persistent for adult *T. cacoeciae*, or Ji-Sheng *et al.* (2009) who declared abamectin to be slightly persistent for *T. chilonis* at greenhouse conditions. Based on the results of Sabahi *et al.* (2009) regarding the effect of abamectin in semi-field conditions on *Lysiphlebus fabarum* (Marshall), abamectin was classified in short-lived category that differs with the results of this research due to differences in natural enemies. This research also clearly showed that flubendiamide caused less than 20% reduction of emergence rate of parasitoid and persisted less than five days (shortly-lived) at field conditions. In a similar study, the effects of flubendiamide were investigated under laboratory conditions on immature stages of *T. chilonis* within *Helicoverpa armigera* ( Hubbner) eggs (Hussain *et al.*, 2015). Their results showed that flubendiamide had low effects on the emergence rate and was considered as safe for the parasitoid. In another study, Madhusudan (2015) reported that flubendiamide does not have any adverse effect on *T. chilonis* under laboratory conditions. Our results also concur with those obtained by Khan and Ruberson (2017). They studied the effects of flubendiamide on larval and pupal stages of *T. pretiosum* and those by Sattar *et al.* (2011). They also concluded that flubendiamide had low effects on the parasitoid *T. chilonis* in field conditions and ranked flubendiamide as a short-lived compound. We found acetamiprid is a slightly harmful (class 2) insecticide for the tested parasitoids. Some other researchers also emphasized on the harmlessness of acetamiprid. In a similar study Zhu *et al.* (2009) investigated the effects of several insecticides, including acetamiprid, on immature stages of *T. evanescens* under laboratory conditions. Their results showed that acetamiprid had a low toxicity to all developmental stages. Carvalho *et al.* (2010), had declared that acetamiprid is slightly harmful to developmental stages of *T. pretiosum*. Our result showed acetamiprid causes only a 20-30% reduction in parasitoid emergence, which is the same as their findings.

We also classified acetamiprid as a short-lived insecticide. In a similar study, Uma and Jacob (2013) placed flubendiamide as short-lived for *T. chilonis* at field conditions. Emamectin was slightly harmful (class 2) for both parasitoids. These results concur with those declared by Sattar *et al.* (2011) who reported a slight reduction of emergence rate for *T. chilonis* after immature stages were treated at the field recommended concentrations of emamectin benzoate. In a similar study, the effect of emamectin benzoate was tested on immature stages of *T. chilonis*. Hussain *et al.* (2015) found emamectin benzoate had a deleterious effect on the emergence rate of the parasitoid. In this research, emamectin also ranked as a moderately persistent insecticide. In other similar work, Hewa-Kapuge *et al.* (2003) found emamectin benzoate was moderately
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persistent for *T. chilonis*. This study also revealed that both parasitoids responded at the same level of susceptibility after exposure to all the tested insecticides.

**Conclusion**

This research focused on the impact of insecticide exposure on *Trichogramma* species present in Markazi Province. Pesticides that control pests without severe side effects on substantial natural enemies are always a necessity for integrated control programs. Without such insecticides, the use of short-lived insecticides could allow a rapid re-colonization of the parasitoids. We found flubendiamide and acetamiprid are non-harmful to both *T. brassicae* and *T. evanescence* wasps and good candidates to be incorporated into IPM programs in combination with the biological agents for the control of the tomato leaf miner *T. absoluta*. By contrast, emamectin and abamectin should be used with care as a part of IPM procedures.

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ارزیابی سمیت برخی حشره‌کش‌های زبست سازگار روی دو گونه زنبور در شرایط آزمایشگاهی و نیمه مزرعه‌ای

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چکیده: ارزیابی حشره‌کش‌های آبامکتین (T. evanescens) (Hymenoptera: Trichogrammatidae) بر روی مکاتب دو گونه زنبور Trichogramma brassicae از جنس Hymenoptera: Ichneumonidae انجام شد. نتایج نشان داد که استحکام و قدرت ویرانی مرکب برای دو گونه زنبور T. evanescens و T. brassicae متمایز می‌باشد. در مزارع کشاورزی به بزرگی این حشره‌کش‌های زبستگی کننده و ارزیابی قدرت ویرانی، با کمک آزمایشگاهی و نیمه مزرعه‌ای انجام می‌گردد.

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واژگان کلیدی: شب‌پره مینز گوجه‌فرنگی، پارازیت‌های زنبور تخم حشره-کش‌ها، پایداری، مدیریت تلفیقی افاته