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Comparative Lethal and Sublethal Toxicity of Some Conventional Insecticides Against Tomato Leafminer, *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)

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ABSTRACT

This study was conducted to introduce effective agent(s) among some novel and conventional insecticides in the management of *Tuta absoluta* (Meyrick, 1917), the most destructive insect pest of tomato throughout the world, in the lethal and sublethal terms of features. Toxicity of five chemical pesticides, including azadirachtin, emamectin benzoate, imidacloprid, lambda-cyhalothrin, and thiacloprid, was determined on 2nd-instar larvae of *T. absoluta* by leaf-dipping method in a growth chamber with 25 ± 2 °C, 65 ± 5% relative humidity, and a photoperiod of 16:8 h (L:D). The least LC_{50} value was attained with emamectin benzoate (0.52 mg A.I./L) among tested insecticides. Demographic parameters of the pest, including *GRR* (gross reproductive rate), R_0 (net reproductive rate), r_m (intrinsic rate of increase), T (mean generation time), and λ (finite rate of increase) along with larval, pupal, and pre-adult periods were more affected by emamectin benzoate and azadirachtin. Adult pre-oviposition period (APOP) (1.04 days), female longevity (18.17 days), male longevity (17.88 days), oviposition period (4.21 days), and fecundity (38.67 egg/female) were low by emamectin benzoate. In the treatments by emamectin benzoate and azadirachtin, the survival of fourth-instar larvae, pupae, and adults of insect was reduced in comparison to control. Accordingly, based on the highest adverse possessions of emamectin benzoate and azadirachtin on survival, life history, and demographic parameters of *T. absoluta,* the applicability of other tested insecticides imidacloprid, lambda-cyhalothrin, and thiacloprid may be limited.

Key words: Demographic parameters, *Tuta absoluta*, emamectin benzoate, Azadirachtin, imidacloprid.

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INTRODUCTION

Arthropod pests have a critical role in diminishing food production and cause high loss of crops (Lietti, Botto, & Alzogaray, 2005). Tomato leafminer [*Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae)], as detracutive insect pest, annually reduces the quantity and quality of the tomato (Terzidis, Wilcockson, & Leifert, 2014). *T. absoluta* with the origin of South America quickly dispersed to European and Mediterranean countries (Guillemaud et al, 2015), and recently to Afro-Eurasia and Southwest and Central Asian countries (Biondi, Guedes, Wan, & Desneux, 2018). *T. absoluta* damages some of the most important crops of the Solanaceae family, such as tomatoes, potatoes, eggplant and sweet peppers, and even some weeds (Desneux et al, 2010; Smith et al, 2018). Although this pest mainly harms the leaves and fruits of tomato, buds, stems, and flowers can also be affected by decreasing the photosynthetic capacity and production surface area and indirect damages with secondary pathogenic contaminations (Lietti, Botto, & Alzogaray, 2005; Tropea, Siscaro, Biondi, & Zappalà, 2012).

The management of *T. absoluta* is generally dependent on multiple applications of chemical insecticides (Guedes & Picanco, 2012; Urbaneja, González-Cabrera, Arnó, & Gabarra, 2012; Tomé et al, 2013). However, over-reliance on the synthetic chemicals' application results in insecticide resistance in *T. absoluta* and insecticide residues on the environment (Guedes & Siqueira, 2013; Gontijo et al, 2013). Because tomatoes are consumed freshly, it is needed to use insecticides that have low residual and less adverse effects on human health (Silva, Berger, Bass, & Balbino, 2015). Therefore, researchers have recently focused on the discovery of insecticides that, in addition to being environmentally friendly features, have effective control on *T. absoluta* with the possible lowest doses (Soares, 2019).

In addition to the direct toxicity assessed based on the mortality of insect pests, insecticides have adverse effects on their developmental stages, physiology, and behavior (Desneux, Decourtye, & Delpuech, 2007). Investigation of the life table parameters, as one of the useful tools providing an in-depth understanding of the survival and development of insect populations, is a well-recognized method in determining sublethal impacts of insecticides (Chi & Yang, 2003). Demographic toxicology is a noble method to examine the general effects of insecticides on population parameters in insect pests, including finite rate of increase (λ), intrinsic rate of increase (r_m), mean generation time (T), and net reproductive rate (R_0) (Yin et al, 2008; Cloyd, 2012; Rasheed et al, 2020). The intrinsic rate of increase, along with other life table parameters, has been recommended as an applicable ecological parameter for demographic toxicology (Stark, Sugayama, & Kovaleski, 2007).

Several studies have conducted on the toxicity of different insecticides on *T. absoluta* (Santos, Bueno, Vieira, & Bueno, 2011; Gacemi & Guenaoui, 2012; Michaelides, Seraphides, Pitsillou, & Fenthourakis, 2019; Kandil et al, 2020). For example, Mahmoud, Soliman, Abdel-Moniem, & Abdel-Raheem (2013) examined the lethal effects of emamectin benzoate on the larvae of cotton bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae), and found that the insecticide caused a significant decline in the population of pest. The effect of azadirachtin was investigated on different stages of the *T. absoluta*, and the highest lethal effect was shown on the larval stage of this pest (Branherotto & Vendraim, 2010). The lethal effects of imidacloprid, phenoxycarb, fentoat, thiocyclam, and dinotefuran were studied on *T. absoluta* larvae and the highest and the lowest lethal percentages were recognized with imidacloprid and phenoxycarb, respectively (Eman, Redwan, & Hanan, 2012). Imidacloprid was reported as a toxic compound for the larval stages of *T. absoluta* (Mahmoud et al, 2014). The adaptability of the emamectin benzoate, imidacloprid, and azadirachtin with the IPM programs were revealed in some studies (Iwasa, Motoyama, Ambrose, & Roe, 2003; Charleston, Kafir, Dicke, & Vet, 2006; Tomé et al, 2013; Jin et al, 2014). Further, previous studies discovered that life table parameters of *T. absoluta* could be influenced by chemical insecticides (Nozad-Bonab, Hejazi, Iranipour, & Arzanlou, 2017; Zibaee & Esmaeily, 2017).

Due to the necessity of investigating the lethal and sub-lethal effects of insecticides and introduce more effective ones, the current study was conducted to assess the lethal and sublethal effects of conventional insecticides azadirachtin, lambda-cyhalothrin, emamectin benzoate, imidacloprid, and thiacloprid on the mortality, demographic parameters, and life history of *T. absoluta*.

MATERIALS AND METHODS

Host plant

The seeds of tomato, *Solanum lycopersicum* L. (Solanaceae, cultivar Super strain B), were obtained from the Ardabil Agricultural and Natural Resources Research and Education Center, AREEO, Ardabil, Iran. The seeds were cultivated in plastic pots (20 cm diameter and 19 cm height) containing sand, soil, and perlite at greenhouse with 20 ± 3 °C, 55 ± 10% relative humidity, and natural photoperiod. They were irrigated once every three days and covered with nets to protect from other pests. Plants of about 30 cm in height were carried to the growth chamber to be infested with Tomato leafminer.

Rearing of insect

The initial population of Tomato leafminer was collected from non-sprayed tomato greenhouses around Ardabil city (38.2514° N, 48.2973° E) in Northwest of Iran, and transferred to the above-mentioned greenhouse condition. To maintain the population, old plants were replaced by fresh ones every few days. Adults were transferred to shelves containing tomato pots to begin spawning on tomato leaves. Insects were reared in the growth chamber for up to three generations and the second-instar larvae of the third generation were selected for bioassays. Adults of pest were fed with 10% solution of water and honey. Insect rearing, along with all experiments, were performed in a growth chamber with 25 ± 2 °C, 65 ± 5% relative humidity, and a photoperiod of 16:8 h (L:D).

Insecticides

Commercial formulations of the following chemicals were used: azadirachtin (Neem Azal 1% EC; Trifolio, Germany), emamectin benzoate (Proclaim 5% SG; Syngenta, Switzerland), imidacloprid (Imidacloprid 35% SC; Ariashimi, Iran), lambda-cyhalothrin

(Lambda-cyhalothrin 10% SC; Ariashimi, Iran), and thiacloprid (Biscaya 240% OD; Bayer, Germany).

Toxicity bioassay

Due to the nature of the studied insecticides, which are most effective through digestive and contact routes, bioassays were performed by leaf-dipping method. Preliminary experiments performed to distinguish the suitable concentration ranges of the insecticides, determining concentrations responsible for mortalities between 20% and 80%, and the intermediate concentrations selected by logarithmic intervals. Finally, the main experiment was done using five concentrations (0.3, 0.35, 0.47, 0.72, and 1.25 mg A.I./L for emamectin benzoate, 1.87, 3.09, 5.25, 8.91, and 15 mg A.I./L for azadirachtin, 10.85, 17.85, 30.45, 51.8, and 87.5 mg A.I./L for imidacloprid, 88.8, 148.8, 252, 427. 2, and 720 mg A.I./L for thiacloprid, and 400, 512.9, 645.6, 812.8, and 1000 mg A.I./L for lambda-cyhalothrin) with distilled water as the solvent. Only distilled water was utilized in the control groups. Then, tomato leaves were dipped at mentioned concentrations for 15 s and kept for one hour to dry in the laboratory conditions. For each replicate, group of 20 larvae of 2nd instar were placed in a Petri dish (9 cm diameter). A hole was made on the lid of each Petri dish and covered with a mesh to ventilate. Petri dishes were covered thoroughly with parafilm to prevent larval escape. Experiments were replicated four times for each insecticide concentration. The dishes were then retained inside the growth chamber at the above-mentioned conditions, and the larval mortality was recorded after 72 h (Galdino et al, 2011).

Life table experiments

The leaves of tomato were immersed in sublethal LC_{30} concentrations of insecticides which were obtained from toxicity bioassays (Dong, Wang, Li, & Wang, 2017). Seventy second-instar larvae were transferred on the leaves after drying within 30 minutes in the Petri dishes. A damp cotton pad was placed on the petioles inside the aluminum foil. The Petri dishes were then transferred to the growth chamber under the mentioned conditions and the survived larvae were transferred onto untreated leaves after 24 h. They were monitored daily, and the mortality and developmental period were recorded in each treatment. After the adults' emergence and to measure the fecundity and longevity, each male was paired with a female moth and retained in rectangular plastic containers (14 × 10 cm × 4 cm). The number of eggs deposited per female was daily documented pending the death of all individuals for calculation of fecundity. The longevity of adult male and female was also documented separately. Demographic parameters, including finite rate of increase (λ), gross reproductive rate (GRR), intrinsic rate of increase (r_m), mean generation time (T), net reproductive rate (R_0) along with age-stage specific survival rate (s_{xj}) were calculated.

Data analysis and statistical calculations

The Shapiro-Wilk test (Moscardini et al, 2013) was used to check the normality of data. Mortality of the *T. absoluta* larvae was modified using Abbott's formula (Abbott, 1925). Lethal concentrations with 95% fiducial limits were calculated using Probit analysis obtain in SPSS software (version 24). Data of life table parameters were analyzed through the TWO-SEX-MS Chart program, based on the two-sex theory and the method prescribed by Chi et al, (2020). Life table parameters, including GRR, R_0, r_m, λ, T, and s_{xj} were measured according to Carey method (1993). Their means and standard errors were evaluated using the bootstrap technique according to Efron and Tibshirani (1993). Variance analysis and mean comparisons via the Paired bootstrap test were done in the TWOSEX-MS Chart program (Chi et al, 2020).

RESULTS AND DISCUSSION

Toxicity bioassay

The LC_{30} and LC_{50} values along with regression lines details for the insecticidal activity of emamectin benzoate, azadirachtin, imidacloprid, thiacloprid, and lambda-cyhalothrin against the second-instar larvae of insect pest are displayed in Table 1. Toxicity bioassays revealed that, based on the LC_{50} values, emamectin benzoate (0.52 mg A.I./L) and azadirachtin (5.19 mg A.I./L) were more toxic to *T. absoluta* than the other insecticides; imidacloprid (44.63 mg A.I./L), thiacloprid (293.92 mg A.I./L), and lambda-cyhalothrin (610.08 mg A.I./L). The calculated LC_{30} of each chemical such as emamectin benzoate (0.31 mg A.I./L) and azadirachtin (2.39 mg A.I./L), imidacloprid (18.64 mg A.I./L), thiacloprid (133.48 mg A.I./L), and lambda-cyhalothrin (438.79 mg A.I./L) was used to evaluate its sublethal effects. According to r^2 values represented in table 1, the mortality of insect pests was positively attributed to the tested concentrations of insecticides.

Table 1. Toxicity of emamectin benzoate, azadirachtin, imidacloprid, thiacloprid, and lambdacyhalotrin against second-instar larvae of *Tuta absoluta* under laboratory conditions.

	Concentration mg A.I/L (95% CL)		X^2 (df)	Slope ± SE	Sig.*	r^2
	LC_{30}	LC_{50}				
Emamectin benzoate	0.31 (0.25 - 0.36)	0.52 (0.46 - 0.59)	14.54 (18)	2.30 ± 0.13	0.69	0.88
Azadirachtin	2.39 (1.75 - 2.97)	5.19 (4.35 - 6.17)	3. 50 (18)	1.56 ± 0.09	0.99	0.86
Imidacloprid	18.64 (13.91 - 23.01)	44.63 (36.75 - 57.00)	14.30 (18)	1.38 ± 0.09	0.70	0.98
Thiacloprid	133.48 (100.10 - 163.80)	293.92 (246.90 - 354.90)	2.68 (18)	1.53 ± 0.09	0.99	0.93
Lambdacyhalotrin	438.79 (382.00 - 483.27)	610.08 (564.50 - 656.14)	6.44 (18)	3.66 ± 0.21	0.96	0.94

*Considering the significance level is more than 0.05, no heterogeneity factor was utilized in the estimation of fiducial limits. The number of tested insects was 480 for each insecticide.

Many studies reported the high efficiency of emamectin benzoate in the control of Lepidopteran pests (Lopez, Latheef, & Hoffmann, 2010; Baniameri & Cheraghian, 2012; Gacemi & Guenaoui, 2012; Mahmoud, Soliman, Abdel-Moniem, & Abdel-Raheem, 2013; Berxolli & Shahini, 2018). Roditakis et al, (2013) studied the effects of some insecticides, including emamectin benzoate, on second-instar larvae of *T. absoluta* with LC_{50} values of 0.08-0.26 mg/l after 72 h exposure time. In the other study, LC_{50} values of emamectin benzoate on *Helicoverpa zea* Boddie (Lepidoptera: Noctuidae) calculated as 0.46, 0.41, and 0.18 ppm within 24, 48, and 72 h, respectively (Lopez, Latheef, & Hoffmann, 2010). According to Roditakis et al (2018), no cases of control failure have reported in Europe to date for emamectin benzoate. On the contrary, Mujica, Pravatiner, & Cisneros (2000) reported that abamectin affects full-grown embryo and first-instar larvae but does not damage the embryo at earlier developmental stage. Therefore, the growth stage would affect the results of using this insecticide. Based on the low LC_{50} value reported in previous and present studies, emamectin benzoate had high efficiency in the management of insect pests, which can be attributed to its translaminar ability into plant tissue (Ishaaya, Barazani, & Horowith, 2002; Bengochea, Sánchez-Ramos, Saelices, & Amor, 2014). High effectiveness of azadirachtin was reported on *T. absoluta* and *Leucoptera coffeella* (Guérin-Méneville and Perrottet) (Lepidoptera: Lyonetiidae) larvae in the previous studies (Venzon et al, 2005; Berxolli & Shahini, 2017). Tomé et al. (2013) indicated that azadirachtin was very toxic to Brazilian populations of *T. absoluta* not only by direct toxicity but also by an egg-laying and larval movement deterrence effects, indicating its multiple modes of actions in the present and previous studies. Also, similar to findings of Mahmoud, Soliman, Abdel-Moniem, & Abdel-Raheem (2013), imidacloprid presented a good control against *T. absoluta* larvae in the present study. In disagreement with our results, imidacloprid was not considerably effective on tomato leafminer eggs in study of Nozad-Bonab, Hejazi, Iranipour, & Arzanlou, (2017). differences can be due to the different stages of the insect being tested.

Sublethal effects on demographic parameters

The studied insecticides had significantly adverse effects on demographic parameters of Tomato leafminer such as r_m, λ, R_0, *GRR*, and *T* (Table 2). The r_m rates were from 0.075 to 0.140 day^{-1} in different treatments, with the highest and lowest levels in control and those treated with emamectin benzoate, respectively. Except for lambda-cyhalothrin, the r_m values in treatments were statistically different from the control groups. The lowest amount of R_0 found in insects treated with emamectin benzoate, while it was the highest in the control group. The lowest (19.33 offspring) and the greatest (59.28 offspring) values of *GRR* were recorded in emamectin benzoate and control treatments, respectively. The *T* values increased from 28.85 days for the control group to 28.85, 29.18, 29.65, 32.91, and 33.65 days for lambda-cyhalothrin, thiacloprid, imidacloprid, azadirachtin, and emamectin benzoate, respectively. Regarding the λ parameter, the lowest value was observed for individuals treated with emamectin benzoate, whereas the highest value was recorded for the control.

We could decrease the pest populations by studying the demographic parameters of a pest and the recognition of the chief factors of population growth rate. Moreover, comprehension of the sublethal effects of insecticides can lead to the thoughtful utilization of these chemicals and decrease their side effects. Sublethal effects have been evaluated to discover the harmful and chronic impacts of pesticides on pest life-table parameters, which may also affect pest population dynamics (Stark & Banks, 2003). The parameter r_m has a suitable statistical base to describe population growth rates. However, r_m is influenced by various factors such as geographical origin, insect species, host type, climatic conditions (such as temperature, humidity, and light), the longevity of adults, and so on. The r_m values for emamectin benzoate and azadirachtin treatments, compared to the control group, decreased by almost 46 and 35%, respectively, while for imidacloprid, thiacloprid, and lambda-cyhalothrin treatments it was dropped to 28, 9, and 4%, respectively. The R_0 parameter signifies the number of offsprings created by a female, considering the probability of female survival per generation. This parameter significantly declined in all insecticide treatments compared to the control groups in the current study. The R_0 value for emamectin benzoate reduced by about 76% compared to the control, which was lower for the other treatments. Lixia, Changhui, & Xiaowei (2011) examined the effects of emamectin benzoate on the developmental periods of *H. armigera*, and noted that when third-instar larvae were treated with the LC_{25} of this insecticide, R_0, r_m, and λ declined by 77, 29, and 5%, respectively, and T increased by 6%. In the other study, in agreement with our results, Zibaee & Esmaeily (2017) reported a value of 22.42 for R_0 in *T. absoluta* under the influence of abamectin LC_{30}. The T parameter is the needed time for a population to increase by the net reproductive rate. In the current study, the amount of T parameter had an increasing trend from the control to emamectin benzoate treatment. This parameter by the LC_{25} of abamectin, chlorantraniliprole, and spinosad on *T. absoluta* had an increasing trend like that of our study (Nozad-Bonab, Hejazi, Iranipour, & Arzanlou, 2017). The gross reproductive rate (*GRR*) denotes the average number of eggs that a female produces in a single generation, providing that the female survives until the last possible day. The highest and lowest *GRR* were obtained in the control and emamectin benzoate treatments, respectively, which are consistent with those reported by Nozad-Bonab, Hejazi, Iranipour, & Arzanlou (2017). The parameter λ indicates the value in which a stable population will increase per day compared to the previous day. Its values with a decreasing trend ranged from 1.15 to 1.07 day^{-1} in the control and emamectin benzoate treatments, respectively. In line with our study, this parameter had a decreasing trend by sublethal effect of abamectin on *T. absoluta* in the study of Nozad-Bonab, Hejazi, Iranipour, & Arzanlou (2017). The sublethal concentration of abamectin significantly reduced the emergence, fecundity, and longevity of *T. absoluta* adults. Further, demographic parameters of the pest, including r_m, *GRR*, R_0, and λ, decreased in comparison to the control (Zibaee & Esmaeily, 2017), which is consistent with the results of the present study.

Sublethal effects on the life history parameters and the age-stage specific survival rate

The LC_{30} of studied insecticides prolonged the period of pre-adult stages and diminished the adult period and fecundity of *T. absoluta* (Table 3). Larval developmental period significantly increased by insecticides except for thiacloprid and lambda-cyhalothrin in comparison with the control group. For instance, the developmental period of forth-instar larvae in the control group was 3.02 days, which increased to 4.25 days in emamectin benzoate treatment. The pupal period was the lowest (7.83 days) in the control group while it was continued to 8.83 days in the treatment of emamectin benzoate. The longevity of adults was the lowest in the emamectin benzoate in comparison with the control. The highest and lowest adult pre-oviposition period (APOP) values were also observed in the control and emamectin benzoate treatments, respectively. The longest total pre-oviposition period, TPOP, was recorded for those treated with emamectin benzoate (32.08 days), while the lowest one occurred in the control group (25.5 days). Fecundity ranged from 38.67 offspring/female in emamectin benzoate treatment to 118.58 offspring/female in the control group. The lowest oviposition period (4.21 days) belonged to the emamectin benzoate treatment.

Table 2. Mean (±SE) demographic parameters of *Tuta absoluta* treated by sublethal concentration (LC30) of emamectin benzoate, azadirachtin, imidacloprid, thiacloprid, and lambdacyhalotrin.

Parameters (unit)	Control	Lambdacyhalotrin	Thiacloprid	Imidacloprid	Azadirachtin	Emamectin benzoate
r_m (day^{-1})	0.140±0.005^{a}	0.134±0.005^{ab}	0.127±0.005^{b}	0.100±0.005^{c}	0.090±0.005^{d}	0.075±0.005^{e}
R_0 (offspring)	56.92±8.47^{a}	50.32±7.66^{b}	44.07±6.84^{c}	27±4.43^{d}	21.22±3.50^{e}	13.64±2.41^{f}
GRR (offspring)	59.28±8.66^{a}	55.56±8.11^{a}	50.5±7.40^{b}	33.75±5.12^{c}	27.85±4.15^{c}	19.33±3.07^{d}
T (day)	28.85±0.35^{c}	29.18±0.34^{c}	29.65±0.34^{c}	32.91±0.34^{b}	33.65±0.34^{ab}	34.45±0.31^{a}
λ (day^{-1})	1.15±0.006^{a}	1.14±0.006^{ab}	1.13±0.006^{b}	1.10±0.005^{c}	1.09±0.005^{c}	1.07±0.005^{d}

The same letters in each row indicate no significant difference at the 5% probability level (paired bootstrap test). rm, R0, GRR, T, and λ are the intrinsic rate of increase, net reproductive rate, gross reproductive rate, mean generation time, and finite rate of increase, respectively.

Table 3. Mean (± standard error) life-history parameters of *Tuta absoluta* treated by sublethal concentration (LC30) of emamectin benzoate, azadirachtin, imidacloprid, thiacloprid, lambdacyhalotrin.

Parameters (unit)	Control	Lambdacyhalotrin	Thiacloprid	Imidacloprid	Azadirachtin	Emamectin benzoate
2nd-instar (days)	2.84±0.09^{c}	2.92±0.0^{9}C	2.98±0.08^{c}	3.57±0.11^{b}	3.65±0.11^{ab}	4.03±0.08^{a}
3rd-instar (days)	2.28±0.06^{d}	2.38±0.06^{d}	2.43±0.07^{d}	2.92±0.07^{b}	3.02±0.07^{ab}	3.34±0.08^{a}
4th-instar (days)	3.02±0.09^{b}	3.2±0.08^{b}	3.38±0.07^{b}	3.92±0.09^{a}	4±0.09^{a}	4.25±0.08^{a}
Pupa (days)	7.83±0.10^{b}	7.96±0.09^{b}	8.02±0.09^{b}	8.56±0.07^{ab}	8.67±0.08^{a}	8.83±0.09^{a}
Pre-adult (days)	24.15±0.21^{d}	24.79±0.22^{cd}	25.42±0.2^{c}	29.02±0.23^{b}	29.92±0.23^{b}	31.23±0.22^{a}
Female longevity (days)	28±3.53^{a}	27.17±3.61^{ab}	26.04±3.68^{b}	24.33±3.79^{c}	22.17±3.85^{d}	18.17±3.94^{e}
Male longevity (days)	25.88±2.58^{a}	25.33±3.47^{ab}	24.50±3.54^{b}	23.42±3.64^{c}	21.04±3.79^{d}	17.88±3.87^{e}
APOP (days)	1.79±0.08^{a}	1.71±0.09^{ab}	1.67±0.1^{abc}	1.29±0.09^{cd}	1.21±0.08^{d}	1.04±0.04^{d}
TPOP (days)	25.5±0.33^{c}	26.08±0.35^{c}	26.83±0.35^{c}	30.42±0.3^{b}	31.25±0.28^{ab}	32.08±0.29^{a}
Fecundity (egg/female)	118.58±2.58^{a}	111.12±2.44^{a}	101±2.45^{b}	67.5±3.10^{c}	55.71±2.17^{d}	38.67±2.6^{e}
Oviposition period (days)	12.58±0.12^{a}	10.21±0.12^{b}	9.04±0.13^{c}	6.21±0.15^{d}	5.38±0.12^{e}	4.21±0.2^{f}

The same letters in each row indicate no significant difference at the 5% probability level (paired bootstrap test). APOP and TPOP are the adult pre-oviposition period and total pre-oviposition period, respectively.

Reduction in the incubation period of *T. absoluta* through sublethal concentration of a well-known insecticide pyriproxyfen reported in a recent work (Tomé, Cordeiro, Rosado, & Guedes, 2011). According to our outcomes, sublethal concentrations of tested insecticides, except for lambda-cyhalothrin, decreased the fecundity of *T. absoluta*. A 55% accumulation of spinosad in the ovaries of the parasitoid wasp *Hyposoter didymator* (Hymenoptera: Ichneumonidae) was reported (Williams, Valle, & Viuela, 2003). It is probably the main reason for the fecundity reduction of *T.*

absoluta by tested insecticides, especially emamectin benzoate. According to the study of Hamdy & El-Sayed (2013), biocompatible insecticides such as emamectin benzoate were more effective than other chemicals such as indoxacarb in controlling *H. armigera* and *T. absoluta* larvae, same to our outcomes. Tomé et al, (2013) presented evidence that azadirachtin was a suitable insecticide for organic agriculture, which could significantly reduce the *T. absoluta* population. The dynamics of populations may be affected by infertility in adults, as mating not generated fertile eggs (Desneux, Decourtye, & Delpuech, 2007). Unfertile eggs of *T. absoluta* influenced by the sublethal concentration of tested chemicals were also found in the present study.

The evaluation of age-stage specific survival rate (s_{xj}) of *T. absoluta* before insecticide treatments exhibited diverse survival rates for different stages (Fig. 1). The longevity of females (34 days) was more extended than the males (32 days) in control, but this amount was almost equal in insecticide treatments. In the insects treated with emamectin benzoate, azadirachtin, and imidacloprid, the survival of forth-instar larvae, pupae, and adults of insect pest was reduced compared to control.

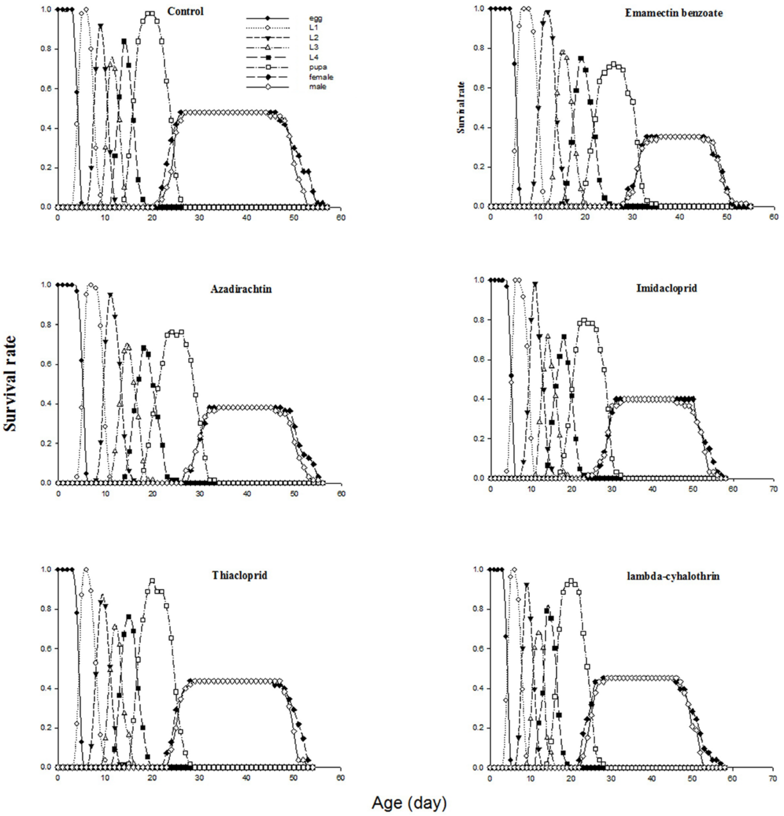

Fig. 1. Age-stage specific survival rate (sxj) curve of *Tuta absoluta* treated by the sublethal concentration of emamectin benzoate, azadirachtin, imidacloprid, thiacloprid, lambdacyhalotrin, and control. The curve of egg and first instar larvae is untreated.

Survival reduction will reduce the population and number of generations per year. Based on differences in the growth rate of treated individuals, an overlap is observed in this curve between the different stages. This curve shows the probability that treated individuals will survive to age *x* and stage *j*. Similar to this study, notable reduction was found in the survival of *T. absoluta* larval stages by sublethal concentrations of abamectin (Zibaee & Esmaeily, 2017).

CONCLUSION

According to results of the present study, the toxicity and efficiency of emamectin benzoate and azadirachtin were higher than lambda-cyhalothrin, imidacloprid, and thiacloprid in all biological stages of *T. absoluta*. Due to the insecticidal effects on the mortality, life history, and demographic parameters of *T. absoluta*, emamectin benzoate can be distinguished as a potential agent for the management of this damaging insect pest. Accordingly, emamectin benzoate, as one of the novel insecticides in Iran, would be an excellent option for operative control of *T. absoluta*, if confirmed by the further filed data.

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