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Article

Application of demographic analysis for assessing effects of pesticides on the predatory mite, *Phytoseiulus persimilis* (Acari: Phytoseiidae)

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ABSTRACT

Knowing pesticides' side-effects on non-target beneficial phytoseiids is crucial for integrated mite management (IMM) programs. The present study investigates the sublethal effects of three fungicides: previcur N (Propamocarb-Hydrochloride 72.2%), penazol 10% EC (Penconazol) and sumi-eight 5% EC (Diniconazole); two insecticides: confidor 20% SL (Imidacloprid) and penny 9% SC (Emamectin benzoate 1.5% & Indoxacarb 7.5%), and two common acaricides: agnar (Spirodiclofen 18% + Abamectin 2%) and biomectin 5% EC (Abamectin) on the predatory mite, *Phytoseiulus persimilis* Athias-Henriot under both laboratory and greenhouse conditions. The toxicity bioassay and greenhouse experiments revealed that the effects of agnar, confidor and previcur N on *P. persimilis* is less than other compounds. Therefore, they were selected to evaluate their influence on the population parameters of *P. persimilis*. Based on the age-stage two-sex life table theory, the LC_{25} of tested pesticides significantly reduced the longevity, life span and total fecundity of female *P. persimilis*. Also, it reduced the net (R_0) and gross (*GRR*) reproductive rates. Consequently, the intrinsic (r) and finite (λ) rates of increase were affected. In conclusion, the selected pesticides should not be used with *P. persimilis* in integrated pest management programs due to their unfavorable effects on the population parameters of this predatory mite.

KEY WORDS: Integrated pest management; life table parameters; pesticides; side-effects; toxicity.

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INTRODUCTION

Information about the side-effects of pesticides on non-target beneficial species is necessary for integrated pest management (IPM) programs. Since 1950s, the outbreaks of spider mites has increased in many crops due to the extensive use of synthetic pesticides that destruct their predators (Van de Vrie *et al.* 1972). The flow of mite pests during any planting season need to be controlled by pesticides that might negatively affect the predatory mites which consequently obstruct the biological control of tetranychid mites (Sato *et al.* 2000; Abraham *et al.* 2013). Selection of efficient pesticides with lowest negative effects on the natural enemies is highly important in the integrated pest management (IPM) programs (Colomer *et al.* 2011). Several research projects are regularly performed to study the

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side effects of different compounds on the predatory mites; whether used to control the mite pests or any other agricultural pests to be included in IPM programs (e.g. Kavousi and Talebi 2003; Hamedi *et al.* 2011; Glinushkin *et al.* 2019).

Phytoseiids mites are extensively used as biocontrol agents for management of mites as well as small insect pests such as whiteflies and thrips on crops grown in greenhouses and fields. Global interest in research on phytoseiids has steadily increased during the last 50 years (McMurtry *et al.* 2015). *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) is the main predator of the two-spotted spider mite *Tetranychus urticae* Koch (Helle and Sabelis 1985) and to maximize its role as a biocontrol agent, it is important to know the impact of pesticides on it (Hassan 1982). Nevertheless, in IPM programs, the use of pesticides can seriously affect the performance of this natural enemy since phytoseiids mites are generally more susceptible to pesticides than other mites (Croft 1990). To minimize the deleterious effects of chemical control on their natural enemy and provide an ecological balance between pests and their natural enemies, these control strategies can be combined to provide a more reliable form of pest management (Kogan 1998). As a result, the use of low toxic levels of chemical agents to natural enemies and/or the use of pesticide- resistant predatory mites have been exploited in the IPM programs (Croft 1990).

The side-effects of pesticides on the predatory mites can be studied in several levels (e.g. laboratory, semi-field and field conditions). Laboratory trials are considered as the initial step in toxicity studies, while semi-field and field trials are required when a pesticide demonstrated to be effective in the laboratory trials (Hassan *et al.* 1985; EPPO 1990). Several studies assessed the impacts of pesticides on the predatory mites (e.g. Samsøe-Petersen 1983; Ibrahim and Yee 2000; Duchovskienė *et al*. 2009; Hamedi *et al.* 2011; Kaplan *et al.* 2012; Glinushkin *et al.* 2019). The sublethal effects can be very subtle and affect populations at concentrations lower than the conventional concentration and may supplement our information about its sublethal effects on physiology and behavior of arthropods (Stark and Banks 2003; Desneux *et al.* 2007).

In some cases of IPM programs, we have to use some pesticides or fungicides to control pests and pathogens coexisting with *T. urticae*. Some of these pesticides or fungicides, which we don't fully know their side effects on the predators, could be harmless or harmful to the predatory mite *P. persimilis*. Therefore, this study is a trial to widen the spectrum of safe pesticides and fungicides that could be used in IPM programs which include using the predatory mite *P. persimilis*. For that reason, three fungicides (previcur N, penazol and sumi-eight), two insecticides (confidor and penny) and two acaricides (agnar and biomectin) are selected to evaluate their effects on the predatory mite *P. persimilis* under laboratory and greenhouse conditions to determine which is compatible with this predatory mite.

MATERIALS AND METHODS

Rearing mites

The stock culture of *T. urticae* and *P. persimilis* were collected from bean plants (*Phaseolus vulgaris* L.) grown in Unit of Predatory Mites Production in Al Mansouria, Giza Governorate, Egypt, and were transferred to Acarology Lab., Agricultural Zoology Department, Faculty of Agriculture, Cairo University.

Both prey and predator were reared on leaves of copperleaf shrubs (*Acalypha wilkesiana* Müll. Arg.) placed on water-saturated cotton pads in dishes. Water-saturated, absorbent cotton strip (1 cm height) was placed around the edge of the leaves to prevent mites from escaping. The rearing was maintained in a climate-controlled room (25 ± 5 °C, 60 ± 10 % RH and L14:D10 h photoperiod) to maintain a continuous source of mites to be used during experiments. The cotton bed was soaked with water daily. The colonies of both prey and predator was left intact for more than two months before starting the experiments. Leaves were replaced every 7 days. A thin paint brush was used to transfer the mites from old leaves to the new ones.

Tested chemicals

The toxic effects of seven pesticides, three fungicides: previcur N (Propamocarb-Hydrochloride 72.2%), penazol 10% EC (Penconazol) and sumi-eight 5% EC (Diniconazole); two insecticides: confidor 20% SL (Imidacloprid) and penny 9% SC (Emamectin benzoate 1.5% and Indoxacarb 7.5%); two common acaricides: agnar (Spirodiclofen 18% + Abamectin 2%) and biomectin 5% EC (Abamectin) on *P. persimilis* under laboratory and greenhouses conditions were tested in the current study (Table 1).

Table 1. Pesticides used in this study with active ingredient and recommended rate.

Pesticides and formulation types	Active ingredient (%)	Manufacturer	Recommended rate (ml/100 L water)
Fungicides			
previcur N 72.2 % SL	Propamocarb-Hydrochloride (72.2%)	Bayer Crop Science	250
penazol 10% EC	Penconazol (10%)	Shoura Chemicals	25
sumi-eight 5% EC	Diniconazole (5%)	Sumitomo Chemical LTD	35
Insecticides			
confidor 20% SL	Imidacloprid (20%)	Bayer Crop Science	25
penny 9% SC	Emamectin benzoate (1.5%) & Indoxacarb (7.5%)	Shoura Chemicals	37.5
Acaricides			
agnar 20% SC	Abamectin (2%) & Spirodiclofen (18%)	Shoura Chemicals	40
biomectin 5% EC	Abamectin 5%	Shoura Chemicals	20

EC: emulsifiable concentrate, SC: suspension concentrate, SL: soluble concentrate

Toxicity bioassay

In the toxicity bioassay, *P. persimilis* were sprayed with five different concentrations of previcur N (1805, 902. 5, 451.25, 225.63 and 112.81 ppm), penazol (25, 12.5, 6.25, 3.125 and 1.563 ppm), sumi-eight (17.5, 8.75, 4.375, 2.188 and 1.094 ppm), confidor (50, 25, 12.5, 6.25 and 3.125 ppm), penny (33.75, 16.875, 8.438, 4.219 and 2.109 ppm), agnar (80, 40, 20, 10, and 5 ppm) and biomectin (10, 5, 2.5, 1.25 and 0.625 ppm). The recommended dose was chosen to be the highest concentration for each pesticide.

The predatory mite, *P. persimilis* was sprayed with five different concentrations of each pesticide with five replicates/concentration with 50 female individuals per concentration. Leaf discs of copperleaf shrubs (5 cm diameter) were placed on moist cotton pads in dishes to prevent predatory mites from escaping. Ten adult females of *P. persimilis* were transferred from the stock culture to each leaf disc and sprayed with the pesticide concentrations or distilled water (control). Spraying was done using a hand sprayer. *Tetranychus urticae* movable stages were used as prey of the predatory mites. The experiment was conducted in a climate-controlled room (25 ± 5 °C, 60 ± 10 % RH and L14:D10 h photoperiod). Mites' mortality was measured one day after exposure. Natural mortality was estimated using Abbott's formula (Abbott 1925).

The lethal (LC_{90}, LC_{50}), sublethal (LC_{25}) and slope values for *P. persimilis* adult females with tested pesticides were estimated by LdP Line® Program Bakr (2000) devoted to calculate probit analyses according to Finney (1971).

Influence of pesticides on P. persimilis *under greenhouse conditions*

This experiment was conducted to assess the influence of the seven pesticides on *P. persimilis* under greenhouse conditions. Elhama bean plants were grown under greenhouse conditions (9 × 40 m) and received all normal agricultural processes without any pesticide application. After the appearance of *T. urticae* infestation on the plants, *P. persimilis* was released and left for one week for reproduction. Then, the mean number of *P. persimilis* on bean plants was recorded before pesticide treatments.

The experimental area was divided into three blocks according to the Randomized Complete Block Design, each block including seven treatments and a control. The tested pesticides were applied on the bean plants (treatments), while the control was only sprayed with water. A compressor spryer (20 L capacity) was used. An additional spray was conducted after three weeks of the first spray application; the second spray application was done under the same earlier conditions. In both experiments, the movable stages of *P. persimilis*/10 plant leaves/replicate were recorded at 3, 5, 7 and 14 days after the two applications.

The reduction of *P. persimilis* population (%) was calculated according to Henderson and Tilton equation (1955) as:

$$\text{Reduction}\% \equiv (1 - \frac{\text{Treatment after} \times \text{Control before}}{\text{Treatment before} \times \text{Control after}}) \times 100$$

Effect of pesticides on biological parameters of offspring of treated females

The influence of LC_{25} sublethal concentration of three selected pesticides (previcur N, confidor and agnar) on the biology and life table parameters of *P. persimilis* was evaluated under laboratory conditions. Mated females were sprayed with the tested pesticides while water was used as control. After pesticide treatment, one mated female/replicate was transferred on the leaf section of copperleaf shrubs (3 cm of diameter) placed on wet cotton pads in a Petri dish (6 cm in diameter) and left for 24 h for oviposition. All dishes were maintained in an incubator at 28 ± 2 °C, 65 ± 5 % R.H and L14: D10 h photoperiod.

After oviposition, female and all eggs except one were removed from dishes. Thirty eggs per replications/pesticide and the control (n = 120 eggs) were used. The eggs were observed daily until the larvae hatched. The period of each developmental stage was observed till all larvae became adults. During the experiment, leaves of discs were replaced every 7 days. Newly emerged adults were separated by sex, paired into couples, and transferred to new discs for evaluating the pre-ovipositional and ovipositional periods, fecundity, and adult longevity. In discs where males died before females, new males were added from stock colony to the relevant experimental units. However, the data from these males were not used in the analysis. The dead mites and the eggs laid by female individuals in each disc were counted and removed daily until the end of the experiment. The life tables were developed based on the data for all individuals tested (including females, males, and individuals that died during the development of the immature stage) as proposed by Chi (1988).

Statistical analysis

The data obtained were subjected to one-way ANOVA "$P < 0.05$" after checking for normality. Means were compared by Tukey's test, admitting significant differences at $P < 0.05$. Statistical Package of Social Science (SPSS), version 16.0 was used for mean comparisons.

The raw data of the life table parameters were analyzed according to the theory of age-stage, two-sex life table using the TWOSEX MSChart program (Chi 2020). The age-stage specific survival rate (s_{xj}) (where x = age in days and j = stage); the age-specific survival rate (l_x); the age-specific fecundity (m_x); and the population growth parameters [the net reproductive rate (R_0); the intrinsic rate of increase (r); the finite rate of increase (λ); mean generation time (T) and the gross reproductive rate (GRR)] were also calculated (Chi and Liu 1985; Chi and Su 2006).

The means and standard errors of the population parameters were estimated by using the Bootstrap procedure with 100,000 re-sampling and the life table parameters of *P. persimilis* untreated (control) and treated with pesticides (previcur N, confidor and agnar) were compared by using a paired bootstrap test (Wei *et al.* 2020).

RESULTS

Concentration-response bioassay

The lethal and sublethal concentrations of seven pesticides on *P. persimilis* adult females are mentioned in Table 2. Based on LC_{50} and LC_{90} values and their fiducial limits, biomectin was the most toxic pesticide followed by sumi-eight and penny. While previcur N, agnar and confidor were less toxic. Hence, previcur, confidor, and agnar were selected to evaluate their influence on the life table parameters of *P. persimilis*.

Influence of pesticides on P. persimilis *under the greenhouse conditions*

In the greenhouse experiments, the populations of movable stages of *P. persimilis* were variably influenced in the first and second pesticides applications compared to the control (Table 3). The mean number of *P. persimilis* on bean plants treated with biomectin, penny, and sumi-eight decreased on day 3 and 5 after treatment compared to the control in the first and second applications. It was decreased from 2.03, 1.90, and 1.80 to 1.33, 1.27, and 1.40 and from 2.10, 2.37, and 2.03 to 1.50, 1.67, and 1.63 individual/leaf on day 3 after the first and second applications, respectively. Also, it was decreased on day 5 to 1.93, 1.80 and 2.00 and 1.73, 1.97 and 1.87 individual/leaf, in the first and second applications, respectively.

The populations of movable stages of *P. persimilis* on bean plants sprayed by all the pesticides were not affected on day 14 after treatment compared to the control in both pesticide applications.

Highest reduction percentages of movable stages of *P. persimilis* were recorded with the treatments of biomectin, penny, and sumi-eight. They averaged (41.66 and 36.99%), (40.48 and 37.84%), and (30.74 and 29.17%) on day 3 after the first and second applications, respectively. The lowest reduction percentages were recorded at treatments agnar, confidor, and previcur N, which averaged “27.60 and 22.68%”, “28.57 and 20.02%”, and “22.38 and 17.25%” on day 3 after the first and second treatments, respectively. So, the influence of agnar, confidor, and previcur N on *P. persimilis* is less effective than biomectin, penny, sumi-eight, and penazol. On the days 7 and 14 after pesticides application, there was no significant difference among most treatments and control.

Table 2. Mean lethal and sublethal concentrations (ppm) of seven pesticides on *Phytoseiulus persimilis*.

Pesticides	***P. persimilis* adult females**			Slope ± SE	*P*
	LC_{25} (ppm)	**LC_{50} (ppm)**	**LC_{90} (ppm)**		
previcur N	**439.44** 285.62–605.91*	**1020.56** 735.66–1659.54	**5060.21** 2690.20–18579.98	1.84 ± 0.35	0.95
penazol	**4.85** 3.06–6.68	**11.31** 8.25–17.22	**56.49** 31.46–179.81	1.83 ± 0.33	0.90
sumi-eight	**2.53** 1.48–3.59	**6.26** 4.51–9.28	**34.51** 19.24–109.71	1.73 ± 0.32	0.95
confidor	**9.10** 5.52–12.75	**22.40** 16.20–35.09	**123.90** 65.97–447.73	1.73 ± 0.32	0.89
penny	**4.79** 3.12–6.41	**9.81** 7.44–13.15	**38.35** 25.28–79.18	2.16 ± 0.34	0.76
agnar	**14.82** 9.93–19.68	**30.37** 23.08–41.87	**118.66** 75.66–266.16	2.16 ± 0.35	0.98
biomectin	**1.42** 0.98–1.84	**2.63** 2.04–3.39	**8.48** 6.00–14.94	2.52 ± 0.37	0.79

* Fiducial limits (ppm).

Table 3. Effect of spraying seven pesticides on the predatory mite, *Phytoseiulus persimilis* after releasing on bean plants infested with *Tetranychus urticae* under greenhouse conditions.

	Sampling	Mean numbers and reduction percentages of *P. persimilis* movable stages /Leaf							Control	*F*	*P*
		previcur N	penazol	sumi-eight	confidor	penny	agnar	biomectin			
	Pre-treatment	1.87 ± 0.32a	1.77 ± 0.35a	1.80 ± 0.27a	1.87 ± 0.15a	1.90 ± 0.27a	2.30 ± 0.17a	2.03 ± 0.24a	1.87 ± 0.09a	0.487	0.831
First spraying	After 3 days	1.63 ± 0.19a (22.38%)*	1.53 ± 0.09a (23.03%)	1.40 ± 0.21a (30.74%)	1.50 ± 0.12a (28.57%)	1.27 ± 0.27a (40.48%)	1.87 ± 0.09a (27.60%)	1.33 ± 0.26a (41.66%)	2.10 ± 0.12a	2.421	0.068
	After 5 days	2.33 ± 0.33a (19.66%)	2.17 ± 0.37a (20.94%)	2.00 ± 0.17a (28.35%)	2.13 ± 0.12a (26.55%)	1.80 ± 0.32a (38.91%)	2.67 ± 0.07a (25.14%)	1.93 ± 0.23a (38.69%)	2.90 ± 0.23a	2.220	0.088
	After 7 days	2.90 ± 0.50a (15.45%)	2.57 ± 0.35a (20.84%)	2.47 ± 0.27a (25.19%)	2.87 ± 0.19a (16.33%)	2.27 ± 0.37a (34.86%)	3.37 ± 0.18a (20.12%)	2.43 ± 0.33a (34.74%)	3.43 ± 0.22a	1.867	0.142
	After 14 days	2.50 ± 0.27a (0.00%)	2.43 ± 0.30a (0.00%)	2.13 ± 0.24a (6.63%)	2.33 ± 0.20a (1.69%)	2.23 ± 0.38a (7.39%)	2.93 ± 0.07a (0.00%)	2.27 ± 0.22a (11.77%)	2.37 ± 0.29a	0.882	0.542
	Pre-treatment	2.10 ± 0.12a	2.53 ± 0.35a	2.03 ± 0.09a	2.57 ± 0.37a	2.37 ± 0.52a	2.43 ± 0.35a	2.10 ± 0.23a	2.47 ± 0.35a	0.429	0.870
Second spraying	After 3 days	1.97 ± 0.03ab (17.25%)	2.30 ± 0.35ab (19.81%)	1.63 ± 0.37b (29.17%)	2.33 ± 0.09ab (20.02%)	1.67 ± 0.30b (37.84%)	2.13 ± 0.07ab (22.68%)	1.50 ± 0.20b (36.99%)	2.80 ± 0.36a	2.899	0.037
	After 5 days	2.20 ± 0.15bc (16.53%)	2.63 ± 0.30ab (17.17%)	1.87 ± 0.34bc (26.60%)	2.60 ± 0.21abc (19.39%)	1.97 ± 0.35bc (33.77%)	2.47 ± 0.15abc (19.01%)	1.73 ± 0.15c (34.36%)	3.10 ± 0.35a	3.076	0.030
	After 7 days	2.13 ± 0.09a (13.61%)	2.67 ± 0.33a (10.11%)	1.90 ± 0.21a (20.28%)	2.77 ± 0.18a (8.20%)	2.30 ± 0.31a (17.34%)	2.53 ± 0.29a (11.32%)	1.80 ± 0.29a (27.00%)	2.90 ± 0.25a	2.559	0.057
	After 14 days	2.30 ± 0.20a (0.00%)	2.73 ± 0.27a (0.00%)	2.20 ± 0.30a (0.00%)	2.97 ± 0.03a (0.00%)	2.30 ± 0.30a (6.86%)	2.60 ± 0.21a (0.00%)	2.17 ± 0.17a (2.95%)	2.63 ± 0.24a	1.561	0.217

Means within a row followed by the same letter are not significantly different (Tukey's test: $P < 0.05$)

* The reduction % of *P. persimilis* movable stages was calculated according to Henderson and Tilton equation (1955).

Influence of pesticides on biological parameters of offspring of treated females

Three pesticides, agnar, confidor, and previcur N were selected to evaluate their influence on developmental stages and life table parameters of *P. persimilis* (Tables 3–5). The egg incubation of both female and male was significantly affected by the LC_{25} of agnar and confidor.

Also, the developmental stages of nymphs and pre-adult of female offspring from females exposed to agnar and confidor were longer than control individuals. However, the larval developmental period in both sexes was not affected by pesticides. The study of LC_{25} showed that the longevity of adult males and females was shorter in comparison with control. Also, the total life span of treated females was significantly reduced (Table 4).

There were no significant differences among agnar, confidor, and previcur N pesticides on longevity and total life span on both sexes.

The LC_{25} of agnar and confidor significantly increased the adult pre-oviposition period (APOP) and total pre-oviposition period (TPOP) of *P. persimilis* females compared with control. On the contrary, the oviposition period of female offspring from females exposed to agnar, confidor, and previcur N was shorter than in control. It was reduced from 21.15 days in control to 13.50, 15.00, and 15.68 days, respectively.

Table 4. Mean (± SEM) developmental time, longevity and total life span (days) of offspring from females of *Phytoseiulus persimilis* treated with sublethal concentrations of three pesticides.

Sex	Control (20)	Treatments		
		agnar (18)	confidor (17)	previcur N (19)
Female				
Egg	1.45 ± 0.11c	2.00 ± 0.11a	1.94 ± 0.16ab	1.63 ± 0.11bc
Larva	1.10 ± 0.07a	1.17 ± 0.09a	1.18 ± 0.10a	1.16 ± 0.09a
Nymph	2.85 ± 0.11c	3.83 ± 0.19a	3.65 ± 0.12ab	3.21 ± 0.20bc
Pre-adult	5.40 ± 0.18c	7.00 ± 0.16a	6.76 ± 0.25a	6.00 ± 0.23b
Adult	28.35 ± 0.98a	22.44 ± 0.81b	22.53 ± 0.68b	22.63 ± 0.59b
Life span	33.75 ± 0.99a	29.50 ± 0.89b	29.29 ± 0.74b	28.63 ± 0.63b
Male	**(10)**	**(7)**	**(8)**	**(9)**
Egg	1.20 ± 0.13c	1.86 ± 0.14a	1.75 ± 0.16ab	1.33 ± 0.16bc
Larva	1.00 ± 0.00a	1.14 ± 0.14a	1.13 ± 0.12a	1.09 ± 0.09a
Nymph	2.70 ± 0.21a	3.00 ± 0.22a	3.00 ± 0.33a	3.00 ± 0.29a
Pre-adult	4.90 ± 0.18b	6.00 ± 0.31a	5.88 ± 0.35a	5.33 ± 0.33ab
Adult	21.70 ± 0.78a	17.29 ± 0.98b	17.25 ± 0.91b	19.67 ± 0.87ab
Life span	26.60 ± 0.85a	23.29 ± 0.93b	23.13 ± 0.89b	25.00 ± 0.97ab

Numbers in parentheses represent the number of replicates.
Means in each row with the same letters are not significantly different (Paired bootstrap test, $P < 0.05$).

Table 5. Mean (± SEM) reproductive period and total fecundity of offspring from females of *Phytoseiulus persimilis* treated with sublethal concentrations of three pesticides.

Stages and Fecundity	Control (20)	Treatments		
		agnar (18)	Confidor (17)	previcur N (19)
APOP	1.45 ± 0.11c	2.11 ± 0.14a	1.82 ± 0.15ab	1.68 ± 0.11bc
TPOP	6.85 ± 0.22c	9.11 ± 0.22a	8.59 ± 0.30a	7.68 ± 0.24b
Oviposition	21.15 ± 0.72a	13.50 ± 0.71c	15.00 ± 0.55bc	15.68 ± 0.53b
Total fecundity	33.45 ± 1.57a	18.22 ± 1.13c	24.47 ± 1.28b	25.95 ± 1.40b

APOP, Adult pre-oviposition period and TPOP total pre-ovipositional period.
Means in each row with the same letters are not significantly different (Paired bootstrap test, $P < 0.05$).

The pesticides showed an adverse effect on daily fecundity. The total fecundity per female was decreased from 33.45 eggs/female in control to 18.22, 24.47, and 25.95 eggs/female by LC_{25} of these pesticides, respectively (Table 5).

Population parameters

The population parameters of offspring from the treated females by LC_{25} of agnar, confidor and previcur N are presented in Table 6. Results showed that exposure of females to agnar and confidor reduced the net reproductive rate (R_0) and intrinsic rate of increase (r) compared to control. Similarly, the finite rate of increase (λ) and gross reproduction rate (GRR) for the control were significantly higher than those of agnar, and confidor. The mean generation time (T) of *P. persimilis* was not significantly affected by agnar and confidor (Table 6).

The pesticides treatment decreased the values of the intrinsic rate of increase (r) which was 0.158, 0.171 and 0.202 day^{-1} with agnar, confidor, and previcur N treatments, respectively as compared to the control (0.216 day^{-1}). The results of this study revealed that the sublethal concentration of agnar and confidor affect the adult longevity, total fecundity and biological parameters of *P. persimilis*.

Table 6. Mean (± SEM) population parameters of offspring from females of *Phytoseiulus persimilis* treated with sublethal concentrations of three pesticides.

Parameters	Control	Treatments		
		agnar	confidor	previcur N
Gross reproductive rate (*GRR*)	24.70 ± 0.50a	14.34 ± 0.34c	17.43 ± 0.42bc	17.99 ± 0.40bc
Net reproductive rate (R_0)	22.27 ± 0.56a	10.93 ± 0.32c	13.87 ± 0.47bc	16.43 ± 0.43abc
Intrinsic rate of increase (*r*)	0.218 ± 0.02a	0.158 ± 0.02c	0.178 ± 0.02bc	0.202 ± 0.02ab
Finite rate of increase (λ)	1.243 ± 0.03a	1.171 ± 0.02c	1.195 ± 0.03bc	1.224 ± 0.03ab
Mean generation time (*T*)	14.25 ± 0.08ab	15.17 ± 0.06a	14.78 ± 0.06a	13.85 ± 0.05b

Means in each row with the same letters are not significantly different (Paired bootstrap test, $P < 0.05$).

Survivorship and fecundity

The age-stage specific survival rate (S_{xj}) of *P. persimilis* represents the probability that newly born individual will survive to each age-stage unit age x and stage j (Fig. 1). The probability of newly emerged larvae to survive until the adult stage was higher in the control (0.67 for females and 0.33 for males) than in agnar, confidor and previcur N treatments (0.60, 0.57 and 0.63 for females and 0.23, 0.27 and 0.30 for males, respectively). The age-specific survivorship (l_x) remained as high as 1.0 until age 23, 4, 3, and 4 days in control, agnar, confidor and previcur N treatments, respectively. The lowest survival rate of all age stages was observed in *P. persimilis* treated with agnar and confidor.

The lowest peaks of m_x and the lowest fecundity were observed in the predatory mites treated with agnar (Fig. 2). The highest values of m_x were observed on the 10th day of the life span, which were 1.23 eggs/female/day in the control, while they were decreased to 1.12 eggs/female/day with agnar treatment. In contrast, it was increased to1.25 and 1.29 eggs/female/day on the 16th and 11th day of the female life span with confidor and previcur N treatments, respectively.

The mean number of offspring produced by *P. persimilis* individuals of the age x and stage j per day (f_{xj}) is shown in Figure 2. The start of oviposition in control, agnar, confidor, and previcur N treatments occurred at the age 6, 8, 6 and 5 days, respectively. The highest daily fecundity of the predatory mite was 1.85, 1.61, 1.76, and 1.89 eggs, respectively, that occurred at the age of 11, 13, 13 and 12 days, respectively.

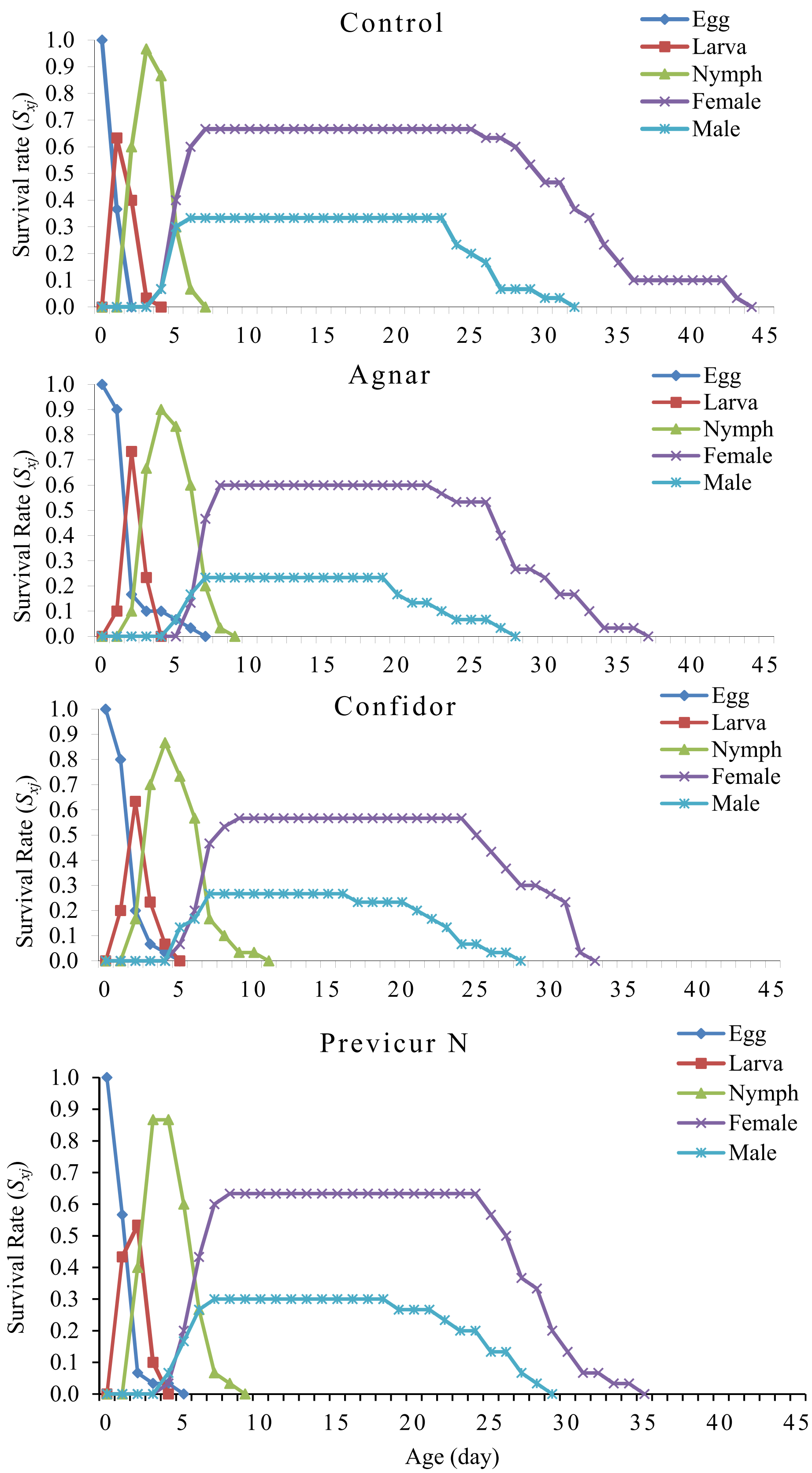

Figure 1. Age-stage specific survival rate (s_{xj}) of offspring from *Phytoseiulus persimilis* females treated with LC_{25} of three pesticides compared with untreated females.

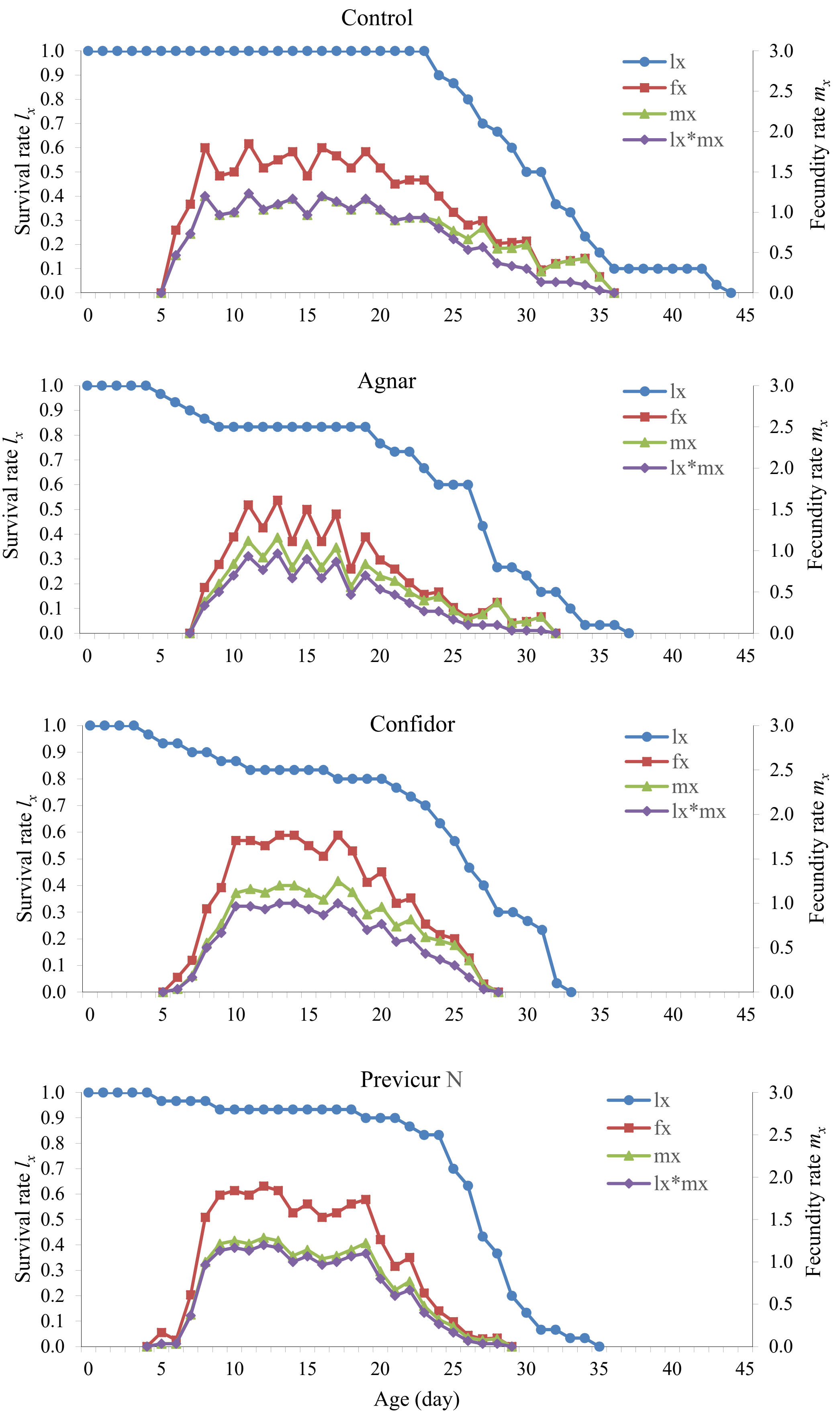

Figure 2. Age specific survival rate (l_x), fecundity (m_x), maternity (l_xm_x) and age-stage specific fecundity (f_{xj}) of offspring from *Phytoseiulus persimilis* females treated with LC25 of three pesticides compared with untreated females.

The highest values of $l_x m_x$ were 1.23, 0.97, 1.00, and 1.20 for control and treated individuals which occurred on day 11, 13, 13 and 12, respectively (Fig. 2).

The age-stage life expectancy (e_{xj}) represents the length of time that an individual of age x and stage j is expected to survive. The age-stage-specific life expectancy for *P. persimilis* in different treatments is shown in Figure 3. Overall, the female's life expectancy of treated individuals was shorter than control.

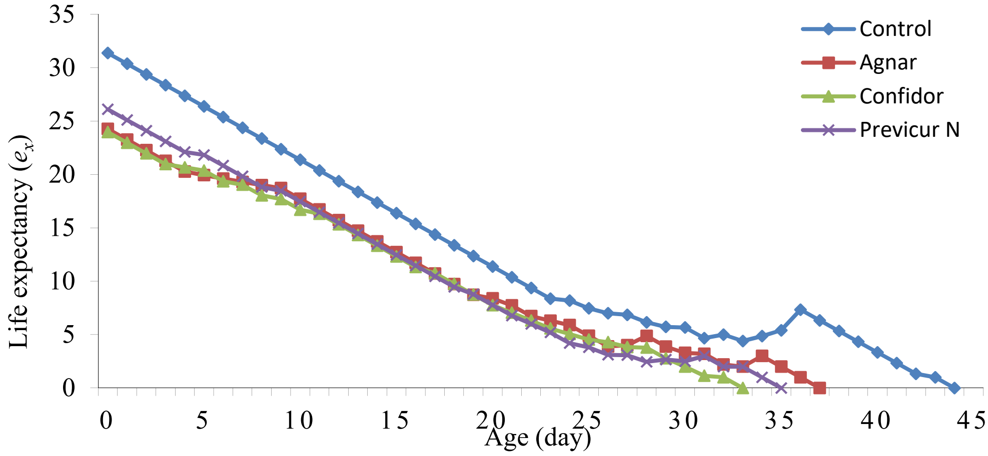

Figure 3. Age-specific life expectancy (e_x) of offspring of *Phytoseiulus persimilis* females treated with sublethal concentration (LC_{25}) of three pesticides compared with control.

The v_{xj} value defines the contribution of an individual at age x and stage j to the future population. The age-specific reproductive values (v_x) of *P. persimilis* in different treatments are plotted in Figure 4. The peak of the reproductive values for *P. persimilis* treated with LC_{25} of pesticides were higher than that for the control. When females emerge, the v_{xj} values increased to 5.55, 6.10, 6.09 at age 9, 10 and 8 days with agnar, confidor, and previcur N, respectively compared to 5.47 at age 8 days with the control.

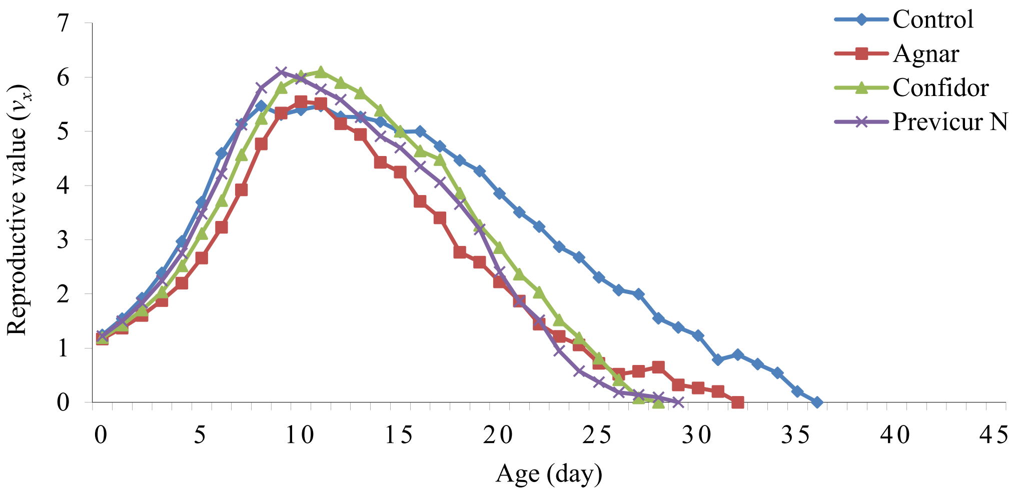

Figure 4. Age-specific reproductive value (v_x) of offspring of *Phytoseiulus persimilis* females treated with sublethal concentration (LC_{25}) of three pesticides compared with control.

DISCUSSION

IPM programs mingle the use of certain pesticide juxtapose to bioagents. So, knowing the side effects of pesticides on natural enemies is essential when taking their use in IPM programs into consideration (Sterk *et al.* 2003; Sohrabi *et al.* 2012). Pesticides must be efficient on pests, but relatively safe to non-target beneficial arthropods, so it is important to know their impacts on these organisms (Campbell *et al.* 1991). Thus, when pesticides are utilized in IPM programs, selectivity is an essential requirement.

In this study, the results show sumi-eight had the highest toxic effect on *P. persimilis*, followed by penazol which was moderately toxic to the predator. On the other hand, previcur N had the lowest toxic effect on this predator when compared to the other chemicals. These outcomes are consistent with those reported by Halloum and Qerhaili (2013) who stated that penconazole is moderately toxic to *Neoseiulus fallacis* (Garman) and *Typhlodromus cotoneastri* Wainstein under laboratory conditions. Also, Pijnakker *et al.* (2015) recommended penconazole as a mite compatible fungicide.

In this study, penny 9% achieved 30.41 and 24.45% reduction on *P. persimilis,* while confidor 20% achieved 18.29 and 11.90 % reduction on the predator in the first and second applications, respectively. Similarly, Tawfik and Elgohary (2015) stated that exposure to emamectin benzoate residues at recommended rates executed 33.33 % of *P. persimilis* at 24 h post-treatment. Also, Kuk and Kim (2018) found that emamectin benzoate is very toxic to adult females of *P. persimilis*. In contrast, indoxacarb was found to be harmless to the females of *P. persimilis* and *N. fallacis* (Bostanian and Akalach 2006). Recently, confidor was found to be low toxic to *N. californicus* females (0–1.0 % mortality) (Glinushkin *et al.* 2019). As for selected acaricides, it was found that biomectin 5% has more adverse impact on the predator than agnar 20%. Likewise, spirodiclofen was slightly toxic to *N. californicus* (Sarbaz *et al.* 2017) and *Amblyseius andersoni* Chant (Raudonis 2006).

In the present study, the results obtained from greenhouse experiments indicated that the influence of agnar, confidor, and previcur N on *P. persimilis* is less than biomectin, penny, sumi-eight, and penazol.

The conclusions of this study confirmed that LC_{25} of selected pesticides could reduce the survival rate, oviposition period, longevity, and fecundity of *P. persimilis* females. Several researchers repeatedly reported that pesticides have sublethal effects on population parameters of phytoseiid mites. The population parameters of *N. longipinosus*, *P. plumifer*, *A. swirski*, *N. californicus* and *P. persimilis* were decreased when exposed to sublethal concentrations of abamectin, fenazaquin, spirodiclofen, spiromesifen, pyridaben, fenpyroximate, and cyflumetofen, respectively reported by Ibrahim and Yee (2000), Hamedi *et al.* (2011), Ghaderi *et al.* (2013), Alinejad *et al.* (2014, 2016), Ghadim-Mollaloo *et al.* (2017a, b), and Abdel-Rahman and Ahmed (2018).

The sublethal concentration (LC_{25}) of the three pesticides decreased the fecundity of *P. persimilis* females; this may be due to the reduction in the oviposition period and female longevity after pesticides treatments. Likewise, the fecundity of *N. californicus* females were significantly decreased by spirodiclofen treatment (Maroufpoor *et al.* 2016; Sarbaz *et al.* 2017). In consistence with our results, the pre-oviposition period has been shown to increase while the oviposition period decreased as a consequence of abamectin treatment (Ibrahim and Yee 2000; Hamedi *et al.* 2011). Also, declining total fecundity of *Neoseiulus womersleyi* (Schicha) when treated with LC_{10}, LC_{30} and LC_{50} of pyridaben was reported by Park *et al.* (2011). The longevity of *P. persimilis* females was considerably decreased by the tested pesticides; a reduction in longevity of *N. californicus* (Maroufpoor *et al.* 2016; Sarbaz *et al.* 2017), *P. plumifer* (Hamedi *et al.* 2011) and *N. longispinosus* female (Ibrahim and Yee 2000) due to pesticide treatments has also been reported.

The present study revealed that there are significant differences in performance of *P. persimilis* when exposed to the sublethal concentration (LC_{25}) of the three pesticides. Tested pesticides had notable effects on the population parameters of the predatory mite (R_0, r, λ, and GRR) ($P < 0.05$). The pesticides agnar and confidor are the most influential for *P. persimilis*, due to the reduction in the intrinsic natural increase (*r*), net reproductive rate (R_0), and fecundity. Also, Argolo *et al.* (2013) observed a decrease in R_0 value of *N. californicus* after imidacloprid treatment. The decrease of *r* value was recorded in *N. californicus* treated with spirodiclofen (Maroufpoor *et al.* 2016; Sarbaz *et al.* 2017). In addition, declining values of R_0, *r* and *λ* of *N. longispinosus*, *P. plumifer*, and *P. persimilis* treated with abamectin and cyflumetofen have been reported (Ibrahim and Yee 2000; Hamedi *et al.* 2011; Abdel-Rahman and Ahmed 2018).

The age-specific survival and fecundity curves demonstrated that sublethal concentrations of agnar, confidor, and previcur N caused reductions in survival and fecundity of offspring of treated females compared to control. This indicates that exposure of females to sublethal concentrations of the tested pesticides affected the survivorship of subsequent generation. The LC_{25} of agnar and confidor had reduced the reproduction and survivorship of offspring of treated females than the control. Because of the variable developmental rates occurring among *P. persimilis* individuals, the survival curve of *P. persimilis* treated by agnar and confidor showed significant stage overlap. This is consistent with those reported by Ghaderi *et al.* (2013) and Alinejad *et al.* (2014).

In the current study, the predators treated with the pesticide had reduced age-specific survival rate (l_x) values (Fig. 2), Also, the age-specific maternity ($l_x m_x$) values were reduced by agnar and confidor. These findings are in concordance with Sarbaz et al. (2017) who indicated that the tested acaricides would significantly reduce mite development. Similarly, age-specific reproductive value and life expectancy were decreased in mites treated by acaricides. The age-stage specific life expectancy (e_{xj}) of a newborn (e_{01}) is the same as the mean longevity (Fig. 3). The age-specific life expectancy of female predators in pesticides treated cohort was shorter than untreated cohort (Fig. 4), and that is compatible with results reported by Sarbaz *et al.* (2017).

CONCLUSION

This study has revealed that the tested pesticides decreased the population numbers of *P. persimilis* under both laboratory and greenhouse conditions. However, the sublethal concentration (LC_{25}) of tested pesticides (agnar, confidor, and previcur N) had notable effects on all biological parameters of *P. persimilis* female. The pesticides, agnar and confidor are the most influential for *P. persimilis*, because of reducing the intrinsic natural increase (*r*), net reproductive rate (R_0), and fecundity. Therefore, these pesticides should not be used in IPM programs where the predatory mite *P. persimilis* is used to control pest species.

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کاربرد تجزیه و تحلیل جمعیتی برای ارزیابی اثرات آفتکش‌ها بر کنه شکارگر، *Phytoseiulus persimilis* (Acari: Phytoseiidae)

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چکیده

دانستن عوارض جانبی آفتکش‌ها روی فیتوزئیدهای مفید غیر هدف برای برنامه‌های مدیریت یکپارچه کنه‌ها (IMM) بسیار مهم است. مطالعه حاضر اثرات کشنده سه قارچ‌کش: پرویکور ان (Propamocarb-Hydrochloride 72.2%)، امولسیون ۱۰٪ پنازول (Penconazol) و سامی– هشت ۵٪ (Diniconazole)؛ دو حشره‌کش: محلول ۲۰٪ کنفیدور (Imidacloprid) و سوسپانسیون ۹٪ پنی (امامکتین بنزوات ۱/۵٪ و ایندوکساکارب ۷/۵٪) و دو کنه‌کش رایج: اگنار (اسپیرودیکلوفن ۱۸٪ + آبامکتین ۲٪) و امولسیون ۵٪ بیومکتین را روی کنهٔ شکارگر، *Phytoseiulus persimilis* Athias-Henriot در هر دو شرایط آزمایشگاهی و گلخانه‌ای بررسی می‌کند. سنجش سمیت و آزمایش‌های گلخانه‌ای نشان داد که اثرات اگنار، کنفیدور و پرویکور ان روی *P. persimilis* کمتر از سایر ترکیبات است. بنابراین، آنها برای ارزیابی تأثیرشان بر پارامترهای جمعیت *P. persimilis* انتخاب شدند. بر اساس تئوری جدول زندگی دو جنسی مرحله‌ای سنی، LC_{25} آفتکش‌های مورد بررسی به طور معنی‌داری طول عمر، طول دورهٔ زندگی و باروری کل ماده *P. persimilis* را کاهش می‌دهد. همچنین، نرخ باروری خالص (R_0) و ناخالص (GRR) را کاهش داد. در نتیجه، میزان ذاتی (r) و متناهی (λ) افزایش تحت تأثیر قرار گرفت. در نتیجه، به دلیل اثرات نامطلوب آنها بر پارامترهای جمعیت این کنهٔ شکارگر، نباید از آفتکش‌های انتخاب شده همراه با *P. persimilis* در برنامه‌های مدیریت تلفیقی آفات استفاده شود.

واژگان کلیدی: مدیریت تلفیقی آفات؛ آماره‌های جدول زندگی؛ آفتکش‌ها؛ اثرات جانبی؛ سمیت.

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