J. Crop Prot. 2021, 10 (2): 295-308

Research Article

Impact of hexythiazox on life table parameters of the *Amblyseius swirskii* (Acari: Phytoseiidae) and its prey *Tetranychus urticae*

Mohammadreza Havasi[1], Niloufar Sangak Sani Bozhgani[2], Gholamreza Golmohmmadi[3] and Katayoon Kheradmand[4*]

1. Department of Plant Protection, Faculty of Agriculture, University of Tehran, Karaj, Iran.
2. Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran.
3. Agricultural Entomology Department, Iranian Research Institute of Plant Protection, AREEO, Tehran, Iran.
4. Department of Entomology and Plant Pathology, College of Aburaihan, University of Tehran, Tehran, Iran.

Abstract: The two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae) is one of the most important and destructive herbivorous mites in farm and greenhouse that has developed high levels of resistance to many acaricides. In this study, we investigated the effect of sublethal concentrations of hexythiazox at LC_{10}, LC_{20}, and LC_{30} on the development and reproduction parameters of *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) and its prey *T. urticae.* The crude data were analyzed based on age-stage, two-sex life table analysis. Hexythiazox (at LC_{20} and LC_{30} levels) reduced the oviposition period (9.68, 8.06 days), total lifespan (22.37, 20.88 days), and total fecundity (50.97, 46.21 eggs/female) compared to the control but did not affect those parameters of *A. swirskii*. The intrinsic rate of increase (r) and finite rate of increase (λ) were not significantly different at tested concentrations, but the net reproductive rate (R_0), gross reproductive rate (GRR), and mean generation time (T) reduced significantly. Our study demonstrated lower toxicity of hexythiazox on *A. swirskii* compared to its prey. It could be concluded that the use of selective acaricides at lower concentrations may be helpful in integrated pest management programs.

Keywords: Two-spotted spider mite, LC_{50}, life table, biological parameters, Phytoseiidae

Introduction

Species belonging to the Phytoseiidae family have good potential for use against tetranychid herbivorous mites, whiteflies, and thrips on various agricultural systems in fields and greenhouse crops (Nomikou *et al.,* 2001; Ghazy *et al.,* 2013; Fathipour and Maleknia, 2016). One of the most effective species is *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) because of its ability to develop and reproduce on a wide range of food sources (Alinejad *et al.,* 2016), including the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), an economically important pest, on which it feeds on eggs and nymphs (El-Laithy and Fouly, 1992; Momen and El-Saway, 1993; Zhang, 2003). *Amblyseius swirskii* could be considered an excellent candidate to regulate two-spotted spider mite population density under a desirable level (Asadi *et al.,* 2019). The control of *T. urticae* is mainly based on the use of acaricides (Wang *et al.,* 2014; Sarbaz *et al.,* 2017; Havasi *et al.,* 2018,

Handling Editor: Yaghoub Fathipour

* Corresponding author: kkheradmand@ut.ac.ir
Received: 03 August 2020, Accepted: 21 February 2021
Published online: 14 March 2021

2019b). However, a high rate of fecundity and a short development time leads to the rapid development of resistance to a wide variety of chemical classes of acaricides (Van Leeuwen *et al.*, 2010; Sangak Sani *et al.,* 2019), thereby causing difficulty in their control (Hoyt *et al.,* 1985). Thus, this mite can develop resistance against applied acaricides, increasing production costs and reducing crop profitability. Several studies have shown that some phytoseiid mites cannot maintain *T. urticae* populations below the economic injury level, especially when pest mite density is high (Ibrahim and Yee, 2000; Alzoubi and Cobanoglu, 2007). Therefore, the combination of using compatible pesticides, along with biological control agents, has been widely recommended as an essential part of integrated pest management (IPM) strategies (Sáenz de Cabezón Irigaray *et al.*, 2007) in agricultural systems. Hexythiazox is a non-systemic acaricide (Saber *et al.,* 2016) of the thiazolidine group (Salman and Ay, 2014) with contact and stomach action. This acaricide is not effective on adults, but the eggs laid by treated females are non-viable (Ganjisaffar and Perring, 2017). This compound is used to control many tetranychid mites, such as genera *Panonychus*, *Tetranychus,* and *Eotetranychus* (Sanatgar *et al.,* 2011; Salman and Ay, 2014; Ganjisaffar and Perring, 2017).

The overall effects of acaricides or pesticides on predatory mites should be evaluated by considering the impact on the biology of both species (Alinejad *et al.,* 2014; Havasi *et al.,* 2019a, 2020a). A sound approach to this problem is to examine the demographic toxicology of the pesticide. Sublethal effects are determined as physiological and behavioral effects on individuals that survive the exposure to a toxic compound (Desneux *et al.*, 2007); on the other hand, the study on the life table parameters provides accurate information relating to growth, survival, reproduction, and mortality (Bozhgani *et al.*, 2019). Although a large body of research has focused on measuring the sublethal effects of different acaricides/pesticides on the life table parameters of phytoseiid and two-spotted spider mites (Marcic, 2007; Park *et al.*, 2011; Ghaderi *et al.*, 2013; Lopez *et al.*, 2015; You *et al.,* 2016; Havasi *et al.*, 2020a), no study has determined the sublethal (LC_{10}, LC_{20}, and LC_{30}) effects of hexythiazox on the demographic parameters of *T. urticae* and its predator *A. swirskii,* based on the age-stage, two-sex life table theory. Research on the toxicological effects of hexythiazox on *T. urticae* and its predator (*A. swirskii*) will enhance the ability to design and execute mite management programs. Our results first demonstrated the lethal and sublethal effects of hexythiazox on *T. urticae* and improved the potential use of hexythiazox for *T. urticae* control for future use.

Materials and Methods

Stock colonies of *T. urticae* and *A. swirskii*

Stock colonies of *Amblyseius swirskii* were provided from rearing in the College of Agriculture and Natural Resources, University of Tehran (Alborz, Iran), and then reared in the laboratory on *Phaseolus vulgaris* L. var. Khomein (Fabaceae). Colonies were kept and fed with *T. urticae.* The two-spotted spider mites were set up from samples collected from infested plants in Pakdasht (South-east of Tehran, Iran) and were released on bean plants under greenhouse conditions of 25 ± 2 °C, 60 ± 5% RH, and 16: 8 (L: D) h. According to McMurtary and Scriven (1965) method, the predator rearing arenas were made and stored in a growth chamber at 25 ± 2 °C and 70 ± 5% RH and a photoperiod of 16:8 (L: D) h. Finally, bean leaves heavily infested with *T. urticae* were added daily to each arena as the food source.

Acaricide tested

A selective miticide, hexythiazox (Nisorun, EC 10%; SUMI AGRO, Turkey), was used in our experiments (Fontes *et al.*, 2018). The recommended field rate for controlling the two-spotted spider mite is 10-24 oz/acre, based on the instruction mentioned in the label (Onager EW Miticide EW MITICID, 2016). The acaricide was diluted with distilled water to achieve the desired concentration.

Concentration–response bioassay

The concentration-response bioassay was carried out based on the leaf-dipping method (Helle and Overmeer, 1985; Ibrahim and Yee, 2000) (the mortality covering the range of 10%–90%). Petri-dishes were prepared based on the Alinejad *et al.* (2014) method. Bean leaf discs (4 cm) were submerged for 15 seconds into hexythiazox solutions. The control leaf discs were treated only with distilled water. The leaf discs were dried at room condition for about 3 hours and placed into Petri dishes (6 × 1.5 cm). Then, twenty same-aged (24-hour-old) adult mites (male and female, 10: 10) were placed on the treated leaf discs for each concentration. The fertilized adult female was placed on a leaf disc and removed after 24 h to obtain the same-age cohorts. The mites that hatched from those eggs completed their juvenile development on the same treated leaf surfaces. The bioassay was replicated four times at five concentrations (4000, 4600, 5400, 6500, and 7700 mg/l for *A. swirskii*; 1000, 1450, 2200, 3300, 5000 mg/l for *T. urticae*) of hexythiazox and control. The mortality of the mites was counted after 24 hours. The mites were considered dead when they did not move after stimulation. All experiments were conducted in the laboratory at 25 ± 2 °C, LD 16:8 h and 60 ± 5% (70 ± 5% for predators) RH.

Life table assay

The number of 45 *A. swirskii* and 100 *T. urticae* females (< 24 h) from the laboratory colony were used to evaluate the sublethal effects of hexythiazox. Bean leaf discs were treated with sublethal concentrations including LC_{10}, LC_{20}, $LC_{30,}$ distilled water (control), and allowed to dry for three hours. Then females were placed on the leaf discs. After 24 h, the surviving females, in each treatment, were separately introduced onto the untreated bean leaf discs (4 cm diameter). After that, the only one laid egg was saved in each experimental arena after 24 h, and the mortality rates were recorded until adults. Then newly-emerged females were coupled with males (males from the stock colony were used when not enough males were available for mating with females) for mating after the adult emergence. All information relating to these males was not included in the life table analysis. Finally, the experimental units were monitored daily. The fecundity of females was recorded daily. Population parameters were calculated in both males and females, and changes were recorded until the last mite's death. Further, in each experimental arena, 15 to 30 immature stages of *T. urticae* were added as a food source of *A. swirskii.* Every 48 h, the old and highly infested leaf discs were replaced with new ones.

Statistical analysis

The dose-response curve was used to estimate LC_{50} LC_{10}, LC_{20}, and LC_{30} for both mites species using the Probit method (SPSS, version 19.0). The original data for all individuals were analyzed according to the theoretical model (Chi, 1988). All parameters, including the age-stage-specific survival rate (s_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), as well as all population growth parameters the intrinsic rate of increase (r), the finite rate of increase (λ), the gross reproductive rate (*GRR*), and the net reproductive rate (R_0) (Fathipour and Maleknia, 2016) were calculated according to the method of Chi and Liu (1985) and Chi (1988) using TWOSEX-MS Chart (Chi, 2019b). The mean and standard errors of the population growth parameters were estimated by the bootstrap technique (Efron and Tibshirani, 1993). Furthermore, the paired bootstrap test (100,000) test using TWO-SEX-MS Chart program was employed for the statistical differences among the means of parameters related to development, fecundity, reproductive periods as well as population growth parameters (Efron and Tibshirani, 1993; Huang and Chi, 2013; Akkopru *et al*., 2015).

Results

Concentration-response bioassay

The results showed that the LC_{50} of *A. swirskii* and *T. urticae* (for both sexes) were 5617 and 2352 mg/l, respectively. No mortality was recorded in control (Table 1).

Development time, adult longevity, and total life span

The sublethal effects of the hexythiazox on developmental time, adult longevity, and total lifespan of *A. swirskii* and *T. urticae* for both sexes are shown in Tables 2 and 3, respectively. The developmental times of *A. swirskii* and its prey were not significantly different among all experimental treatments. The longevity of *T. urticae* significantly decreased in the LC_{30} treatment (varying from 9.74 to 10.56 days for males; 10.29 to 12.98 days for females) in comparison with the control. However, longevity did not change in *A. swirskii* males and females (Table 2). In control, the lifespan (mean number of days from egg to death) of *T. urticae* females was significantly reduced in response to increasing concentrations from LC_{20} to LC_{30}. However, the lifespan of *A. swirskii* in both sexes was not affected.

Table 1 Probit analysis for the concentration-mortality response of hexythiazox on adult stages of *Tetranychus urticae* and *Amblyseius swirskii.*

Species	N[1]	df	LC_{10} (mg/l)	LC_{20} (mg/l)	LC_{30} (mg/l)	LC_{50} (mg/l)	Slope ± SE	*P*-value	x^2
T. urticae	480	4	925.2	1274.6	1605.6	2352.7	3.42 ± 0.32	0.38	6.87
A. swirskii	480	4	3824.7	4364.3	4799.9	5617.6	9.28 ± 0.72	0.48	7.98

[1] 20 individuals per replicate, four replicates per concentration, six concentrations per assay.

Table 2 Effects of sublethal concentrations of hexythiazox on developmental time, longevity, and total life span (day ± SE) of *Amblyseius swirskii.*

Sex	Parameters	Control	LC_{10}	LC_{20}	LC_{30}
Male	Developmental time (day)	6.16 ± 0.33a	6.08 ± 0.26a	6.21 ± 0.38 a	6.15 ± 0.30a
	Longevity (day)	21.55 ± 0.28a	21.60 ± 0.24a	21.54 ± 0.31a	21.62 ± 0.21a
	Total life span (day)	27.73 ± 0.34a	27.69 ± 0.29a	27.74 ± 0.36a	27.77 ± 0.34a
Female	Developmental time (day)	5.91 ± 0.21a	5.87 ± 0.19a	5.85 ± 0.18a	5.87 ± 0.20a
	Longevity (day)	23.26 ± 0.22a	23.17 ± 0.24a	23.23 ± 0.21a	23.21 ± 0.17a
	Total life span (day)	29.15 ± 0.32a	29.03 ± 0.32a	29.01 ± 0.25a	29.07 ± 0.23a

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by similar letters in the same row are not significantly different using the paired bootstrap test at 5% significance level.

Table 3 Effects of sublethal concentrations of hexythiazox on developmental time, longevity, and total life span (day ± SE) of *Tetranychus urticae.*

Sex	Parameters	Control	LC_{10}	LC_{20}	LC_{30}
Male	Developmental time (day)	10.52 ± 0.11a	10.49 ± 0.11a	10.47 ± 0.12 a	10.43 ± 0.10a
	Longevity (day)	10.56 ± 0.18a	10.62 ± 0.41a	10.09 ± 0.35a	9.74 ± 0.44b
	Total life span (day)	21.04 ± 0.25a	21.06 ± 0.45a	20.59 ± 0.41a	20.11 ± 0.49b
Female	Developmental time (day)	10.69 ± 0.08a	10.72 ± 0.07a	10.57 ± 0.06a	10.55 ± 0.04a
	Longevity (day)	12.98 ± 0.07a	12.95 ± 0.09a	11.91 ± 0.11b	10.29 ± 0.13c
	Total life span (day)	23.69 ± 0.08a	23.67 ± 0.11a	22.37 ± 0.12b	20.88 ± 0.12c

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level.

Reproductive Periods

The highest fecundity of *A. swirskii*: 14.16; *T. urticae*: 61.19 eggs/female was observed in control (Tables 4 and 5). Conversely, higher concentration (LC_{30}) resulted in the lowest fecundity. The females treated with LC_{20} and LC_{30} had no significant difference on adult and total pre-oviposition periods (APOP: the duration from female emergence to first oviposition; TPOP: time from egg to first oviposition) compared to the control. The maximal oviposition period of *T. urticae* was observed in control, reach a maximum of 10.89 days. This parameter significantly decreased in response to increasing concentrations from LC_{20} to LC_{30} (ranging from 10.89 to 8.06 days), but no significant effect was observed on the oviposition period of *A. swirskii*. The mean number of eggs per *A. swirskii* female was not affected by sublethal concentrations, while it showed a declining trend for *T. urticae* exposed to LC_{20} and LC_{30} (Table 5).

Population growth parameters

The *GRR* and R_0 parameters of *A. swirskii* were significantly reduced by all treatments of hexythiazox (Table 6). However, *r* and *λ* and *T* parameters were essentially the same. *GRR,* and R_0 of *T. urticae* at LC_{20} and LC_{30} were also significantly reduced (Table 7). Similarly, *r* and *λ* were not affected by any concentration of hexythiazox, but *T* declined in both higher treatments (LC_{20} and LC_{30}). In *A. swirskii,* likewise, *T. urticae*, the shortest *T* was obtained for LC_{30} treatment (Tables 6, 7).

Table 4 Mean (± SE) reproductive period and total fecundity of *Amblyseius swirskii* for control and sublethal concentrations of hexythiazox.

Parameters	Control	LC_{10}	LC_{20}	LC_{30}
Oviposition period (day)	14.07 ± 0.34 a	14.03 ± 0.29 a	14.00. ± 0.34a	14.03 ± 0.34 a
APOP (day) [1]	3.15 ± 0.12a	3.13 ± 0.09a	3.11 ± 0.12a	3.03 ± 0.14a
TPOP (day) [2]	9.03 ± 0.23a	9.00 ± 0.21a	8.96 ± 0.19a	8.95 ± 0.28a
Total fecundity (eggs/female)	14.16 ± 0.35a	14.08 ± 0.28a	14.03 ± 0.39a	14.11 ± 0.36a

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the each row are significantly different using the paired bootstrap test at 5% significance level.[1] APOP = adult pre-oviposition period (the duration from adult emergence to the first oviposition); [2], TPOP= total pre-oviposition period (the duration from egg to the first oviposition).

Table 5 Mean (± SE) reproductive period and total fecundity of *Tetranychus urticae* for control and sublethal concentrations of hexythiazox**.**

Parameters	Control	LC_{10}	LC_{20}	LC_{30}
Oviposition period (day)	10.89 ± 0.08a	10.41 ± 0.09a	9.68. ± 0.11b	8.06 ± 0.13c
APOP (day)[1]	1.09 ± 0.05a	1.11 ± 0.05a	1.12 ± 0.02a	1.12 ± 0.03a
TPOP (day)[2]	11.66 ± 0.09a	11.71 ± 0.10a	11.57 ± 0.09a	11.55 ± 0.08a
Total fecundity (eggs/female)	61.19 ± 0.27a	58.69 ± 0.29a	50.97 ± 0.29b	46.21 ± 0.39c

The standard errors were calculated using the bootstrap procedure with 100,000 samples. The means followed by different letters in the each row are significantly different using the paired bootstrap test at 5% significance level.[1] APOP = adult pre-oviposition period (the duration from adult emergence to the first oviposition); [2], TPOP= total pre-oviposition period (the duration from egg to the first oviposition).

Table 6 The effect of sublethal concentrations of hexythiazox on the life table parameters (Mean ± SE) of *Amblyseius swirskii*.

Population growth parameters	Control	LC_{10}	LC_{20}	LC_{30}	Unit
Gross reproduction rate (*GRR*)	10.89 ± 0.95a	9.96 ± 1.01b	9.99 ± 1.02b	9.97 ± 1.02b	Eggs/female
Net reproductive rate (R_0)	9.62 ± 0.96a	8.51 ± 0.98b	8.55 ± 0.99b	8.48 ± 0.99b	Eggs/female
Intrinsic rate of increase (*r*)	0.1413 ± 0.007a	0.1303 ± 0.008a	0.1323 ± 0.008a	0.1339 ± 0.007a	Day^{-1}
Finite rate of increase (*λ*)	1.151 ± 0.008a	1.139 ± 0.009a	1.141 ± 0.004a	1.143 ± 0.008a	Day^{-1}
Mean generation time (*T*)	16.01 ± 0.29a	16.39 ± 0.28a	16.11 ± 0.24a	15.98 ± 0.30ab	Day

Means within each row followed by the same letters are not significantly different. The SE was estimated by using 100,000× bootstraps and compared by using the paired bootstrap test at 5% level

Table 7 The effect of sublethal concentrations of hexythiazox on the life table parameters (Mean ± SE) of *Tetranychus urticae*.

Population growth parameters	Control	LC_{10}	LC_{20}	LC_{30}	Unit
Gross reproduction rate (*GRR*)	55.08 ± 2.09a	54.78 ± 2.01a	45.89 ± 1.64b	42.39 ± 1.62b	Eggs/female
Net reproductive rate (R_0)	49.32 ± 2.44a	49.11 ± 2.45a	41.92 ± 2.07b	36.69 ± 1.86c	Eggs/female
Intrinsic rate of increase (*r*)	0.2391 ± 0.004a	0.2342 ± 0.003a	0.2288 ± 0.003a	0.2212 ± 0.003a	Day^{-1}
Finite rate of increase (λ)	1.265 ± 0.005a	1.260 ± 0.005a	1.245 ± 0.004a	1.236 ± 0.004a	Day^{-1}
Mean generation time (*T*)	16.59 ± 0.07a	16.54 ± 0.09a	16.03 ± 0.09b	15.58 ± 0.07c	Day

Means within a row followed by the same letters are not significantly different. The SE was estimated by using 100,000 × bootstraps and compared by using the paired bootstrap test at 5% significance level

Survival and fecundity curves

The total lifetime of decreased from 26 days in the control and LC_{10} treatment to 25 and 24 days in the LC_{20} and LC_{30}, respectively (Fig. 1). For *A. swirskii*, the maximal value of the total lifetime for the control was 33 days, while it was 32, 31, and 32 days for the cohort treated with LC_{10}, $LC_{20,}$ and LC_{30}, respectively (Fig. 2). The results of l_x curves indicated decreased *T. urticae* and *A. swirskii* treated with experimental doses. The m_x for *T. urticae* was estimated to be 5.13, 4.82, and 4.86 eggs/female/day for the mites treated with LC_{10}, $LC_{20,}$ and LC_{30} of hexythiazox, respectively, which appeared on days 17, 16, and 15 during the life span, respectively (Fig. 3). Also, the value of m_x on *A. swirskii* were 0.68, 0.62, 0.63, and 0.65 eggs/individual/day for the mites treated with the control, LC_{10}, $LC_{20,}$ and LC_{30} observed on days 13, 18, 17, and 15 of *A. swirskii* lifespan, respectively (Fig. 4).

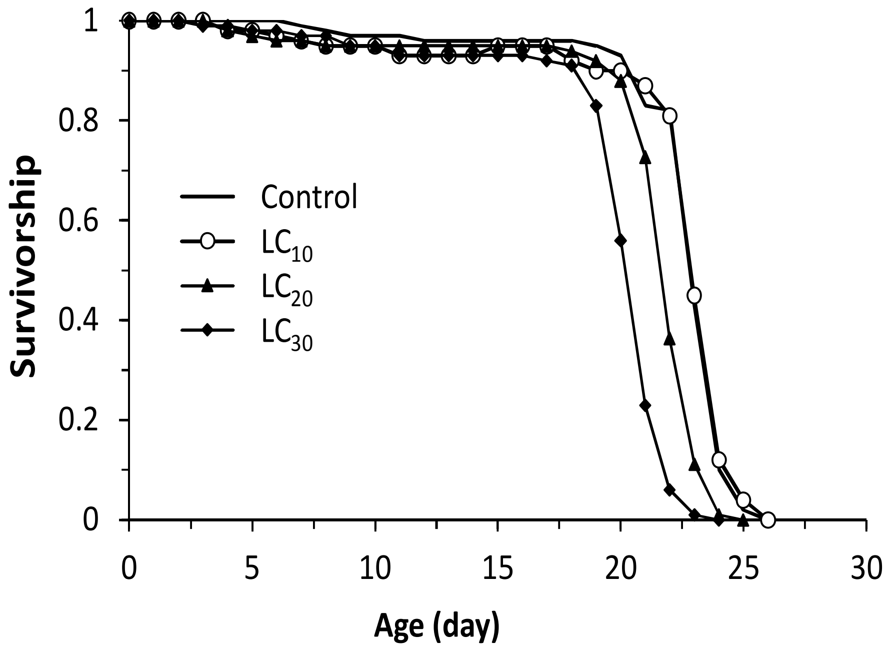

Figure 1 Age-specific survivorship (l_x) of *Tetranychus urticae* at sublethal concentrations of hexythiazox.

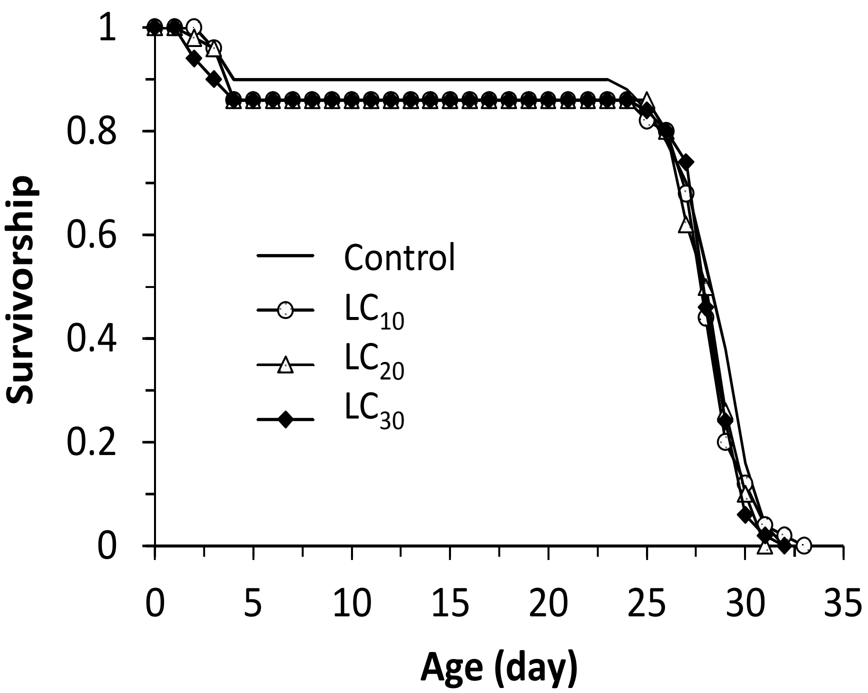

Figure 2 Age-specific survivorship (l_x) of *Amblyseius swirskii* at sublethal concentrations of hexythiazox.

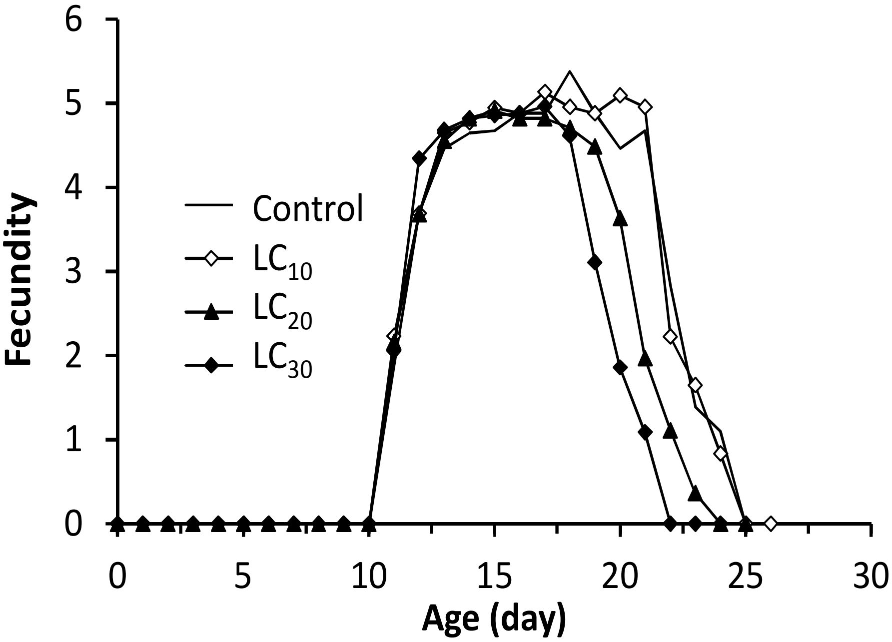

Figure 3 Age-specific fecundity (m_x) of *Tetranychus urticae* at sublethal concentrations of hexythiazox.

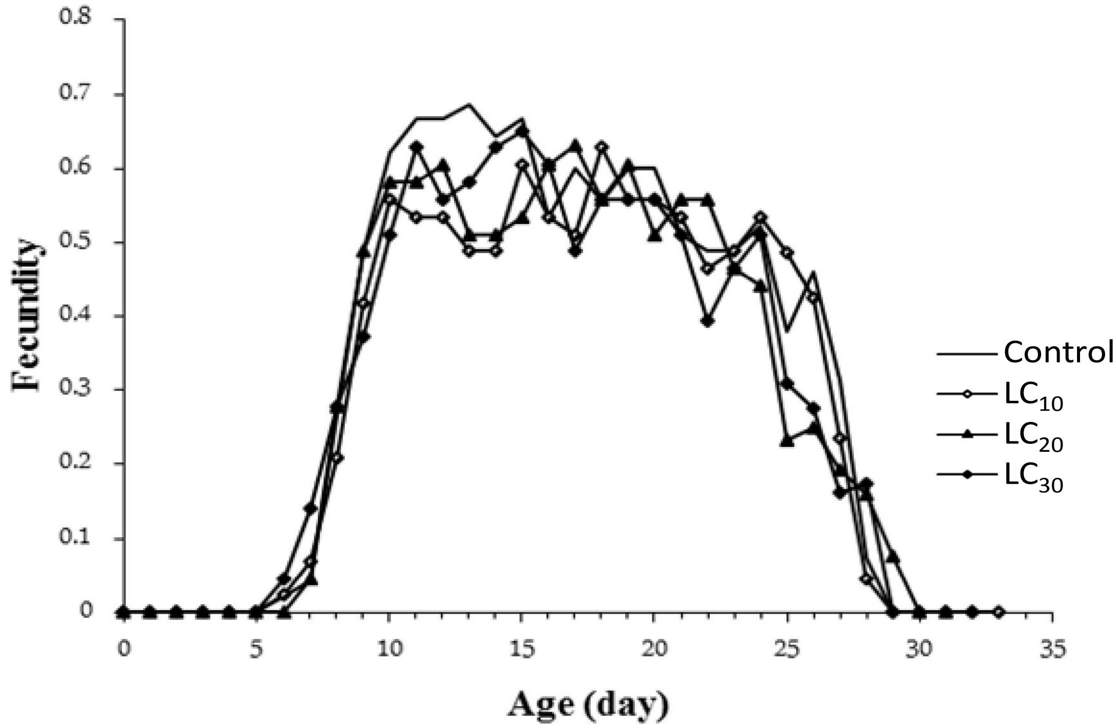

Figure 4 Age-specific fecundity (m_x) of *Amblyseius swirskii* at sublethal concentrations of hexythiazox.

Discussion

The increase of resistance to pesticides in phytoseiid mites is known to be associated with variations in biological characteristics (Salman and Ay, 2014). On the other hand, finding efficient biological control agents is the first step in developing biological control programs (Fathipour *et al*., 2020). In the current study, we investigated the efficacy of *A. swirskii* as a predator of *T. urticae* LC_{10}, $LC_{20,}$ and LC_{30} of hexythiazox using life table parameters as our measurements of survivorship quality. We found that hexythiazox had no significant effect on the development time of *T. urticae* and *A. swirskii*. The findings are in agreement with Alinejad *et al*. (2016) and Sanatgar *et al.* (2011), reporting that the development time of *A. swirskii* and *Phytoseiulus persimilis* (Athias–Henriot) did not influence by sublethal concentrations of spirodiclofen and hexythiazox, respectively. Hamedi *et al*. (2010), Alinejad *et al*. (2014), and Li *et al*. (2017) showed that the development time of *Phytoseius plumifer* (Canestrini and Fanzago), *A. swirskii,* and *T. urticae* was decreased as concentrations of fenpyroximate, fenazaquin, and bifenazate increased. In the current study, hexythiazox affects adult longevity and a total lifetime in both sexes of *T. urticae* but not on *A. swirskii*. Saber *et al*. (2018), Sangak Sani *et al*. (2019), Havasi *et al*. (2018), and Bozhgani *et al*. (2018a) reported that the longevity and total lifespan of *T. urticae* significantly decreased when the cohort was exposed to the sublethal concentrations of abamectin, spirodiclofen, diflovidazin, and chlorfenapyr. In other studies, Sarbaz *et al*. (2017), Bozhgani *et al*. (2018b), and Havasi *et al*. (2019a) found that longevity and total lifespan of *N. californicus* are decreased when treated by spiromesifen, spirotetramat, and thiamethoxam.

The adverse effects of sublethal treatments of hexythiazox on ovipositional period and total fecundity of *A. swirskii* were confirmed by Havasi *et al*. (2020b), who found a similar trend for the total fecundity of *N. californicus* exposed to Biomite®. In contrast, Ghasemzadeh and Qureshi (2018) and Shahbaz *et al.* (2019) demonstrated an adverse effect of acetamiprid on *A. swirskii* and *Amblyseius cucumeris* Oudemans. This difference might be due to the susceptibility of the phytoseiid species or the formulation type. Acetamiprid is widely used as second-generation chloro-neonicotinoids with systemic activity (Devan *et al*., 2015). Examination of three sublethal concentrations tested in the current study showed that the shortest oviposition period of *T. urticae* was strongly affected as concentration increased from LC_{20} to LC_{30}. We found the lowest fecundity of *A. swirskii* on higher LC_{30}. Many studies have demonstrated the adverse effect of various pesticides on fecundity and oviposition period of phytoseiid predators (e.g., Li *et al*., 2017; Havasi *et al*., 2018; Bozhgani *et al*., 2018b, 2019; Leviticus *et al*., 2019).

Life table response experiments at the population level are considered a better measure of response to pesticides than individual life history characteristics (Stark and Banks, 2003); this approach discusses lethal and sublethal effects and their mixture (Stark *et al*. 1998; Stark and Banks, 2000). The *r*-values integrate the impact of mortality and fecundity into a single value, so it is greatly affected by the wide range of variables consisting of survival, developmental time, longevity, fecundity schedule, and sex ratio, which are affected by climatic and nutritional conditions (Khederi and Khanjani, 2014). The *r*-value and finite rate of increase did not differ for either species.

In the present study, *r* value varied from 0.1413 to 0.1339 and 0.2391 to 0.2213 day^{-1} for predatory mite and *T. urticae,* respectively. Variable growth rates of *A. swirskii* in response to fenazaquin (0.130 to 0.060 day^{-1}; Alinejad *et al.,* 2014), fenpyroximate (0.13 to 0.06 day^{-1}; Ghasemzadeh and Qureshi, 2018), spirodiclofen on *N. californicus* (0.237 to 0.153 day^{-1}; Maroufpoor *et al.,* 2016); spirodiclofen on *P. persimilis* (0.24 to 0.26 day^{-1}; Salman and Keskin, 2019) have been reported. However, Sanatgar *et al*. (2011), Maroufpoor *et al*. (2016), and Leviticus *et al*. (2019) reported that hexythiazox, spirodiclofen, and fluralaner a significant reduction in *r* and *λ* parameters on *P. persimilis*, *N. californicus*, and *T. urticae*. In the present study, R_0, *GRR*, and *T* of *T. urticae* and *A. swirskii* populations changed when exposed to LC_{20} and LC_{30}. Our findings are consistent with Ghasemzadeh and Qureshi (2018) and Sanatgar *et al*. (2011), showing that the parameters above significantly declined by dose dependence of thiacloprid and hexythiazox on *A. swirskii* and *P. persimilis*. Due to l_x and m_x curves, hexythiazox at tested concentrations reduces these parameters in *A. swirskii* and its prey *T. urticae*. Furthermore, all tested concentrations demonstrated that the chances of reaching adulthood were decreased as concentration increased. In the present study, the highest mortality rate occurred at the LC_{20}, and the l_x of *A. swirskii* decreased from 33 days in control to 31 days in treatment. Li *et al*. (2017) and Havasi *et al*. (2018) proposed a similar trend for the curves of l_x and m_x of *T. urticae* treated with diflovidazin bifenazate, which is consistent with the findings of the present study. In another study, Shahbaz *et al*. (2019) noted that both l_x and m_x showed a declining trend for *A. swirskii* treated with acetamiprid. Sanatgar *et al*. (2011) found that hexythiazox had little effect on the survival of immature stages of treated *P. persimilis,* and the most influence was reported on adult mites.

Improvement of IPM programs requires understanding how pesticides affect the pests' natural enemies (Havasi *et al*., 2020a). Universally, a single chemical control system against pests cannot be successful (Kaplan *et al.,* 2012). Remarkably, exposure to LC_{20} and LC_{30} resulted in a detrimental effect on *T. urticae* population increase (i.e., R_0, *T* and *GRR*, and fecundity). Findings indicated that hexythiazox does not have adverse effects on the *r* and *λ* parameters of *A. swirskii* at sublethal concentration.

In conclusion, it seems that pesticides can be considered as an economic, labor-saving, and effective tool of pest management (Damalas and Eleftherohorinos, 2011). Still, IPM programs are complex and variable, and there is more work to be conducted to understand these control strategies (Ullah, 2017). From this study, it could be concluded that hexythiazox could reduce life table parameters of *T. urticae* more than its predator, *A. swirskii*. Finally, the hexythiazox demonstrated minor harm to *A. swirskii* by its lower toxicity than its prey *T. urticae*.

Acknowledgments

The University of Tehran financially supported this study.

References

Akköprü, E. P., Atlıhan, R., Okut, H. and Chi, H. 2015. Demographic assessment of plant cultivar resistance to insect pests: a case study of the dusky-veined walnut aphid (Hemiptera: Callaphididae) on five walnut cultivars. Journal of Economic Entomology, 108: 378-387.

Alinejad, M., Kheradmand, K. and Fathipour, Y. 2014. Sublethal effects of fenazaquin on life table parameters of the predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae). Experimental and Applied Acarology, 64(3): 361-373.

Alinejad, M., Kheradmand, K. and Fathipour, Y. 2016. Assessment of sublethal effects of spirodiclofen on biological performance of the predatory mite, *Amblyseius swirskii*. Systematic and Applied Acarology, 21(3): 375-385.

Alzoubi, S. and Cobanoglu, S. 2007. Effects of sublethal dose of different pesticides on the two-spotted spider mite '*Tetranychus urticae* Koch' and its predatory mites under greenhouse conditions. World Journal of Agriculture Science, 3(6): 764-770.

Asadi, P., Sedaratian-Jahromi, A., Ghane-Jahromi, M. and Haghani, M. 2019. How Spiromesifen affects some biological parameters and switching behavior of predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae) when feeding on different ratios of mixed preys. Persian Journal of Acarology, 8(3).

Bozhgani, N. S. S., Ghobadi, H. and Riahi E. 2018a. Sublethal effects of chlorfenapyr on the life table parameters of two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Systematic and Applied Acarology, 23(7): 1342-52.

Bozhgani, N. S. S., Kheradmand, K. and Talebi, A A. 2018b. The effects of spirotetramat on the demographic parameters of *Neoseiulus californicus* (Phytoseiidae). Systematic and Applied Acarology, 23(10): 1952-1964.

Bozhgani, N. S. S., Kheradmand, K. and Talebi, A A. 2019. The effects of Spiromesifen on life history traits and demographic parameters of predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae) and its prey *Tetranychus urticae* Koch (Acari: Tetranychidae). Systematic and Applied Acarology, 24(8): 1512-1525.

Chi, H. 1988. Life table analysis incorporating both sexes and variable development rates among individuals. Environmental Entomology, 17(1): 26-34.

Chi, H. 2019. TWOSEX-MSChart: a computer program for the age-stage, two-sex life table analysis. URL. Available from http://140.120.197.173/ecology/prod02.htm.

Chi, H. and Liu, H. 1985. Two new methods for the study of insect population ecology. Bulletin of the Institute of Zoology Academia Sinica, 24(2): 225-240.

Damalas, C. A. and Eleftherohorinos, I. G. 2011. Pesticide exposure, safety issues, and risk assessment indicators. International Journal of Environmental Research and Public Health, 8 (5): 1402-1419.

Desneux, N., Decourtye, A. and Delpuech, J. M. 2007. The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology, 52:81-106.

Devan, R. K. S., Mishra, A., Prabu, P. C., Mandal, T. K. and Panchapakesan, S. 2015. Sub-chronic oral toxicity of acetamiprid in

Wistar rats. Toxicology Environmental Chemical 97: 1236-1252.

Efron, B. and Tibshirani R. J. 1993. Permutation tests. In *An introduction to the bootstrap* (pp. 202-219). Springer US.

El-Laithy, A. Y. M. and Fouly, A. H. 1992. Life table parameters of the two phytoseiid predators *Amblyseius scutalis* A. H. and *Amblyseius swirskii* A. H. Acari: Phytoseiidae in Egypt. Journal of Applied Entomology 113: 8-12.

Fathipour, Y. and Maleknia, B. 2016. Mite Predators. In: Omkar (ed.) Ecofriendly Pest Management for Food Security San Diego, USA, Elsevier: 329-366.

Fathipour, Y., Maleknia, B., Bagheri, A., Soufbaf, M. and Reddy, G. V. 2020. Functional and numerical responses, mutual interference, and resource switching of *Amblyseius swirskii* on two-spotted spider mite. Biological Control, 146: 104266.

Fontes, J., Roja, I. S., Tavares, J. and Oliveira, L. 2018. Lethal and sublethal effects of various pesticides on *Trichogramma achaeae* (Hymenoptera: Trichogrammatidae). Journal of Economic Entomology, 111(3): 1219-1226.

Ganjisaffar, F. and Perring, T. M. 2017. Effects of the miticide hexythiazox on biology of *Galendromus flumenis* (Acari: Phytoseiidae). International Journal of Acarology 43(2): 169-172.

Ghaderi, S., Minaei, K., Kavousi, A., Akrami, M. A., Aleosfoor, M. and Ghadamyari, M. 2013. Demographic analysis of the effect of Fenpyroximate on *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae). Entomologia Generalis 34(3): 225-233

Ghasemzadeh, S. and Qureshi, J. A. 2018. Demographic analysis of fenpyroximate and thiacloprid exposed predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae). PloS One, 13(11).

Ghazy, N., Suzuki, T., Amano, H. and Ohyama, K. 2013. Humidity-controlled cold storage of *Neoseiulus californicus* (Acari: Phytoseiidae): Effects on male survival and reproductive ability. Journal of Applied Entomology, 137(5): 376-382.

Hamedi, N., Fathipour, Y. and Saber, M. 2010. Sublethal effects of fenpyroximate on life table parameters of the predatory mite *Phytoseius plumifer*. BioControl, 55(2): 271-278.

Havasi, M., Kheradmand, K., Mosallanejad, H. and Fathipour, Y. 2018. Sublethal effects of diflovidazin on life table parameters of two-spotted spider mite *Tetranychus urticae* (Acari: Tetranychidae). International Journal of Acarology, 44(2-3): 115-120.

Havasi, M., Kheradmand, K., Mosallanejad, H. and Fathipour, Y. 2019a. Sublethal effects of diflovidazin on demographic parameters of the predatory mite, *Neoseiulus californicus* (Acari: Phytoseiidae). International Journal of Acarology, 1-7.

Havasi, M., Kheradmand, K., Mosallanejad, H. and Fathipour, Y. 2020a. Influence of low-lethal concentrations of thiamethoxam on biological characteristics of *Neoseiulus californicus* (Acari: Phytoseiidae). Journal of Crop Protection 9: 41-55.

Havasi, M., Kheradmand, K., Mosallanejad, H. and Fathipour, Y. 2020b. Life history traits and demographic parameters of *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) treated with the Biomite®. Systematic and Applied Acarology, 25(1): 125-138.

Havasi, M., Kheradmand, K., Parsa, M. and Riahi, E. 2019b. Acaricidal activity of *Punica granatum* L. peels extract against *Tetranychus urticae* Koch (Acari: Tetranychidae). Archives of Phytopathology and Plant Protection, 1-14.

Helle, W. and Overmeer, W. P. J. 1985. Toxicological test methods. In: Helle, W, Sabelis MW (eds) Spider mites: their biology, natural enemies and control, vol 1A. Elsevier, Amsterdam, 391-395.

Hoyt, S. C., Westigard, P. H. and Croft, B. A. 1985. Cyhexatin resistance in oregon populations of *Tetranychus urticae* Koch (Acarina: Tetranychidae). Journal of Economic Entomology, 78: 656-659.

Huang, Y. B. and Chi, H. 2013. Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. Journal of Applied Entomology, 137(5): 327-339.

IBM SPSS. 2010. IBM SPSS Statistics for Windows, Version 19.

Ibrahim, Y. B. and Yee, T. S. 2000. Influence of sublethal exposure to abamectin on the biological performance of *Neoseiulus longispinosus* (Acari: Phytoseiidae). Journal of Economic Entomology, 93(4): 1085-1089.

Kaplan, P., Yorulmaz, S. and Ay, R. 2012. Toxicity of insecticides and acaricides to the predatory mite *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae). International Journal of Acarology, 38(8): 699-705.

Khederi, S J. and Khanjani, M. 2014. Modeling demographic response to constant temperature in *Bryobia rubrioculus* (Acari: Tetranychidae). Ecologica Montenegrina, 1(1): 18-29.

Leviticus, K., Cui, L., Ling, H., Jia, Z. Q., Huang, Q. T., Han, Z. J. and Xu, L. 2019. Lethal and sublethal effects of fluralaner on the two-spotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae). Pest Management Science, 76(3): 888-893.

Li, Y. Y., Fan, X., Zhang, G. H., Liu, Y. Q., Chen, H. Q. and Liu, Wang, J. J. 2017. Sublethal effects of bifenazate on life history and population parameters of *Tetranychus urticae* (Acari: Tetranychidae). Systematic and Applied Acarology, 22(1): 148-159.

Lopez, L., Smith, H. A., Hoy, M. A. and Bloomquist, J. R. 2015. Acute toxicity and sublethal effects of fenpyroximate to *Amblyseius swirskii* (Acari: Phytoseiidae). Journal of Economic Entomology, 108(3): 1047-1053.

Marcic, D. 2007. Sublethal effects of spirodiclofen on life history and lifetable parameters of two-spotted spider mite (*Tetranychus urticae*). Experimental and Applied Acarology, 42(2): 121-129.

Maroufpoor, M., Ghoosta, Y., Pourmirza, A. A. and Lotfalizadeh, H. 2016. The effects of selected acaricides on life table parameters of the predatory mite, *Neoseiulus californicus* fed on European red mite. North-Western Journal of Zoology, 12(1): 1-6.

McMurtry, J. A. and Servien, G. T. 1965. Insectary production of phytoseiid mites. Journal of Economic Entomology, 58: 282-286.

Momen, F. M. and Elsaway, S. A. 1993. Biology and feeding behavior of the predatory mite, *Amblyseius swirskii* (Acari, Phytoseiidae). Acarologia, 34(3): 199-204.

Nomikou, M., Janssen, A., Schraag, R. and Sabelis, M. W. 2001. Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. Experimental and Applied Acarology, 25(4): 271-291.

Park, H. H., Shipp, L., Buitenhuis, R. and Ahn, J. J. 2011. Life history parameters of a commercially available *Amblyseius swirskii* (Acari: Phytoseiidae) fed on cattail (*Typha latifolia*) pollen and tomato russet mite (*Aculops lycopersici*). Journal of Asia-Pacific Entomology, 14(4): 497-501.

Saber, A. N., Malhat, F. M., Badawy, H. M. and Barakat, D. A. 2016. Dissipation dynamic, residue distribution and processing factor of hexythiazox in strawberry fruits under open field condition. Food chemistry 196: 1108-1116.

Saber, M., Ahmadi, Z. and Mahdavinia, G. 2018. Sublethal effects of spirodiclofen, abamectin and pyridaben on life-history traits and lifetable parameters of two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Experimental and Applied Acarology, 75(1): 55-67.

Sáenz de Cabezón Irigaray, F. J., Zalom, F. G. and Thompson, P. B. 2007. Residual toxicity of acaricides to *Galendromus occidentalis* and *Phytoseiulus persimilis* reproductive potential. Biological Control, 40(2): 153-159.

Salman, S. Y. and Ay, R. 2014. Effect of hexythiazox and spiromesifen resistance on the life cycle of the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae). Experimental and Applied Acarology, 64(2): 245-252.

Salman, S.. Y. and Keskin, C. 2019. The effects of milbemectin and spirodiclofen resistance on *Phytoseiulus persimilis* AH (Acari:

Phytoseiidae) life table parameters. Crop Protection, 124: 104751.

Sanatgar, E., Shoushtari, R. V., Zamani, A. A. and Nejadian, E. S. 2011. Effect of frequent application of hexythiazox on predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae). Academic Journal of Entomology, 4(3): 94-101.

Sangak Sani, N., Kheradmand, K. and Talebi, A. A. 2019. Sublethal effects of spirodiclofen on the demographic parameters of *Tetranychus urticae* Koch (Acari: Tetranychidae). Archives of Phytopathology and Plant Protection, 52(9-10): 938-952.

Sarbaz, S., Goldasteh, S., Zamani, A. A., Solymannejadiyan, E. and Vafaei Shoushtari, R. 2017. Side effects of spiromesifen and spirodiclofen on life table parameters of the predatory mite, *Neosiseulus californicus* McGregor (Acari; Phytoseiidae). International Journal of Acarology, 43(5): 380-38.

Shahbaz, M., Khoobdel, M., Khanjani, M., Hosseininia, A. and Khederi, S. J. 2019. Sublethal effects of acetamiprid on biological aspects and life table of *Amblyseius swirskii* (Acari: Phytoseiidae) fed on *Aleuroclava jasmini* (Hemiptera: Aleyrodidae). Systematic and Applied Acarology, 24(5): 814-824.

Stark, J. D. and Banks, J. E. 2003. Population-level effects of pesticides and other toxicants on arthropods. Annual Review of Entomology, 48: 505-519.

Stark, J. D. and Banks, J. E. 2000. The toxicologists' and ecologists' point of view unification through a demographic approach. In: Kammenga, J. and Laskowski, R. (Eds.), Demography in Ecotoxicology. New York, John Wiley and Sons, pp. 9-23.

Stark, J. D., Banken, J. O. and Walthal, W. K. 1998. The importanceof population perspective for the evaluation of side effects of pesticides on beneficial species. In: Haskell, P. T. and McEwen, P. (Eds.), Ecotoxicology: pesticides and beneficial organisms. Dordrecht, The Netherlands, Kluwer Academic Publishers, 348-359.

Ullah, M. S. and Lim, U. T. 2017. Synergism of *Beauveria bassiana* and *Phytoseiulus persimilis* in control of *Tetranychus urticaeon* bean plants. Systematic and Applied Acarology, 22 (11): 1924-1935.

Van Leeuwen, T., Vontas, J., Tsagkarakou, A., Dermauw, W. and Tirry, L. 2010. Acaricide resistance mechanisms in the two-spotted spider mite *Tetranychus urticae* and other important Acari: a review. Insect Biochemistry and Molecular Biology, 40 (8): 563-572.

Wang, S., Tang, X., Wang, L., Zhang, Y., Wu, Q. and Xie, W. 2014. Effects of sublethal concentrations of bifenthrin on the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae). Systematic and Applied Acarology, 19: 481-490.

You, Y., Lin, T., Wei, H., Zeng, Z., Fu, J., Liu, X., Lin, R. and Zhang, Y. 2016. Laboratory evaluation of the sublethal effects of four selective pesticides on the predatory mite *Neoseiulus cucumeris* (Oudemans)(Acari: Phytoseiidae). Systematic and Applied Acarology, 21(11): 1506-1514.

Zhang, Z. Q. 2003. Mites of Greenhouses: Identification, Biology and Control, CABI.

تأثیر هگزی تیازوکس در غلظت‌های مختلف بر پارامترهای جدول زندگی *Amblyseius swirskii* (Acari: Phytoseiidae) و طعمه آن *Tetranychus urticae*

محمدرضا هواسی[۱]، نیلوفر سنگک‌ثانی بژگانی[۲]، غلامرضا گل‌محمدی[۳] و کتایون خردمند[۴*]

۱- گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه تهران، کرج، ایران.
۲- گروه حشره‌شناسی کشاورزی، دانشکده کشاورزی، دانشگاه تربیت مدرس، تهران، ایران.
۳- گروه حشره‌شناسی کشاورزی، سازمان آموزش و ترویج تحقیقات کشاورزی (AREEO)، تهران، ایران.
۴- گروه حشره‌شناسی و بیماری‌های گیاهی، پردیس ابوریحان، دانشگاه تهران، تهران، ایران.
پست الکترونیکی نویسنده مسئول مکاتبه: kkheradmand@ut.ac.ir
دریافت: ۱۳ مرداد ۱۳۹۹؛ پذیرش: ۳ اسفند ۱۳۹۹

چکیده: کنه تارتن دو لکه‌ای *Tetranychus urticae* Koch (Acari: Tetranychidae) یکی از آفات مهم کشاورزی می‌باشد که به‌بسیاری از کنه‌کش‌ها مقاوم شده است. در این پژوهش اثرات زیرکشندگی هگزی تیازوکس در سه غلظت LC$_{10}$، LC$_{20}$ و LC$_{30}$ بر پارامترهای جدول زندگی *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) و طعمه آن *T. urticae* مطالعه شد. افراد بالغ *A. swirskii* به‌طور عمده تحت تأثیر این غلظت‌ها قرار نگرفت اما افراد بالغ *T. urticae* تیمار شده با غلظت LC$_{20}$ و LC$_{30}$ هگزی تیازوکس، کاهش معنی‌داری را در طول دوره تخم‌ریزی (LC$_{20}$: ۹/۶۸; LC$_{30}$: ۸/۰۶ روز) و کل دوره زندگی (LC$_{20}$: ۲۲/۳۷; LC$_{30}$: ۲۰/۸۸ روز) و میزان کل باروری (LC$_{20}$: ۵۰/۹۷; LC$_{30}$: ۴۶/۲۱ نتاج/ماده) نشان دادند. مقادیر نرخ ذاتی افزایش جمعیت (r)، نرخ متناهی افزایش جمعیت (λ) تفاوت معنی‌داری را در هر سه تیمار نشان ندادند اما نرخ خالص تولیدمثل (R_0) و میانگین دوره یک نسل (T) تفاوت معنی‌داری را نشان داد. این مطالعه نشان می‌دهد که هگزی تیازوکس سمّیت کم‌تری بر *A. swirskii* نسبت به *T. urticae* نشان داد. می‌توان نتیجه گرفت که استفاده از کنه‌کش‌های انتخابی در غلظت‌های پایین می‌تواند در برنامه‌های مدیریت تلفیقی آفات مفید باشد.

واژگان کلیدی: کنه تارتن دولکه‌ای، LC$_{50}$، جدول زندگی، پارامترهای بیولوژیکی، Phytoseiidae