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Article *in* Systematic and Applied Acarology · May 2019

DOI: 10.11158/saa.24.5.7

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Systematic & Applied Acarology 24(5): 814–824 (2019)
http://doi.org/10.11158/saa.24.5.7

ISSN 1362-1971 (print)
ISSN 2056-6069 (online)

Article

Sublethal effects of acetamiprid on biological aspects and life table of *Amblyseius swirskii* (Acari: Phytoseiidae) fed on *Aleuroclava jasmini* (Hemiptera: Aleyrodidae)

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Abstract

The whitefly, *Aleuroclava jasmini* (Takahashi) (Hemiptera: Aleyrodidae), is an important pest on paper mulberry *Broussonetia papyrifera* (L.) Vent. (Moraceae) plants in green spaces of Tehran, Iran. The predator mite *Amblyseius swirskii* Athias-Henriot is one of the most common species found in paper mulberry landscape and it is a major biological control agent of this pest. Knowledge of the impact of insecticides on predatory mites is crucial for integrated management programs of this whitefly. This study assessed, under laboratory conditions, the sublethal effect of acetamiprid on the life table parameters of *A. swirskii* fed on *A. jasmini*. The sublethal concentrations LC_{10}, LC_{20} and LC_{30} were obtained based on a dose-effect test. Exposure to the sublethal concentrations of acetamiprid had significant effects on the total immature periods of both males and females. The total fecundity and oviposition period decreased with an increase in concentration. The estimated life table parameters indicated that sublethal concentrations of acetamiprid caused greater reduction in r, λ and R_0 of *A. swirskii* compared to the control. Therefore, the use of acetamiprid to control of *A. jasmini* may have serious implications for integrated pest management programs that aimed at exploiting *A. swirskii* biological control in paper mulberry landscape.

Keywords: Predator mite, Sublethal effect, Acetamiprid, Life table, Whitefly, Integrated pest management.

Introduction

The intensive cultivation of paper mulberry *Broussonetia papyrifera* (L.) Vent. (Moraceae) in green spaces of Tehran, Iran often leads to injuries by insect pests and may require the implementation of pest control measures (Javadi Khederi *et al*. 2018, 2019). Since the end of 2010, production of paper mulberry has been threatened by one of the most important insect pests, *Aleuroclava jasmini* (Takahashi) (Hemiptera: Aleyrodidae) (Javadi Khederi *et al*. 2019). This pest removes a large amount of phloem sap from plants, causing chlorosis in the infected leaves, decreasing fruit yield and quality (Bi & Toscano 2007; Javadi Khederi *et al*. 2019). In addition, they excrete honeydew, which promotes the growth of sooty mold fungi, and affects plant physiology (Bi *et al*. 2002). Over the past decades, chemical control has been the most effective way to reduce whitefly damage to crop production in Iran (Hosseininia *et al*. 2017; Javadi Khederi *et al*. 2019), however, such practices can lead to overuse of these compounds and induce various issues such as environmental pollution, food contamination, effect on biological agents (Guedes *et al*. 2016; Javadi Khederi *et al*. 2019) and the selection of pest resistant populations (Horowitz *et al*. 2007; Liang *et al*. 2012).

Therefore, alternative control methods such as biological control practices and predators became necessary (Bale *et al*. 2008). Among predators that can reduce populations of pests, phytoseiid mites are important biological agents against a wide range of dangerous insects and mites and are commercially applied for pest control (Nomikou *et al*. 2001). Some predatory mites such as *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) are important predators of whiteflies and this predator is widely used in the world (Calvo *et al*. 2011; Zhang *et al*. 2015). Hence, integration of *A. swirskii* with compatible pesticides could decrease the use of pesticides, an aim of integrated pest management (Zhang *et al*. 2015; Sheng 2013).

Among the common insecticides, acetamiprid is a broad spectrum, neonicotinoids systemic compound with activity against sucking insects such as whiteflies (James 2003b; Babar *et al*. 2013). Babar *et al*. (2013) suggested that acetamiprid was found to be the most effective insecticide compared to all other insecticides for whitefly control. In addition, Nadeem *et al*. (2011) and Said (2011) maintained that acetamiprid was effective for the control of whitefly adult on the cotton crop. For optimal biological whitefly management, it is important to know if this insecticide has any effect on *A. swirskii* abundance in the green spaces of the Tehran region, Iran. In previous studies, the susceptibility of phytoseiid species such as *Neoseiulus californicus* (McGregor), *Phytoseiulus macropilis* (Banks), to neonicotinoid insecticides was highly varied from no effect observed to moderately toxic according to phytoseiid species and strains (Poletti *et al*. 2007; Barbar 2017). Poletti *et al*. (2007) reported that *Phytoseius finitimus* Ribaga and *Typhlodromus* (*Anthoseius*) *recki* Wainstein appeared simultaneously in acetamiprid treatments and in untreated control one week after the 3rd application. Also, their abundances were ≥ 8-fold in acetamiprid-treated plots, suggesting that this insecticide is harmless to those predators. Similarly, imidacloprid as a neonicotinoid insecticide has been reported as non-toxic to some species of phytoseiid mites e.g., *Amblyseius womersleyi* Schicha and *Typhlodromus* (*Anthoseius*) *doreenae* Schicha (Park *et al*. 1996; James & Vogele 2001). However, Maroufpoor *et al*. (2016) observed that application of lethal concentrations of acetamiprid highly decreased the survival of immature stages of *N. californicus* (McGregor) and they concluded that this insecticide should not be used in pesticide programs where *N. californicus* is being used to control of *Panonychus ulmi* (Koch). Also, Beers & Schmidt (2013) have also noted the moderately toxicity of acetamiprid and imidacloprid on various life stages of *G. occidentalis* (Nesbitt). Moreover, experience to date on the toxicity for beneficial arthropods of neonicotinoid insecticides, suggests caution in some author's conclusions for phytoseiid mites (James 2003a).

It is possible that some phytoseiid species are more susceptible to neonicotinoid insecticide toxicity than the relatively few species already studied. Specifically, we need to determine the compatibility of acetamiprid with *A. swirskii* so that it can be used for integrated pest management (IPM) of *A. jasmini* populations. A few studies attend to lethal effects of acetamiprid on the life table parameters of phytoseiid mites but none of them determined the sublethal effects of acetamiprid on the life table parameters of *A. swirskii* (Poletti *et al*. 2007; Beers & Schmidt 2013; Maroufpoor *et al*. 2016). This study provides data from laboratory bioassays on the impact of sublethal concentrations of acetamiprid on the biological parameters of *A. swirskii* when fed on *A. jasmini.*

Materials and methods

Mite and whitefly colonies

Stock culture of *A. swirskii* was obtained from Koppert Biological Systems Inc., Netherlands and they were reared on paper mulberry plants infested with *A. jasmini* whiteflies in the Laboratory of Predatory Mites, National Ornamental Plant Institute, Mahallat, Iran. The initial population of *A.*

jasmini was established using nymph-infested foliage collected from paper mulberry fields, Garm Dare (35˚ 45' 28.4" N, 51˚ 4' 1.06" E, 1287 m. a.s.l.), Tehran vicinity, Iran. The leaves bearing nymphs and pupae were brought to the laboratory and were placed with paper mulberry plants in insect rearing cages at 25 ± 1 °C, 70 ± 5% RH and a photoperiod of 16:8 h (L:D).

Rearing units

Each rearing unit included a paper mulberry leaf placed in a Huffaker cell between two glass plates (about 8×11×7 cm). The plates were held in place by rubber bands. A small hole (2 cm) was cut in the middle part of each glass. The cage was located on a wet sponge in a plastic tray including water and the leaf stem was placed in the water (Nomikou *et al*. 2005). The leaves were surrounded by saturated cotton to prevent escape of the mites. The prey (8–12 crawler stages of *A. jasmini* per predator) were introduced on the leaves as a food source and left to settle for 24 h. Subsequently, *A. swirskii* adult females were transferred to the rearing unit with a soft pointed brush and allowed to feed. The paper mulberry leaves were refreshed every week.

Life table assay

A commercial formulation of acetamiprid (Mospilan 20%) was obtained from Arya Shimi Company, Iran. A modified leaf-dip method was applied to assess the life table parameters of *A. swirskii* in different concentrations of acetamiprid (Nauen & Konanz 2005). All tests were carried out at 25 ± 1 °C and 70 ± 5% RH and a photoperiod of 16:8 (L: D) h. The sublethal concentrations including LC_{10}, LC_{20} and LC_{30} were calculated by a probit procedure (SAS Institute 2004), as 13.25, 31.32 and 39.16 µg ml^{-1}, respectively. Also there were four replicates per each concentration. The fresh paper mulberry leaf discs (about 4 cm diameter) were dipped in the acetamiprid solutions for 10 s, were allowed to dry for about 2 hours and were kept in petri dishes on moist pads. The control leaf discs were treated with distilled water. Then, twenty unmated predator females and males (24 h old) were introduced on each leaf disc using a fine soft pointed brush. After 48 hours, the surviving mites were separately transferred to new paper mulberry leaf discs and allowed to lay eggs for 12 hours. Survival of the eggs and the subsequent stages (larva, protonymph and deutonymph) was carefully checked once a day. Moreover, 100 eggs were used as an initial cohort in the life table experiments. After the emergence of adults, males and females were paired and the duration of pre-oviposition (The adult pre-oviposition period (APOP) (the duration from adult emergence to first oviposition) and total pre-oviposition period (TPOP) (the duration from egg to first oviposition), oviposition and post-oviposition periods as well as longevity and the total fecundity were recorded for each treatment. In whole assays, each predatory mite was provided with 8–12 crawler stages of *A. jasmini* daily as a food source.

Statistical analysis

The life history data were analyzed based on the age-stage and two sex life table theory (Chi & Liu 1985; Chi 1988) by using the TWOSEX-MSChart program (Chi 2017). As calculating life table is extremely time consuming and replication is impractical, we used bootstrap method to calculate standard errors of the life table parameters with 10,000 replications. The differences of life table bootstrap-values among the treatments were compared using the paired bootstrap test while differences of biological parameters such as development time, longevity, life span, reproductive period and fecundity of predator were compared using Tukey-Kramer procedure ($P < 0.05$) (Chi 2017; Bahari *et al.* 2018). The age-specific survival rate (l_x), age-specific fecundity (m_x), and population parameters (*r,* intrinsic rate of increase; R_0, net reproductive rate; *GRR* and the gross reproductive rate; *T*) were calculated accordingly.

The intrinsic rate of increase is estimated by using iterative bisection method;

$$\sum_{x=0}^{\omega} e^{-r(x+1)} l_x m_x = 1$$

with age indexed from 0 to ω (Goodman 1982). To take stage differential into consideration, the l_x and m_x by the use of the following formulae:

$$l_x = \sum_{j=1}^{k} s_{xj}$$

and

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

where k is the number of stages (Chi & Liu 1985). The mean generation time is defined as the time length that a population needs to increase to R_0-fold of its size (i.e., $e^{rT} = R_0$ or $\lambda^T = R_0$) at the stable age–stage distribution. The mean generation time is calculated as $T = \ln R_0/r$. The TWOSEX–MS Chart program is available at http://140.120.197.173/Ecology/Download/Twosex-MSChart-B100000.rar (Chi 2017). All graphs were plotted by Sigma Plot version 11.0 (Systat Software Inc. 2008).

Results

Development time, adult longevity and total life span

The longest egg incubation periods in males and females were 2.31 and 2.31 days, respectively, which were obtained at the LC_{30} concentration ($F_{3, 38} = 2.88$, $P = 0.011$; $F_{3, 62} = 3.65$, $P = 0.033$). The mean larval developmental time of both sexes treated with the LC_{20} and LC_{30} concentrations was significantly increased in comparison with the control ($F_{3, 38} = 6.93$, $P < 0.0001$; $F_{3, 62} = 2.34$, $P = 0.035$). No significant differences were observed in protonymphal duration of males and females ($F_{3, 35} = 0.29$, $P = 0.68$; $F_{3, 65} = 0.37$, $P = 0.64$). In addition, the highest values of deutonymphal duration of both sexes were observed at the LC_{30} ($F_{3, 31} = 0.55$, $P = 0.031$; $F_{3, 40} = 0.38$, $P = 0.022$). The longest and shortest developmental times of males (8.81 and 6.99 days) and females (8.79 and 7.31 days) were recorded at the LC_{30} and the control, respectively ($F_{3, 43} = 15.73$; $F_{3, 62} = 16.28$, both $P < 0.0001$). Adult longevity decreased with increasing insecticide concentration in both sexes ($F_{3, 40} = 5.28$; $F_{3, 65} = 87.49$, both $P < 0.0001$). The highest values of male and female longevity observed were 23.15 and 25.14 days, in the control. The shortest and longest total life span of males and females were observed in the LC_{30} treatment and control, respectively ($F_{3, 43} = 35.74$; $F_{3, 62} = 53.24$, both $P < 0.0001$) (Tables 1 and 2).

Oviposition period and fecundity

The longest and the shortest oviposition periods were recorded as 12.50 and 7.09 days for the mites treated with distilled water and the LC_{30} ($F_{3, 62} = 73.26$, $P < 0.0001$). The adult pre-oviposition period (APOP) and total pre-oviposition period (TPOP) were significantly different among all assayed treatments and the shortest of these periods were attained with the water control ($F_{3, 62} =$

12.29; $F_{3, 62}$ = 12.29, 15.26, both $P < 0.0001$). The shortest post-oviposition period was observed as 5.34 days at the LC_{30} ($F_{3, 62}$ = 29.33, $P < 0.0001$). Total fecundity decreased with an increase in sublethal concentrations from 11.77 to 5.12 in the control and the LC_{30} treatment, respectively ($F_{3, 62}$ = 73.28, $P < 0.0001$) (Table 2).

TABLE 1. Mean (± SE) duration and survival of offspring from males of *Amblyseius swirskii* treated with sublethal concentrations of acetamiprid or distilled water.

		Mean response at each acetamiprid concentrations		
Biological variable	Water control	LC_{10}	LC_{20}	LC_{30}
Egg incubation period (day)	1.79 ± 0.23c	2.04 ± 0.23b	2.30 ±0.28a	2.31 ± 0.35a
Larva duration (day)	1.34 ± 0.19b	1.44 ± 0.23b	1.97 ± 0.31a	2.10 ± 0.37a
Protonymph duration (day)	2.18 ± 0.11a	2.17 ± 0.23a	2.24 ± 0.23a	2.30 ± 0.12a
Deutonymph duration (day)	1.86 ± 0.31b	1.97 ± 0.79a	2.10 ± 0.26a	2.11 ± 0.33a
Duration of the immature stage (day)	6.99 ± 0.36c	7.46 ± 0.35b	8.61 ± 0.34a	8.81 ± 0.58a
Adult longevity (day)	23.15 ± 1.25a	21.96 ± 1.05b	15.23 ± 0.53c	12.63 ± 0.98d
Total life span (day)	30.14 ± 1.41a	29.42 ± 1.11a	23.84 ± 0.97b	21.44 ± 1.01c

The means followed by the same letter in each row do not differ significantly ($P < 0.05$, Tukey–Kramer).

TABLE 2. Mean (± SE) duration and survival of offspring from females of *Amblyseius swirskii* treated with sublethal concentrations of acetamiprid or distilled water.

		Mean response at each acetamiprid concentration		
Biological variable	Water control	LC_{10}	LC_{20}	LC_{30}
Egg incubation period (day)	1.74 ± 0.24c	1.81 ± 0.44b	2.11 ± 0.25ab	2.31 ± 0.84a
Larva duration (day)	1.27 ± 0.28c	1.56 ± 0.47ab	1.71 ± 0.76a	1.81 ± 0.87a
Protonymph duration (day)	2.15 ± 0.24a	2.11 ± 0.42a	2.26 ± 0.41a	2.21 ± 0.57a
Deutonymph duration (day)	2.16 ± 0.27b	2.21 ± 0.51b	2.41 ± 0.52ab	2.46 ± 0.46a
Duration of the immature stage (day)	7.31 ± 0.34c	7.69 ± 0.49b	8.49 ± 0.11a	8.79 ± 0.35a
Adult pre-oviposition (APOP) (day)	4.68 ± 0.54c	5.09 ± 0.71b	5.44 ± 0.35ab	5.64 ± 0.51a
Total pre-oviposition period (TPOP) (day)	8.51 ± 0.14c	9.18 ± 0.23b	10.11 ± 0.22ab	10.52 ± 0.47a
Oviposition (day)	12.50 ± 0.04a	9.91 ± 0.58b	8.59 ± 0.85b	7.09 ± 0.74c
Post-oviposition (day)	7.96 ± 0.57a	8.44 ± 0.64a	6.79 ± 0.50b	5.34 ± 0.31c
Total fecundity (offspring)	11.77 ± 0.35a	8.02 ± 0.72b	6.37 ± 0.75c	5.12 ±0.62d
Adult longevity (day)	25.14 ± 0.49a	23.44 ± 0.56a	20.82 ± 0.54b	18.07 ± 0.81c
Total life span (day)	32.45 ± 0.66a	31.13 ± 1.19ab	29.31 ± 0.57b	26.89 ± 0.87c

The means followed by the same letter in each row do not differ significantly ($P < 0.05$, Tukey–Kramer).

Stable population parameters

Demographic statistics indicated that the intrinsic rate of increase (r) decreased from 0.195 to 0.122 day^{-1} as sublethal concentrations increased. The net reproductive rate (R_0) varied from 6.94 to 14.03 eggs/individual, with the lowest at the LC_{30} and highest in the water control. The highest and lowest values of gross reproductive rate (*GRR*) were observed for the mites exposed to distilled water and the LC_{30} treatment, respectively. In addition, the finite rate of increase (λ) ranged from 1.216 to 1.121 day^{-1} which was lowest at LC_{30} and highest in the control. Mites reared on water control responded with a more rapid generation time (T) compared to mites reared in the sublethal treatments (Table 3).

TABLE 3. Mean estimates (± SE) of life-table parameters of *Amblyseius swirskii* treated with sublethal concentrations of acetamiprid or distilled water.

Parameters/ Concentrations	Water control	LC_{10}	LC_{20}	LC_{30}
r (day^{-1})	0.195 ± 0.007a	0.172 ± 0.034ab	0.141 ± 0.023c	0.122 ± 0.012cd
R_0 (eggs/individual)	14.03 ± 0.85a	11.07 ± 0.74b	9.12 ± 0.13bc	6.94 ± 0.62cd
GRR (eggs/individual)	15.04 ± 0.93a	12.05 ± 0.39b	11.19 ± 0.53b	9.06 ± 0.73bc
λ (day^{-1})	1.216 ± 0.024a	1.181 ± 0.053ab	1.155 ± 0.046bc	1.121 ± 0.024c
T (day)	13.90 ± 0.22b	14.14 ± 0.45b	15.79 ± 0.73a	16.14 ± 0.56a

The means followed by the same letter in each row do not differ significantly ($P < 0.05$, Paired bootstrap).

Age-specific survivorship (l_x) and age specific fecundity (m_x)

Amblyseius swirskii mortality increased and adult longevity decreased significantly with increasing acetamiprid concentration. Maximum longevity for adult females was attained for mites treated with distilled water (41 d) followed by that for the mites treated with the LC_{10} concentration of acetamiprid (40 d). The highest rate of mortality occurred at the LC_{20} (33 d) and the LC_{30} (30 d) concentrations in which, survivorship (l_x) of *A. swirskii* decreased more sharply than the control (Fig. 1). The age-specific fecundity (m_x) is also displayed in Fig. 1. The highest observed value of the daily age specific fecundity (m_x) of *A. swirskii* was 2.44 eggs/individual on day 14 of the life span for the mites treated with distilled water. In comparison, the maximum values of m_x were 1.87, 1.79 and 1.59 eggs/individual for the mites treated at the LC_{10}, LC_{20} and LC_{30} concentrations of acetamiprid, which were observed on days 15, 17 and 18 of the life span, respectively (Fig. 1).

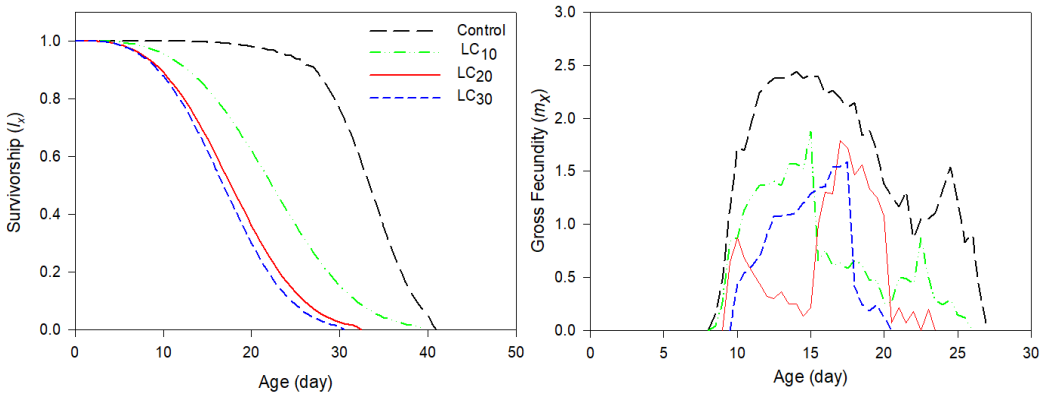

FIGURE 1. Age-specific survivorship (l_x) and age–specific fecundity (m_x) of offspring of the treated and untreated females of *Amblyseius swirskii.*

The age-stage survival rates (s_{xj}) of *A. swirskii* treated with sublethal concentrations of acetamiprid and distilled water are shown in Fig. 2. It shows the probability that an egg will survive to age x while in stage j, as the age-stage, two-sex life table takes the variable developmental rate among individuals into consideration, so significant stage overlapping could be observed (Fig. 2).

Discussion

Determining the compatibility of pesticides with natural enemies is necessary for developing effective IPM tactics. Knowledge of the population level effects of pesticides on beneficial organisms is needed to develop sustainable pest control methods (Javadi Khederi *et al.* 2019). Until

our study, no information was available on the sublethal effects of acetamiprid on *A. swirskii* biological characteristic. The findings of the present study showed that sublethal concentrations of acetamiprid had significant effects on the duration of various growth stages of *A. swirskii* compared to the mites treated with distilled water. The longest egg duration in males and females was obtained in treatment of the highest rate of acetamiprid tested. Our results are confirmed the observations of the egg duration of *P. plumifer, A. swirskii* and *N. californicus* treated with LC_{30} concentrations of fenpyroximate, fenazaquin and acetamiprid (Hamedi *et al*. 2010; Alinejad *et al*. 2014; Maroufpoor *et al*. 2016). The length of larval period of both sexes treated with the highest sublethal concentration was significantly longer than that in control. Also, the mean deutonymphal duration of females treated with the LC_{30} acetamiprid concentration was significantly prolonged compared with control, similar to the results obtained by Maroufpoor *et al*. (2016) for *N. californicus* and Cheng *et al*. (2018) for *Amblyseius cucumeris* (Oudemans) treated with sublethal and lethal concentration of acetamiprid. In addition, the present study demonstrated that the assayed insecticide had negative effects on the duration of the immature stages of both sexes of this predator, similar to previous studies (Maroufpoor *et al*. 2016; Zanardi *et al*. 2017; Ghasemzadeh & Qureshi 2018). These studies demonstrated that the developmental time of *N. californicus, Iphiseiodes zuluagai* Denmark and Muma and *A. swirskii* treated with acetamiprid, imidacloprid and thiacloprid increased significantly compared to the control.

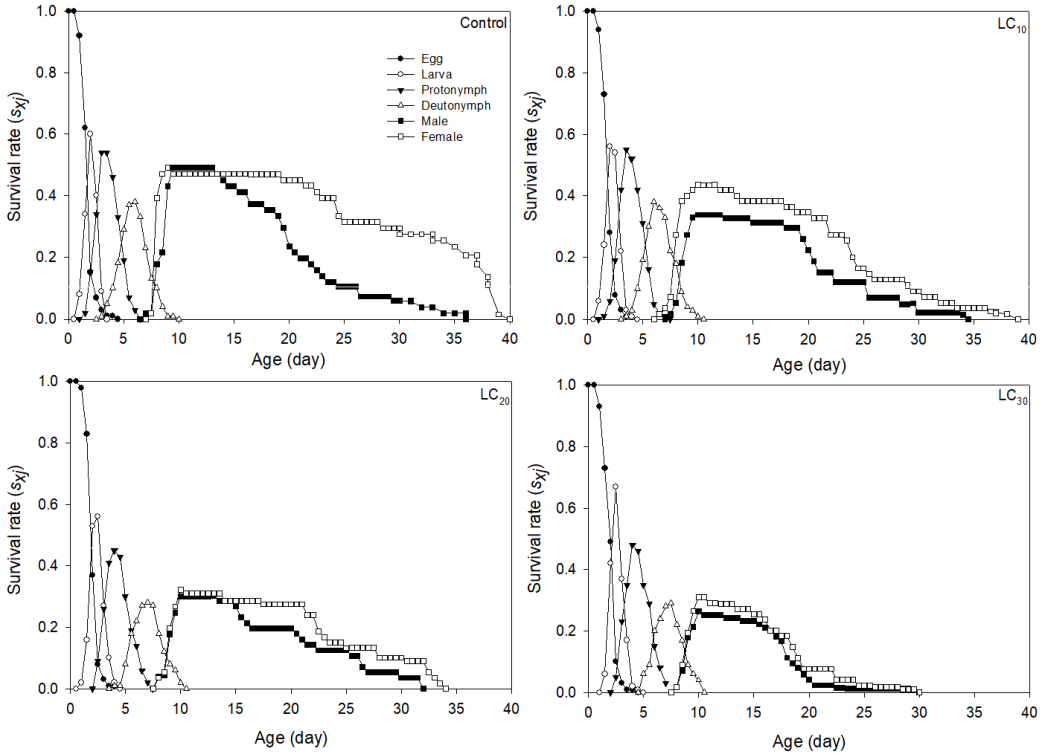

FIGURE 2. Age-stage specific survival rate (s_{xj}) of *Amblyseius swirskii* treated with sublethal concentrations of acetamiprid or distilled water.

Moreover, the longevity and total lifespan of both sexes decreased with increasing acetamiprid concentration. The same results were reported by Ghasemzadeh & Qureshi (2018) who argued that longevity and total life span of *A. swirskii* treated with sublethal concentrations of thiacloprid declined significantly in comparison with the control. These effects may result in a reduced

population growth of *A. swirskii* as observed with declined net reproductive rate and intrinsic rate of increase especially at the highest concentration rates, which can reduce biological control of pests (Ghasemzadeh & Qureshi 2018). In addition, the shorter longevity of *A. swirskii* females and males may be due to reduced food intake as result of pesticide effects (Hamedi *et al.* 2009). Acetamiprid is a nicotinic agonist that reacts with nicotinic acetylcholine receptors (nACh-R) located in post-synaptic neurons, resulting in an acetylcholine degradation process delay and individual mortality (Tomizawa & Casida 2005) which probably caused more adverse effects on life stages of *A. swirskii*.

The pre-oviposition period increased and the oviposition period decreased with an increase in sublethal concentrations of acetamiprid. In addition, total fecundity was significantly reduced by dose dependence. In this way, negative effects of acetamiprid, thiacloprid and imidacloprid used at different rates on phytoseiid mites including *N. californicus, A. swirskii* and *A. cucumeris* were also reported by other researchers (Castagnoli *et al.* 2005; Maroufpoor *et al*. 2016; Ghasemzadeh & Qureshi 2018; Cheng *et al*. 2018). However, relatively few studies have been devoted to the determination of acetamiprid toxicity for *A. swirskii.*

Demographic toxicology is considered a better measure of response to pesticides than individual life history characteristics (Stark & Banks 2003). The parameter *r* integrates the effects of mortality and fecundity into a single value, so, it is greatly affected by the wide range of variables consisted of preimaginal survival, developmental rate, longevity of females, fecundity schedule and sex ratio, which are affected by climatic and nutritional conditions (Javadi Khederi & Khanjani 2014). Based on the present findings, the life table parameters values of *A. swirskii* were significantly reduced in mites treated with sublethal concentrations of acetamiprid compared to the control. Knowing the effects of pesticides on biological control agents is essential for successful implementation of integrated pest management programs (Javadi Khederi *et al*. 2019). A single control method against agricultural pests is sometimes not effective and the success rate without chemical methods can be very low, but pesticides should be selected from the compounds that have the least negative effect on the natural enemies (Kaplan *et al*. 2012). A number of researchers have demonstrated that life table parameters of phytoseiid mites such as *A. swirski*, *P. persimilis*, *P. plumifer* and *Neoseiulus longispinosus* (Evans) were affected by sublethal concentrations of pesticides (Sanatgar *et al*. 2011; Alinejad *et al*. 2014; Maroufpoor *et al*. 2016; Ghasemzadeh & Qureshi 2018). The present results indicated that LC_{20} and LC_{30} sublethal concentrations of acetamiprid significantly reduced the population parameters (i.e., r, R_0, T, λ and *GRR*) of *A. swirski* compared with the control as confirmed in previous studies (Maroufpoor *et al*. 2016; Zanardi *et al*. 2017; Ghasemzadeh & Qureshi 2018). The age-specific survival rate (l_x) and age specific fecundity (m_x) curves showed that sublethal doses of acetamiprid caused reduction in these parameters of *A. swirski* compared to treated mite with distilled water. However, mortality of *Neoseiulus cucumeris* Oudemans (Acari: Phytoseiidae), *Typhlodromips montdorensis* Schicha (Acari: Phytoseiidae) and *A. swirskii* from direct applications and dry residues of thiacloprid was similar to the control (Cuthbertson *et al.* 2012). Differences in phytoseiid species as well as experimental conditions could be responsible for the conflicting results. When individuals of different stages are pooled together, we obtain the age-specific survival rate (l_x). The curve l_x is the simplified version of s_{xj}. The important information of stage differentiation cannot be observed in l_x (Javadi Khederi & Khanjani 2014). Due to the variability in the developmental rate among individuals, the survival curve of predatory mites treated with acetamiprid showed significant stage over-lapping in our study and others (Ghasemzadeh & Qureshi 2018). Acquisition of this result from our experiment was an important outcome of our research, because it showed us that susceptibility to pesticide is stage-dependent, and adults could emerge at different ages, and it disproves the possibility of survival rate based on "female adult age" (Javadi Khederi & Khanjani 2014).

Based on the present findings, although the applied concentrations were lower than the recommended amount for control of *A. jasmini*, our observations showed that these concentrations had negative effects on the survivorship and life table parameters of the next generation of *A. swirskii*. In conclusion, acetamiprid is not a compatible insecticide where *A. swirskii* is effective as a biological control agent of *A. jasmini* and should not be applied in the IPM system of the paper mulberry landscape. Although current research needs to be done to see how long it has an effect, because the residues may break down quickly and the product could be used if that effect is short lived.

Acknowledgements

The authors are grateful to the anonymous referees for comments on the manuscript. This work is part of a military dissertation of the first author that was funded by National Ornamental Plant Institute, Mahallat, Iran and Baqiyatallah University of Medical Sciences, Tehran, Iran.

References

Alinejad, M., Kheradmand, K. & 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. https://doi.org/10.1007/s10493-014-9830-y

Babar, T.K., Karar, H., Saleem, M., Ali, A., Ahmad, S. & Hameed, A. (2013) Comparative efficacy of various insecticides against whitefly, *Bemisia tabaci* (Genn.) adult (Homoptera: Aleyrodidae) on transgenic cotton variety Bt-886. *Pakistan Entomologist*, 35(2), 99–104.

Bahari, F., Fathipour, Y., Talebi, A.A., & Alipour, Z. (2018) Long-term feeding on greenhouse cucumber affects life table parameters of two-spotted spider mite and its predator *Phytoseiulus persimilis, Systematic and Applied Acarology*, 23(12): 2304–2316. https://doi.org/10.11158/saa.23.12.3

Bale, J.S., Van Lenteren, J.C. & Bigler, F. (2008) Biological control and sustainable food production. *Philosophical Transactions of the Royal Society B*, 363, 761–776. https://doi.org/10.1098/rstb.2007.2182

Barbar, Z. (2017) Evaluation of three pesticides against phytophagous mites and their impact on phytoseiid predators in an eggplant open-field. *Acarologia*, 57(3), 529–539.

Beers, E.H. & Schmidt, R.A. (2013) Impacts of orchard pesticides on *Galendromus occidentalis*: Lethal and sublethal effects. *Crop Protection*, 56, 16–24. https://doi.org/10.1016/j.cropro.2013.10.010

Bi, J.L. & Toscano, N.C. (2007) Current status of the greenhouse whitefly (Homoptera: Aleyrodidae) susceptibility to neonicotinoid and conventional insecticides on strawberries in southern California. *Pest Management Science*, 63(8), 747–752. https://doi.org/10.1002/ps.1405

Bi, J.L., Toscano, N.C. & Ballmer, G.R. (2002) Seasonal population dynamics of the greenhouse whitefly Trialeurodes vaporariorum on Strawberries in Southern California. *Journal of Economic Entomology*, 95(6), 1179–1184. https://doi.org/10.1603/0022-0493-95.6.1179

Calvo, F.J., Bolckmans, K. & Belda, J.E. (2011) Control of *Bemisia tabaci* and *Frankliniella occidentalis* in cucumberby *Amblyseius swirskii*. *BioControl*, 56(2), 185–192. https://doi.org/10.1007/s10526-010-9319-5

Castagnoli, M., Liguori, M., Simoni, S., Duso, C. (2005) Toxicity of some insecticides to *Tetranychus urticae*, *Neoseiulus californicus* and *Tydeus californicus*, *BioControl*, 50, 611–622. https://doi.org/10.1007/s10526-004-8121-7

Cheng, S., Lin, R., Lin, T., You, Y., Zeng, Z., Zhou, X., Zhou, Y., Jiang, H., Wei, H., Fu, J., Yu, C. (2018) Effects of acetamiprid on life cycle development of predatory mite *Amblyseius cucumeris* (Acari: Phytoseiidae) after contact exposure, *Chemosphere,* 210, 889–895.

https://doi.org/10.1016/j.chemosphere.2018.07.096
Chi, H. & 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.
Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rate among individuals. *Environmental Entomology*, 17(1), 26–34.
https://doi.org/10.1093/ee/17.1.26
Chi, H. (2017) TWOSEX-MSChart: a computer program for the age-stage, two-sex life table analysis. National Chung Hsing University, Taichung, Taiwan. Available from http://140.120.197.173/Ecology/Download/Twosex-MSChart-B100000.rar
Cuthbertson, A.G., Mathers, J.J., Croft, P., Nattriss, N., Blackburn, L.F. & Luo, W. (2012) Prey consumption rates and compatibility with pesticides of four predatory mites from the family Phytoseiidae attacking *Thrips palmi* Karny (Thysanoptera: Thripidae). *Pest Management Science*, 68, 1289–1295.
https://doi.org/10.1002/ps.3296 PMID: 22517790.
Ghasemzadeh, S. & Qureshi, J.A. (2018) Demographic analysis of fenpyroximate and thiacloprid exposed predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae). *PLOS ONE* 13(11), e0206030.
https://doi.org/10.1371/journal. pone.0206030
Goodman, D. (1982) Optimal life histories, optimal notation, and the value of reproductive value. *The American Naturalist*, 119(6), 803–823.
https://doi.org/10.1086/283956
Guedes, R.N.C., Smagghe, G., Stark, J.D. & Desneux, N. (2016) Pesticide-induced stress in arthropod pests for optimized integrated pest management programs. *Annual Review of Entomology*, 61, 43–62.
https://doi.org/10.1146/annurev-ento-010715-023646
Hamedi, N., Fathipour, Y. & Saber, M. (2010) Sublethal effects of fenpyroximate on life table parameters of the predatory mite *Phytoseius plumifer*. *Biocontrol*, 55(2), 271–278.
https://doi.org/10.1007/s10526-009-9239-4
Hamedi, N., Fathipour, Y., Saber, M. & Sheikhi-Garjan, A. (2009) Sublethal effects of two common acaricides on the consumption of *Tetranychus urticae* (Prostigmata: Tetranychidae) by *Phytoseius plumifer* (Mesostigmata: Phytoseiidae). *Systematic and Applied Acarology*, 14(3), 197–205.
https://doi.org/10.11158/saa.14.3.4
Horowitz, R., Denholm, I. & Morin, S. (2007) Resistance to insecticides in the TYLCV vector, *Bemisia tabaci*. *In*: Czosnek, H. (Ed.), *Tomato yellow leaf curl virus disease*. Dordrecht, Netherlands, Springer, pp. 305–325.
https://doi.org/10.1007/978-1-4020-4769-5_18
Hosseininia, A., Khanjani, M., Khoobdel, M. & Javadi Khederi, S. (2017) Compare the efficiency of the current oils and insecticide compounds in control of greenhouse whitefly *Trialeurodes vaporariorum* (Westwood), (Hem.: Aleyrodidae) on rose and their interaction. *Journal of Plant Protection*, 30(4), 718–726. (In Persian).
James, D.G. & Vogele, B. (2001) The effect of imidacloprid on survival of some beneficial arthropods. *Plant Protection Quarterly*, 16(2), 58–62.
James, D.G. (2003a) Toxicity of imidacloprid to *Galendromus occidentalis*, *Neoseiulus fallacis* and *Amblyseius andersoni* (Acari: Phytoseiidae) from hops in Washington State, USA. *Experimental and Applied Acarology*, 31(3–4), 275–281.
https://doi.org/10.1023/B:APPA.0000010383.33351.2f
James, R.R. (2003b) Combining azadirachtin and *Paecilomyces fumosoroseus* (Deuteromycotina: Hyphomycetes) to control *Bemisia argentifolii* (Homoptera: Aleyrodidae). *Journal of Economic Entomology*, 96(1), 25–30.
https://doi.org/10.1093/jee/96.1.25
Javadi Khederi, S. & Khanjani, M. (2014) Modeling demographic response to constant temperature in *Bryobia rubrioculus* (Acari: Tetranychidae). *Ecologia Montenegrina*, 1(1), 18–29.
Javadi Khederi, S., Khanjani, M., Gholami, M. & de Lillo, E. (2018) Sources of resistance to the erineum strain of *Colomerus vitis* (Acari: Eriophyidae) in grapevine cultivars. *Systematic and Applied Acarology*, 23(3), 405–425.
https://doi.org/10.11158/saa.23.3.1
Javadi khederi, S., Khoobdel, M., Khanjani, M., Hosseininia, A., Sadeghi Sorkhe Dizaji, B., Hosseini, S.M. & Sobati, H. (2019) Insecticidal effects of essential oils from two medicinal plants against *Aleuroclava jasmini* (Hemiptera: Aleyrodidae). *Journal of Crop Protection*, 8(1), 57–67.
Kaplan, P., Yorulmaz, S. & 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.
https://doi.org/10.1080/01647954.2012.719031
Liang, P., Tian, Y.A., Biondi, A., Desneux, N. & Gao, X.W. (2012) Short-term and transgenerational effects of the neonicotinoid nitenpyram on susceptibility to insecticides in two whitefly species. *Ecotoxicology*, 21(7), 1889–1898.
https://doi.org/10.1007/s10646-012-0922-3

Maroufpoor, M., Ghoosta, Y. & Pourmirza, A.A. (2016) Toxicity of diazinon and acetamiprid on life table parameters of the predatory mite, *Neoseiulus californicus* (Acari: Phytoseiidae) when fed on the european red mite *Panonychus ulmi* (Koch). *Egyptian Journal of Biological Pest Control*, 26(1), 15–19.

Nadeem, M.K., Nadeem, S., Hasnain, M., Ahmed, S. & Ashfaq, M. (2011) Comparative efficacy of some insecticides against whitefly *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) under natural field conditions. *The Nucleus*, 48(2), 159–162.

Nauen, R. & Konanz, S. (2005) Spiromesifen as a new chemical option for resistance management in whiteflies and spider mites. *Pflanzenschutz- Nachrichten Bayer*, 58(3), 485–502.

Nomikou, M., Janssen, A., Schraag, R. & Sabelis, M.W. (2001) Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. *Experimental and Applied Acarology*, 25(4), 271–291. https://doi.org/10.1023/A:1017976725685

Nomikou, M., Meng, R., Schraag, R.W., Sabelis, M. & Janssen, A. (2005) How predatory mites find plants with whitefly prey. *Experimental and Applied Acarology*, 36(4), 263–275. https://doi.org/10.1007/s10493-005-6650-0

Park, C.G., Yoo, J.K. & Lee, L.O. (1996) Toxicity of some pesticides to two spotted mite (Acari: Tetranychidae) and its predator, *Amblyseius womersleyi* (Acari: Phytoseiidae). *Korean Journal of Applied Entomology*, 35(3), 232–237.

Poletti, M., Maia, A.H.N. & Omoto, C. (2007) Toxicity of neonicotinoid insecticides to *Neoseiulus californicus* and *Phytoseiulus macropilis* (Acari: Phytoseiidae) and their impact on functional response to *Tetranychus urticae* (Acari: Tetranychidae). *Biological Control*, 40(1), 30–36. https://doi.org/10.1016/j.biocontrol.2006.09.001

Said, M.K. (2011) Varietal Performance and chemical control used as tactics against sucking insect pests of cotton. *Sarhad Journal of Agriculture*, 27(2), 255–261.

Sanatgar, E., Shoushtari, R.V., Zamani, A.A. & 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.

SAS Institute (2004) SAS software version 9.0. SAS Institute, Cary.

Sheng, F.J. (2013) Studies on alternative prey and preliminary exploration and application of *Amblyseius orientalis* (Acari: Phytoseiidae) controlling on *Bemisia tabaci*. *M.Sc. Thesis, Institute of Plant Protection, Chinese Academy of Agricultural Sciences*.

Stark, J.D. & Banks, J.E. (2003) Population-level effects of pesticides and other toxicants on arthropods. *Annual Review of Entomology*, 48, 505–519. https://doi.org/10.1146/annurev.ento.48.091801.112621

Systat Software, Inc. (2008) SigmaPlot statistics users guide, version 11.0. Systat Software, Inc., San Jose, CA.

Tomizawa, M. & Casida, J.E. (2005) Neonicotinoid insecticide toxicology: mechanisms of selective action. *Annual Review of Pharmacology and Toxicology*, 45, 247–268. https://doi.org/10.1146/annurev.pharmtox.45.120403.095930

Zanardi, O.Z., Bordini, G.P., Franco, A.A., Oliveira Jacob, C.R. & Yamamoto, P.T. (2017) Sublethal effects of pyrethroid and neonicotinoid insecticides on *Iphiseiodes zuluagai* Denmark and Muma (Mesostigmata: Phytoseiidae). *Ecotoxicology*, 26(9), 1188–1198. https://doi.org/10.1007/s10646-017-1844-x

Zhang, X., Lv, J., Hu, Y., Wang, B., Chen, X., Xu, X. & Wang, E. (2015) Prey Preference and Life Table of *Amblyseius orientalis* on *Bemisia tabaci* and *Tetranychus cinnabarinus*. *PLoS ONE*, 10(10), e0138820. https://doi.org/10.1371/journal.pone.0138820.

Submitted: 4 Mar. 2019; accepted by Zhi-Qiang Zhang: 6 Apr. 2019; published: 8 May 2019