NORTH-WESTERN JOURNAL OF ZOOLOGY 12 (1): 1-6 ©NwjZ, Oradea, Romania, 2016
Article No.: e151101 http://biozoojournals.ro/nwjz/index.html

The effects of selected acaricides on life table parameters of the predatory mite, *Neoseiulus californicus*, fed on European red mite

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Received: 09. May 2014 / Accepted: 30. December 2014 / Available online: 07. April 2016 / Printed: June 2016

Abstract. Knowledge of the effects of pesticides on biological control agents is necessary for successful implementation of integrated pest management programs. The objective of this research was to evaluate the lethal effects of selected acaricides recommended for the control of European red mite, fenazaquin and spirodiclofen, on the development, survivorship and life-history parameters of *Neoseiulus californicus* as an important natural enemy of this pest mite under laboratory conditions. The acaricides tested significantly reduced the net fecundity/fertility of the predatory mite. The results indicated that adverse effects of the two treatments on population growth of *N. californicus* were significant. For fenazaquin, the intrinsic rate of increase (r_m), net reproduction rate (R_0), and finite rate of increase (λ) were reduced 1.70, 2.77 and 1.11 fold in comparison to the control treatment, respectively. These measures for spirodiclofen were 1.55, 2.61 and 1.09 in the same order. The intrinsic rate of increase (r_m), net reproduction rate (R_0), and finite rate of increase (λ) were significantly reduced in treated females compared to the control. The lethal effects of fenazaquin and spirodiclofen in conjunction with *N. californicus* to achieve efficient control of *Panonychus ulmi* management are discussed.

Key words: demography, fecundity, *Panonychus ulmi*, population growth, intrinsic rate of natural increase.

Introduction

Neoseiulus californicus (McGregor) (Acari: Phytoseiidae) is a predatory mite widely distributed in the world (Canlas et al. 2006, McMurtry & Croft 1997). It has been used to control spider mites in field and greenhouse horticultural crops in North and South America and Europe (McMurtry & Croft 1997, Jolly 2000). Its versatility as a predator has been noteworthy not only because it can prey on stages of the two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), but it also preys on other tetranychid species, as well as on other pest mites and on insects, and can even survive on pollen (Canlas et al. 2006, Croft et al. 1998). Its use is increasingly gaining importance because of pressure on growers to find alternatives to chemical pesticides (Coping 2001).

Use of pesticides cannot be eliminated in a short period of time in perennial crops, because phytoseiid mites, as the most important predators of phytophagous mites, might not be able to maintain spider mite populations below the economically acceptable level on their own, as aptly expressed by Field & Hoy (1986) and McMurtry & Croft (1997). However, in the applied biological control of mites, the use of pesticides can impair the performance of this natural enemy since phytoseiid mites are generally more susceptible to pesticides than phytophagous mites (Croft 1990). To minimize the effect of chemical control on biological control agents and provide an ecological balance between pests and their natural enemies, these control strategies can be integrated to provide a more rational form of management (Kogan 1998). Thus, the use of chemical agents of low toxicity to natural enemies and/or the use of pesticide-resistant predatory mites have been exploited in integrated pest management programs (Croft 1990).

Various cases of predatory mite resistance to carbamate, organophosphate and pyrethroid pesticides have been documented. After collecting populations of predatory mites, *Typhlodromus pyri* Scheuten and *Amblyseius andersoni* (Chant), in commercial grape production regions in south France, Bonafos et al. (2007) detected high levels of resistance to the pyrethroids deltamethrin and lambda-cyhalothrin and to the organophosphate chlorpyrifos-methyl. According to these authors, development of resistance in these predator species under field conditions has played an important role in their conservation in commercial grape production regions, contributing to success of integrated phytophagous mite management programs.

Poletti & Omoto (2005) recorded deltamethrin resistance ratios of 24-fold in *N. californicus* collected in a commercial apple orchard in Fraiburgo, Santa Catarina State, Brazil. High tolerance of *N. californicus* relative to *T. urticae* was detected to fenpyroximate, fenpropathrin, dimethoate, propargite, sulphur and benomyl in mite populations collected in strawberry fields in Brazil (Sato et al. 2002).

One such group of compounds is acaricides that function as mitochondrial electron transport inhibitors (METI) at Complex I (Hirata 1995). Fenazaquin is an acaricide that has this kind of mode of action. This compound quickly gained popularity worldwide owing to high efficacy against both tetranychid and eriophyoid mites, quick knockdown effect and long-lasting impact. In addition, this substance has low to moderate mammalian toxicity and short to moderate environmental persistence (Dekeyser 2005, Kramer & Schirmer 2007, Van Leewen et al. 2010).

Spirodiclofen, a tetronic acid derivative, has recently been commercialized as an acaricide highly effective against all relevant phytophagous mite species. Because of its new mode of action–inhibition of lipid synthesis–this compound effectively controls mite populations resistant to other acaricides (Nauen 2000, Elbert et al. 2002, Dekeyser 2005).

Many studies have examined sublethal effects of pesticides on phytoseiid mites (e.g., Ibrahim & Yee 2000, Chen et al. 2003, Bernard 2004, Adenir et al. 2005), but no literature exists on the lethal effects of this compounds on reproductive characteristics and predation of *N. californicus*. For these reasons, experiments were conducted to evaluate the effects of a pesticide generally used to control European red mite, *P. ulmi* in apple orchard, on the development and fecundityof *N. californicus*. Such information can be used to predict the potential of fenazaquin and spirodiclofen in combination with one of the natural enemies of *P. ulmi*.

Materials and methods

European Red Mite Rearing

Three-year-old apple trees, Golden Delicious cultivar, were used in the experiments. The trees were planted in pots containing approximately 30 kg of mixture of soil, sand and peat (1:1:1). Adults of *P. ulmi* were collected from apple grown in orchards without pesticide application in the region of Nazlo located in West Azerbaijan province in northwestern Iran. Rearing was conducted at the Acarology Laboratory of the Agriculture faculty at the University of Urmia, West Azarbaijan province, Iran, at 25 ± 2ºC, 70 ± 10 % RH 14 h light (L): 10 h dark (D) conditions.

Predatory Mite Rearing

The colony of *N. californicus* was purchased from Koppert Biological Systems (Spical®; Berkel en Rodenrijs, The Netherlands) in 2012 and maintained on leaves of apple were infested with *P. ulmi.* The stock culture of *N. californicus* was maintained in a controlled growth chamber, 25ºC, 60–70% relative humidity (RH) and 16 h light (L): 8 h dark (D) conditions.

Rearing Units

In the present study, each leaf was placed on a Munger cell, which consisted of two glasses (7×10×6 cm). In the middle of each glass there was a small hole (2 cm in diameter) (Overmeer1985). The cell was placed on a wet sponge in a plastic tray containing water (Nomikou et al. 2005). The prey (*P. ulmi*) was introduced onto upper surface leaves and left to settle for 20 h. Adult female *N. californicus* were then introduced and allowed to feed.

Chemicals Tested

Fenazaquin, as commercial formulation Pride 20% SC, and Spirodiclofen, as commercial formulation Envidor, were obtained from Giah Company, Iran.

Life-Table Assay

A modified leaf-dip technique was used to assess life-table parameters of *N. californicus* (Ibrahim &Yee 2000). All experiments were conducted in the laboratory at 25 ± 0.5°C, 50 ± 5% RH and a photoperiod of 16:8 h (L: D). The concentrations of acaricides were chosen based on maximum field recommended concentration (MFRC) of these commercial compounds in Iran.

Concentrations were used as 40 mg a.i. liter^{-1} and 50 mg a.i. liter^{-1} for fenazaquin and Spirodiclofen, respectively. The leaf discs were dipped in the tested acaricide solutions for 10 s and allowed to dry for about 3 h. The control leaf discs were dipped in distilled water. Twenty-five 24-h-old unmated females were transferred on each leaf disc using a fine soft pointed brush. Forty-eight hours after treatment, each survived female was exposed to an untreated male from stock colony. Dead males were replaced with new live ones daily. Over the following seven days, the females were transferred daily to new discs. In all experiments, all stages of *P. ulmi* were provided as a food source.

Daily monitoring of female survivors, the number of eggs laid, number of offspring individuals reaching adult stage, and the offspring sex ratio provided the basic elements for both the construction of life tables and the calculation of life-table parameters. These were age-specific survival, that is, the proportion of living females in age interval x (l_x); and age-specific fertility, that is, the number of female offspring per female in age interval *x* (m_x) where *x* was the age of females in days. Based on procedures developed by Birch (1948) and Carey (1993), the following life-table parameters were calculated: net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ), doubling time (*DT*), and mean generation time (*T*). The jackknife method was used to estimate the pseudo-values of above-described parameters and comparing them statistically (Maia et al. 2000). To analyze population growth parameters, we used SAS (SAS Institute 2003) and Minitab (MINITAB 2000).

Results

Effect of acaricides on biological parameters

Results in Table 1 show that lethal concentrations of both of products significantly affected fecundity, oviposition, female longevity and egg hatch but no significant effect on pre-oviposition in spirodiclofen treatment. Our results indicated that post-oviposition period in spirodiclofen lasted 16.12 days and was closer to control (17.68 days) while in fenazaquin it was significantly lower than control. There was not a significant difference between acaricides (fenazaquin and spirodiclofen) in above-mentioned parameters except in female longevity and postoviposition period.

Our findings revealed that of fenazaquin and spirodiclofen had no significant effects on development duration of different life stages of *N. californicus* in comparison with the control (Table 2).

The acaricides tested had different effects on survival of immature stages (Table 3). Survival to adulthood was affected by both acaricides. The survival of eggs and larvae of predator decreased and was influenced by fenazaquin and spirodiclofen.

The decreased nymph survival exhibited significant difference in the acaricides compared to control.

Life-table parameters of the offspring of treated females are shown in Table 4. Compared to control, females had significantly lower net reproductive rate (R_0). Further, the intrinsic rate of increase (r_m) and finite rate of increase (λ) value were significantly lower than those in the control.

Mean generation time (*T*) was also found to be

Table 1. Effects of fenazaquin and spirodiclofen on biological parameters of *Neoseiulus californicus.*

Biological parameters	Mean± SE		
	Control	Fenazaquin	Spirodiclofen
Pre-oviposition (days)	2.64±0.11	3.76±0.09	3.04±0.09
Oviposition (days)	16.48±0.03	10.08±0.03^{a}	10.96±0.03^{b}
Post-oviposition (days)	17.68±0.64	5.8±0.01^{a}	16.12±0.2^{b}
Fecundity (eggs)	31.64±0.13	11.4±0.12^{a}	12.12±0.13^{b}
Egg hatch (%)	98±0.11	71±0.37^{b}	64±0.13^{a}
Female longevity (days ± SE)	43.12±0.203	19.64±0.09^{a}	30.12±0.27^{b}

Table 2. Effects of fenazaquin and spirodiclofen on developmental durations of different life stages, *Neoseiulus californicus.*

Life stages	Days (mean ± SE)		
	Control	Fenazaquin	Spirodiclofen
Egg	1.8± 0.082	2.48±0.102	2.52±0.10
Larvae	1.04± 0.04	1.8±0.08	1.32± 0.09
Protonymph	1.04± 0.04	2.32±0.09	2.12±0.15
Deutonymph	1.088± 0.09	2.32±0.09	2.24±0.10
Nymph	2.12±0.15	4.64±0.105	4.36±0.05
Total immature stage	5.12±0.17	8.92±0.18	8.2±0.18

Table 3. Effects of fenazaquin and spirodiclofen on survival of immature stages of *Neoseiulus californicus*.

Treatments	Stage specific survival (% ± SE)				Survival to Adulthood (%± SE)
	Egg	Larvae	Protonymph	Deutonymph	
Control	98±0.11	98±0.16	97±0.56	100	95±0.84
Fenazaquin	71 ^{b}±0.37	42^{a}±0.31	50^{a}±0.18	53^{a}±0.58	65^{a}±0.63
Spirodiclofen	64 ^{a}±0.13	56^{b}±0.25	72^{b}±0.29	76^{b}±0.105	71^{b}±0.03

Table 4. Effects of fenazaquin and spirodiclofen on demographic parameters of *Neoseiulus californicus* feeding on *Panonychus ulmi* at 25ºC.

Parameters	Mean		
	Control	Fenazaquin	Spirodiclofen
R_o (females/female)	31.64	11.40^a	12.12^b
T (day)	14.54	17.48	16.27
r_m (females/female/day)	0.237569	0.139^a	0.153^b
λ (females/female/day)	1.2682	1.14^a	1.16^b
DT (day)	1.27	2.16	1.96

significantly lower than the control. In addition, doubling time (DT) of treated mites was higher than untreated ones.

Net reproductive rate (R_o), mean generation time (T), intrinsic rate of increase (r_m), doubling time (D_t), and finite rate of increase (λ).

Discussion

A single control method against pests is not adequate and the success rate without any chemical control is significantly low, but pesticides should be chosen from products with the least effect on the environment and natural enemies and with a narrow spectrum of effects on specific pest species (Kaplan et al. 2012). Toxicological studies on predaceous mites of economic importance are mainly concerned with measuring possible adverse effects of pesticides on these tiny creatures (Alzoubi & Cobanoglu 2007). The evaluation of pesticide effects based solely on treated mites would have incomplete end points. Therefore, to evaluate total effects of the pesticides on predators, determining these effects on subsequent generation is necessary (Hamedi et al. 2010).

Results of the present study indicated that fenazaquin and spirodiclofen considerably affected fecundity and fertility of *N. californicus* females which was in agreement with studies of Kim & Paik (1996) and Hamedi et al. (2010) that have proved the adverse effect of fenpyroximate on fecundity of phytoseiid predators. In addition, egg hatchability of *N. californicus* was affected by these acaricides in our study, which is in contrast with the results of Kim & Paik (1996) and Hamedi et al. (2010) and may be due to the effect of the formulation type or to different type of pesticide and sensitivity of the mites. Kaplan et al. (2012) found that hexythiazox had no effect on egg production of *N. californicus.*

Results of this study showed that the tested acaricides have no negative effect on development times of different life stages of *N. californicus*. Similarly, Kaplan et al. (2012) found that indoxacarb was harmless to nymphs of *N. californicus.*

Longevity of *N. californicus* was affected by lethal concentrations of the acaricides. Reduction in female longevity of *Galendromus occidentalis* Nesbitt (Saenz-de-Cabezon Irrigaría et al. 2007) and *P. plumifer* (Hamedi et al. 2010) using fenpyroximate was reported. Shortened longevity of both treated females and their offspring may be partially explained by reduced food uptake as a consequence of acaricides' effects (Hamedi et al. 2009).

Urbaneja et al. (2008) reported that fenazaquin was even moderately harmful for *N. californicus*. Harmful effects of fenazaquin on another predatory mite occurring in Spanish citrus orchards, *Euseius stipulatus* Athias-Henriot, were already known (Jacas & Garcia-Mar 2002). Such harmful effects on this phytoseiid and other beneficial arthropods, and fenanzaquin's high persistence on foliage, have made it difficult to include in IPM programmes (Viggiani & Bernardo 2001).

Differences in susceptibility of phytoseiid species and populations, and the tested acaricide concentrations and formulations could be responsible for the conflicting results of different studies. Application of lethal concentrations of fenazaquin and spirodiclofen decreased survival of immature stages of affected pre-adult stages.

Demographic toxicology has been considered as a better measure of response to toxicants than individual life history traits (Forbes & Calow 1999). The intrinsic rate of increase (r_m) has been recommended for evaluating the total effects of pesticides, because it is based on both survivorship and fecundity (Stark & Wennergren 1995). Several researchers have reported that life-table parameters of phytophagous and predatory mites were affected by sublethal concentrations of pesticides (Ibrahim & Yee 2000, Marcic 2005, Marcic 2007). Other studies also indicated differences in susceptibility of phytoseiid mites to pyrethroids.

Markwick (1986) reported that adult females of *T. pyri* were approximately 300 times more tolerant to this pyrethroid than *Phytoseiulus persimilis* Athias-Henriot. On the other hand, *Typhlodromus pyri* was only five times more susceptible to this pyrethroid than *Amblyseius andersoni* (Bonafos et al. 2007). Poletti and Omoto (2005) verified that *Euseius concordis* (Chant) was around 50 times more tolerant to deltamethrin than *Iphiseiodes zuluagai* Denmark & Muma. High tolerance to several pesticides in the same population of *N. californicus* evaluated herein was also documented by Sato et al. (2002). Further studies corroborated the high tolerance of this population relative to the susceptibility of *Brevipalpus phoenicis* (Geijskes) and *E. concordis* to several pesticides recommended in citrus groves (Silva et al. 2011).

In our study, the life table parameters showed significant differences in population growth and reproductive performance between treated females of *N. californicus*. The net reproductive rate (R_0), intrinsic rate of increase (r_m), and finite rate of increase (λ) of treated females were inferior to the control and these were achieved within a shorter mean generation time (T). This in turn resulted in a longer doubling time (DT). The reduction of r_m value was noticeable in females.

European red mite is the major pest in apple orchards in Iran. In commercial orchards, the potential of *P. ulmi* to cause severe economic damage necessitates chemical control several times a year (Croft 1976). Fenazaquin and spirodiclofen provided good efficacy against this pest. In the present study, although the acaricides tested have no negative effect on developmental durations of different life stages, other parameters adversely impacted populations of *N. californicus*.

Given the results of this study, it can be concluded that fenazaquin and spirodiclofen should not be used in pesticide programs where *N. californicus* is used to control pest species. Low concentrations may be used in combination with biological control agents within an IPM system (Dent 2000), reducing the selection pressure and development of resistance (Marcic 2007). Herron et al. (1993) and Cheon et al. (2007) suggested that acaricides at reduced rates might be used to adjust the predator/prey ratio.

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