Türk. entomol. derg., 2023, 47 (1): 3-13
DOI: http://dx.doi.org/10.16970/entoted.1171756

ISSN 1010-6960
E-ISSN 2536-491X

Original article (Orijinal araştırma)

The toxic effects of some acaricides on the tomato russet mite and its predator *Amblyseius swirskii* Athias-Henriot, 1962 (Acari: Phytoseiidae)[1]

Bazı akarisitlerin domates pas akarı ve avcısı *Amblyseius swirskii* Athias-Henriot, 1962 (Acari: Phytoseiidae)'ye toksik etkileri

Ayşenur KOLCU[2] **Nabi Alper KUMRAL[3*]**

Abstract

The tomato russet mite, *Aculops lycopersici* (Massee, 1937) (Acari: Eriophyidae) is a common pest of tomatoes. The predatory mite, *Amblyseius swirskii* Athias-Henriot, 1962 (Acari: Phytoseiidae), can control *A. lycopersici* populations. To integrate biological and chemical control of *A. lycopersici*, side effects of the lethal concentrations of acaricides, as a predator, on *A. swirskii* should be considered. The lethal concentrations of 14 acaricides for *A. lycopersici* were determined under laboratory conditions at Bursa Uludağ University during 2017-2018. To understand the toxic impacts of the acaricides on juveniles and females of *A. swirskii*, the LC_{99} values for *A. lycopersici* of each acaricide were applied to *A. swirskii*. The reproduction reduction effects of the LC_{99} values were also assessed. Quite low concentrations of abamectin, milbemectin, pyridaben, azadirachtin and sulphur were found to be toxic for *A. lycopersici*. Based on the side effect scale, the LC_{99} values of abamectin, acequinocyl, bifenazate, fenproximate, fenbutatin oxide, hexythiazox, milbemectin and sulphur that killed *A. lycopersici* were found to be slightly toxic to both females and juveniles of *A. swirskii*. The results of this comparative toxicological study have showed that more field studies should be conducted to evaluate the effectiveness of using low concentrations of acaricides with *A. swirskii* in combination for controlling *A. lycopersici*.

Keywords: Acaricide, biological control, phytoseiids, side-effect, tomato russet mite, toxicology

Öz

Domates pas akarı, *Aculops lycopersici* (Massee, 1937) (Acari: Eriophyidae) domatesin ana zararlılarından biridir. Avcı akar *Amblyseius swirskii* Athias-Henriot, 1962 (Acari: Phytoseiidae), *A. lycopersici* popülasyonlarını baskı altında tutabilmektedir. Ancak, *A. lycopersici*'nin mücadelesinde biyolojik ve kimyasal yöntemleri birbiriyle entegre edebilmek için *A. swirskii*'ye akarisitlerin yan etkilerinin dikkate alınması gerekmektedir. Bu nedenle, öncelikle *A. lycopersici*'ye 14 farklı akarisitin öldürücü konsantrasyonları 2017-2018 yılları arasında Bursa Uludağ Üniversitesi'nde laboratuvar koşullarında belirlenmiştir. Bu akarisitlerin *A. swirskii* üzerindeki yan etkilerini anlamak için, *A. lycopersici* için belirlenen LC_{99} değerleri *A. swirskii*'nin hem ergin öncesi hem de dişi dönemlerine uygulanmıştır. Ayrıca, bu LC_{99} değerlerinin avcının üremesini azaltıcı etkileri değerlendirilmiştir. Çalışmada, abamectin, milbemectin, pyridaben, azadirachtin ve kükürtün çok düşük konsantrasyonları dahi *A. lycopersici* için oldukça zehirli bulunmuştur. Yan etki skalasına göre, abamectin, acequinocyl, bifenazate, fenproximate, fenbutatin oxide, hexythiazox, milbemectin ve kükürtün *A. lycopersici* için bulunan LC_{99} değerleri *A. swirskii*'nin ergin öncesi ve dişi dönemleri için hafif zehirli bulunmuştur. Bu karşılaştırmalı toksikoloji çalışmaya göre, *A. lycopersici*'nin mücadelesinde *A. swirskii*'nin birlikte kullanımı için akarisitlerin düşük konsantrasyonlarının kullanımının ileride yapılacak saha çalışmaları ile değerlendirilmelidir.

Anahtar sözcükler: Akarisit, biyolojik mücadele, phytoseiidler, yan etki, domates pas akarı, toksikoloji

[1] A part of this study was presented and published only as abstract in XI European Congress of Entomology: 2-6 July 2018, Italy. The study was funded by TUBITAK with TOVAG 117O377 grant no project.
[2] Bursa Uludağ University, Graduate School of Natural and Applied Science, Division of Plant Protection, 16059, Bursa, Turkey
[3] Bursa Uludağ University, Agricultural Faculty, Department of Plant Protection, 16059, Bursa, Turkey
* Corresponding author (Sorumlu yazar) e-mail: akumral@uludag.edu.tr
Received (Alınış): 08.09.2022 Accepted (Kabul ediliş): 21.03.2023 Published Online (Çevrimiçi Yayın Tarihi): 27.03.2023

Introduction

The tomato russet mite, *Aculops lycopersici* (Massee, 1937) (Acari: Eriophyidae) is one of the main pests of tomatoes all over the world (Abou-Awad, 1979; Şekeroğlu & Özgür, 1984; Lindquist et al., 1996; Duso et al., 2010; Çobanoğlu & Kumral, 2014; Aysan & Kumral, 2018; Vervaet et al., 2021). Since the first visible symptoms of *A. lycopersici* on tomato leaves are similar to those of microelement deficiencies, most farmers are not able to recognize the early mite infestations. When the mite cannot be controlled, high populations can develop quickly and become a serious threat to tomato production (Abou-Awad, 1979; Royalty & Perring, 1987; Duso et al., 2010; Kumral et al., 2014). Therefore, the detection of *A. lycopersici* populations and the correct timing of the acaricide application are often problematic (Duso et al., 2010; Vervaet et al., 2021). In terms of practical control of *A. lycopersici*, the only feasible method is the chemical control. Abamectin, milbemectin and pyridaben are registered acaricides against *A. lycopersici* in Turkey (BKU, 2021). The effectiveness of these acaricides on *A. lycopersici* was demonstrated in previous studies (Vervaet et al., 2021). Nevertheless, the biological effects of several acaricides/insecticides, to *A. lycopersici* are not known.

The European Union Directive 2009/128/EC encourages member and associated countries to use more environmentally friendly alternatives to synthetic pesticides, such as biological control methods. Various biological control methods have recently been used as part of this effort. For instance, spider mites and eriophyid mites have been controlled successfully by members of the Phytoseiidae family (Gerson et al., 2003). *Amblyseius swirskii* Athias-Henriot, 1962 (Acari: Phytoseiidae) is commercially used as a biological control agent against whiteflies, spider mites and thrips in more than 50 countries (Calvo et al., 2015). This mite is also an effective predator of *A. lycopersici* (Van Houten et al., 2013; Kumral et al., 2022, 2023). The ecological solution for the control of *A. lycopersici* is to prefer acaricides that have no side effect for non-target organisms such as predatory mites. To date, the recommended field concentrations of the registered pesticides are found as very toxic to some predatory mites (Fiedler & Sosnowska, 2012; Döker & Kazak, 2019; Kumral et al., 2021).

The integration of biological control agents with pesticide applications can be successful, only in cases when these agents are not affected negatively (Overmeer & Van Zon, 1982; Blümel et al., 1999). Therefore, side effect studies on the female biological control agents should focus on acute toxic effects including the effects on their reproductions (Overmeer & Van Zon, 1982). As well as examining their juvenile stages. This is because biological control agents are in general more susceptible to insecticide/acaricides during their juvenile stages compared to adults. The survival of juveniles is greatly important for maintaining the population of the predator (van Zon & Wysoki, 1978). One of the aims of this study was to determine the lethal concentrations of 14 acaricides having different modes of action (abamectin, acequinocyl, azadirachtin, bifenazate, bifenthrin, fenbutatin-oxide, fenpyroximate, hexythiazox, sulphur, milbemectin, pyridaben, spiromesifen, spirodiclofen and tebufenpyrad) for *A. lycopersici.* The second aim was to establish the side-effects of these lethal concentrations (LC_{99} values determined for *A. lycopersici*) on juveniles and adult females of *A. swirskii* under laboratory conditions.

Materials and Methods

Chemicals

The 14 commercially used acaricide formulations belonging to different chemical groups and modes of action were tested: abamectin, acequinocyl, azadirachtin, bifenazate, bifenthrin, fenbutatin-oxide, fenpyroximate, hexythiazox, sulphur, milbemectin, pyridaben, spiromesifen, spirodiclofen and tebufenpyrad (Table 1).

Table 1. The information about tested acaricides

Active substance	Chemical group[1]	Mode of Action[1]	Mode of action classes[1]	Commercial name	Company	Formulation type[2]	Rate of active substance (g/L)[2]	HRC (mg/L)[2]
Abamectin	Avermectins	Glutamate-gated chloride channel (GluCl) allosteric modulators	6	Algamek	Agrobest	EC	18	4.5
Milbemectin				Milbeknock	SumiAgro	EC	9.3	9.3
Bifenthrin	Synthetic pyretroids	Sodium channel modulators	3	Bifenstar	Koruma	EC	100	70
Sulphur	Minerals	Compounds of unknown or multible MoA	UN	Power sulphur'H	Safa Tarım	WP	80%	3200
Azadirachtin	Botanical acaricides			Nimbecidine	Agrobest	SC	0.3	1.5
Acequinocyl	Unclassified	Mitochondrial complex III electron transport inhibitors	20A	Kanemite	SumiAgro	SC	156	195
Bifenazate	Hydrazine carboxylate		20D	Fluramite	Hektaş	SC	240	144
Fenbutatine oxide	Organometal	Inhibitors of mitochondrial ATP synthase	12B	Quiz	Hektaş	SC	550	330
Pyridaben	Pyridazinone	Mitochondrial complex I electron transport inhibitors	21A	Sanmite	SumiAgro	WP	20%	150
Fenproximate	Pyrazolium			Raincall	Koruma	SC	50	37.5
Tebufenpyrad				Croshe	Hektaş	WP	20%	150
Hexythiazox	Carboxamide	Mite growth inhibitors	10A	Nissuron	SumiAgro	SC	50	50
Spridomesifen	Tetronic& Tetramic acid derivates	Inhibitors of acetyl CoA carboxylase	23	Oberon	Bayer	SC	240	120
Spirodiclofen				Smach	Hektaş	SC	240	60

[1] The data were obtained from mode of action database of Insecticide Resistance Action Committee (IRAC, 2022).
[2] HRC, highest recommended concentration. The data were provided from Turkish Agricultural Ministry Pesticide Registration Database (BKU, 2021).

Mite populations

The *A. lycopersici* population was collected from the tomato fields of the Gorukle Campus (Nilufer, Turkey) in 2012. The species was identified by Edward Ueckermann (Pretoria, South Africa) based on the photos that were taken by using scanning electron microscopy techniques (Kumral et al., 2014). The mite population was mass reared for numerous generations on potted tomato plants in a climate room at 27 ± 1°C, 70 ± 5% relative humidity and a photoperiod of 16 h light: 8 h dark.

The Turkish native field population of *A. swirskii* was obtained from the Acarology laboratory of Ankara University. The species was collected from an orange orchard of Adana (Turkey) in 2015 and identified by Sultan Çobanoğlu (Ankara, Turkey) based on identification keys by Swirski et al. (1998) and Chant & McMurtry (2007). The predatory mite population was mass reared on bean leaves placed adaxial-side down on water saturated cotton wools in plastic boxes (15 x 10 x 5 cm) with air holes, in the same climate conditions described earlier. The predator was fed with *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) and *Typha latifolia* pollen (Overmeer, 1985). The tested mites were fed on *A. lycopersici* and pollen for two subsequent generations before the bioassays. Newly laid eggs were collected from culture boxes and transferred to the new rearing boxes to obtain a group of individuals at the same age for the experiments.

Bioassays on *Aculops lycopersici*

The acute toxic effects of fresh acaricide residues on *A. lycopersici* adults were evaluated using a modified leaf disc method described by Keskin & Kumral (2015) and Abou-Awad & El-Banhawy (1985) under laboratory conditions. Briefly, each tomato leaf disc (30 mm diameter) prepared by a metal leaf cutter was placed on warm Agar-agar solutions (2%) then poured into a Petri dish (55 mm diameter). Five or more different (max. 10) acaricide concentrations resulting in 10-90% mortality in newly emerged *A. lycopersici* female and male adults were used for the bioassays (Table 2). For each bioassay, three replicates were performed for both concentrations and controls (distilled water). Each replication of a bioassay was performed at a different time. Two ml of different acaricide concentrations were applied on the abaxial-side of the leaf disc for 3 s with spray tower resulting in a deposition of 1.5 mg/cm^2 (Potter precision, Burkard Manufacturing Co. Ltd. Rickmansworth U.K.). The sprayed tomato leaf discs were then dried at room temperature for 30 min (Potter, 1952). Forty *A. lycopersici* females (only protonymphs for the mite growth inhibitors acaricide) were transferred onto the leaf discs using a paintbrush. Then, Petri lids having many ventilation holes (>0.1 µm diameter) opened with hot needles were closed. Finally, the Petri dishes were put in the above-mentioned climate conditions. The survival of mites was checked once every 24 h after the acaricide application. The mites were checked using a brush, and the mites unable to walk were considered as dead. The mortality rates in control trials were lower than 7.5% (Table 2).

Bioassays on *Amblyseius swirskii*

The acute toxic effect of fresh acaricide residues on *A. swirskii* was assessed using a modification of the standardized method described by Overmeer & Van Zon (1982) under laboratory conditions (Kumral et al. 2021). Briefly, 2 mL of LC_{99} values (determined for *A. lycopersici*) for each acaricide were applied on the undersurface of the tomato leaves with the spray tower for 3 s resulting in a deposition of 1.5 mg liquid per cm^2. Following that, the tomato leaf discs were dried during 30 min under room conditions. The tomato leaves sprayed with distilled water were used as a control trial (Potter, 1952). The test tool, Plexiglas Munger cells, which have 8 x 10 x 1 cm dimensions with a circular hole of diameter of 5 cm in the center were used (Overmeer, 1982; Kumral et al., 2021). Sprayed tomato leaf and a filter paper were put between Plexiglasses with a circular hole and without a hole. A piece of filter paper was slightly soaked with distilled water.

To evaluate acute toxic effects to *A. swirskii* females, an equal amount of prey (30 mites) and pollen were put into the cell, followed by the same age phytoseiid females (~5 days old) obtained from same age population. For the juvenile test, matured eggs (1.5-2 days old) were used. A total of twenty predatory mites or eggs were used for each replicate. For each acaricide, three replicates were performed at different times. Munger cells were closed by placing a top Plexiglas plate onto the whole fragment of the Munger cell, which was held together with the aid of four binder clips. The cells were put in a climate room at the same conditions. The numbers of death female and juvenile mites were recorded under a stereomicroscope. Juveniles and females of *A. swirskii* were considered as dead after 4 days if any larva stage did not reach adult stage and no movement for mites were observed when a gentle touch was applied by a brush.

The effects of acaricides on the reproduction of *A. swirskii* females during the lifespan were investigated by using the method described by Overmeer & Van Zon (1982). The LC_{99} values (determined for *A. lycopersici*) were applied to tomato leaves with the same bioassay method. Following the application, a mated *A. swirskii* female (each newly emerged female was paired with a male adult for 12 h) were introduced on the surface of each tomato leaf disc put into a Munger cell. The tomato leaves treated with distilled water only served as control. Ten females were treated for each replicate and each treatment comprised of three replicates. The mortality and number of eggs were recorded once per 24 h until all of the females died naturally.

Data analysis

Mortality percentages for *A. lycopersici* and *A. swirskii* were corrected using control percentages with Abbott's formula (Abbott, 1925). The SPSS 23.0 program was used for the probit analysis of the concentration–response data for generating the LC_{50} and LC_{99} values (Finney, 1971). A one-way ANOVA was conducted to determine differences in mortality rates of juvenile stages and females of *A. swirskii* among different acaricide treatments. Before the analyses, corrected mortality data were transformed by using arcsin transformation. Means obtained in all ANOVAs were separated using Tukey's HSD post-hoc test (α = 0.05). Moreover, the combined total side effect (*E*) of the acaricides on *A. swirskii* was calculated using the following formula as suggested by Overmeer & Van Zon (1982):

$$E= 100- [(100-M) \times R]$$

where *E* is the coefficient of toxicity; *M* shows corrected mortality effects using Abbott formula on *A. swirskii* juvenile stages or females of LC_{99} values calculated for *A. lycopersici; M* was calculated separately for both juvenile stages (*JM*) and females (*FM*); *R* is the ratio between the mean number of eggs laid by *A. swirskii* females treated LC_{99} of acaricides and the mean number of eggs produced by the females exposed to distilled water (control group). If the reproduction reduction rate (R) is found as "1", the reproduction of females treated by any acaricide is not affected when compared with those of the control females (Overmeer & Van Zon, 1982). The concentrations of each acaricides were classified using these *E* results: class I (<30% = harmless), class II (30-79% = slightly harmful), class III (80-99% = moderately harmful), class IV (>99 % = harmful) (Sterk et al., 1999).

Results

Effects on *Aculops lycopersici*

Table 2 shows the toxicity results of 14 acaricides to *A. lycopersici*. The estimated LC_{50} and LC_{99} values showed differences among acaricides. Some acaricides such as pyridaben, azadirachtin, abamectin and milbemectin, respectively, have higher toxic effect to *A. lycopersici* at low concentrations compared with those of other acaricides. The LC_{99} value of each acaricide was used as the side effect studies of *A. swirskii* for further experiments.

Table 2. The bioassay and probit analysis results for *Aculops lycopersici*

Active substance	n[a]	C[b]	T[c] (h)	MC[d] (%)	Slope±SE	LC_{50} (a.i. mg/L)	95% confidental limits		LC_{99} (a.i. mg/L)	95% confidental limits		X^2	P[e]
							Lowest conc.	Highest conc.		Lowest conc.	Highest conc.		
Abamectin	960	7	24	3.3	13.51±1.04	0.059	0.05	0.07	0.23	0.21	0.26	15.52	0.69
Milbemectin	960	7	48	5.0	13.71±1.11	0.095	0.09	0.11	0.26	0.24	0.30	30.97	0.19
Bifenthrin	1320	10	48	2.5	0.29±0.02	3.30	2.69	4.13	11.14	9.09	14.69	139.88	<0.01
Sulphur	716	5	48	3.3	3.26±0.26	5.61	4.77	6.65	28.99	19.13	61.93	41.68	<0.01
Azadirachtin	1080	8	72	3.4	1.55±0.01	0.03	0.02	0.06	0.17	0.12	0.35	154.66	<0.01
Acequinocyl	1080	8	72	3.3	13.51±1.04	32.98	30.97	35.25	79.08	73.06	85.59	25.01	0.46
Bifenazate	1200	9	72	7.5	0.01±0.00	141.45	130.48	152.59	410.56	380.77	447.40	31.36	0.30
Fenbutatin oxide	1080	8	72	0.0	0.02±0.01	47.63	34.99	64.19	180.44	142.32	253.3	57.62	<0.01
Pyridaben	840	6	24	0.0	0.97±0.66	0.004	0.003	0.005	0.12	0.01	0.016	80.78	<0.01
Fenproximate	1080	8	72	5.9	0.09±0.01	13.64	12.59	14.79	41.15	37.71	45.47	23.10	0.57
Tebufenpyrad	1200	9	72	3.3	0.06±0.01	16.43	13.53	20.39	53.43	44.29	68.12	95.04	<0.01
Hexythiazox	1080	8	96	2.5	0.04±0.01	29.99	27.54	32.48	92.87	86.38	100.70	32.17	0.15
Spridomesifen	1080	8	96	6.7	0.02±0.01	17.19	4.69	29.81	128.75	93.27	218.2	189.27	<0.01
Spirodiclofen	960	7	96	6.7	0.076±0.01	12.07	9.74	15.00	42.54	35.13	54.91	56.02	<0.01

[a] number of tested individuals; [b] number of tested concentrations for each acaricides; [c] Observation time for each acaricides; [d] Mortality rate of control individuals; [e] Probability.

Side effects for *Ambylesius swirskii*

The side effects of LC_{99} values (for *A. lycopersici*) of 14 acaricides on juveniles and females of *A. swirskii* are given in Table 3. The corrected mortality rates (JM) differed significantly in juveniles after the exposure of different acaricides ($F_{13,50}$= 11.72; P<0.01). Significantly low JM values (5.48 to 31.68%) were detected for juveniles treated with acequinocyl, milbemectin, bifenazate, abamectin, bifenthrin and fenproximate. Moderate JM values (35.72 to 53.23%) were observed for hexythiazox, fenbutatin oxide, pyridaben and sulphur. Based on JM values, the highly toxic acaricides for juveniles were tebufenpyrad (89.06%), azadirachtin (87.29%), spirodiclofen (82.04%) and spiromesifen (80.14%).

The LC_{99} values of the acaricides significantly reduced the survival of *A. swirskii* females (Table 3). Sulphur (5.55%), fenpyroximate (12.50%), abamectin (13.89%) and pyridaben (15.81%) were much less toxic to *A. swirskii* females compared with other acaricides ($F_{13,50}$=6.69; P<0.01). Moderate mortality rates (24.44 to 54.17%) of females (FM) were observed after milbemectin, spirodiclofen, fenbutatin-oxide, hexythiazox, azadirachtin, bifenazate, acequinocyl and spiromesifen applications. Significantly high FM values were determined in the females by exposure to tebufenpyrad (59.38%) and bifenthrin (77.50%).

Table 3. The side effects on *Amblyseius swirskii* of 14 acaricides

Active substance	C[a] (a.i. mg/L)	N[b]	JM[c] (%)	FM[d] (%)	R[e]	E[f] (%)	Juvenile toxicity scale[g]	E[h] (%)	Female toxicity scale[g]
Abamectin	0.23	60	23.70 cd[i]	13.89 d[i]	0.67	48.88	II	42.29	II
Milbemectin	0.26	60	15.23 cd	24.44 b-d	0.34	71.18	II	74.31	II
Bifenthrin	11.14	60	28.38 cd	77.50 a	0.70	49.87	II	84.25	III
Sulphur	28.99	60	53.23 bc	5.55 d	0.51	76.15	II	51.83	II
Azadirachtin	0.17	60	87.29 a	40.63 b-d	0.21	97.33	III	87.53	III
Acequinocyl	79.08	60	5.48 d	47.50 a-d	0.41	61.25	II	78.48	II
Bifenazate	410.56	60	22.81 cd	40.63 b-d	0.52	59.86	II	69.13	II
Fenbutatin oxide	180.44	60	39.95 b-d	30.55 b-d	0.47	71.78	II	67.36	II
Pyridaben	0.12	60	51.80 b-d	15.81 d	0.40	80.72	III	66.32	II
Fenproximate	41.15	60	31.68 cd	12.50 d	0.51	65.16	II	55.38	II
Tebufenpyrad	53.43	60	89.06 a	59.38 ab	0.40	95.62	III	83.75	III
Hexythiazox	92.87	60	35.72 cd	34.38 b-d	0.41	73.64	II	73.09	II
Spridomesifen	128.75	60	80.14 ab	54.17 a-c	0.52	89.63	III	76.17	II
Spirodiclofen	42.54	60	82.04 ab	27.50 b-d	0.49	91.19	III	64.48	II

[a], Applied concentrations (LC_{99} value for *Aculops lycopersici*) for each acaricides
[b], A number of tested individual, 60 females or 60 juveniles (20 x 3 replicates) also used in the control spraying water. The mortality rates were not exceed 20% in the bioassays.
[c], The corrected mortality rates of juveniles (larvae or nymphs)
[d], The corrected mortality rates of females
[e], Reproduction reduction rate of treated females compared with untreated ones
[f], Total side effect according to juvenile deaths= 100-[(100-JM)) x R]
[g], Total side effect according to female deaths= 100-[(100-FM)) x R]
[h], The side effect scale [I = harmless (<%30), II = slightly harmful (30–79%), III = moderately harmful (80–99%), IV = harmful (>99)] (Sterk et al., 1999)
[i], Means followed by a different letter differ significantly in same column (<0.05)

Compared with untreated control, the decreases in fecundity of *A. swirskii* females (R) were determined by exposure to the LC_{99} values of the acaricides (Table 3). The R ratios were much less in treated females with azadirachtin (0.21) and milbemectin (0.34). Moderate R ratios (0.40 to 0.52) were observed in females treated with tebufenpyrad, pyridaben, acequinocyl, hexythiazox, fenbutatin-oxide, spirodiclofen, sulphur, fenpyroximate, bifenazate and spiromesifen, low to high, respectively. Significant high R ratios were found in females exposed to abamectin (0.67) and bifenthrin (0.70) (Table 3).

Based on the side effect scale, the concentrations that killed *A. lycopersici* for abamectin, acequinocyl, bifenazate, fenproximate, fenbutatin oxide, hexythiazox, milbemectin and sulphur were slightly harmful for both juveniles and females (Table 3). The concentrations of pyridaben, spiromesifen and spirodiclofen were found to be slightly harmful for females but moderately harmful for juveniles. The other acaricides (tebufenpyrad and azadirachtin) were observed as moderately harmful for both juveniles and females. None of the acaricide concentrations was found either harmless or harmful against *A. swirskii.*

Discussion

In this study, the concentrations (lower than their HRCs registered in Turkey) of abamectin, milbemectin, bifenthrin, pyridaben, sulfur and azadirachtin were found to be toxic to *A. lycopersici*. Similarly, previous studies showed that, low concentrations of abamectin, milbemectin, pyridaben and bifenthrin were effective against *A. lycopersici* (Royalty & Perring, 1987; Silva et al., 1988; Arbabi, 2013; Spasov et al., 2014; Fischer & Klötzli, 2015) and some other eriophyid mites such as *Epitrimerus pyri* Nalepa,1898, *Aculus schlechtendali* (Nalepa, 1890) and *Eriophyes dioscoridis* Soliman & Abou-Awad, 1977 (Acari: Eriophyidae) (Van Leeuwen et al. 2010). Furthermore, several laboratory and field studies showed that sulphur was highly toxic to *A. lycopersici* (Cermelli et al., 1982; Silva et al., 1988; Baradan-Anakari & Daneshvar, 1992; Hıncal et al., 2002; Fischer & Klötzli, 2015). Additionally, Kashyap et al. (2015) demonstrated that azadirachtin at a concentration of 0.25% was successful (99% of mite population) for the control of *A. lycopersici* populations in field conditions.

Acequinocyl, fenbutatin oxide, fenpyroximate, tebufenpyrad, spridomesifen and spirodiclofen concentrations proximate to HRCs were found toxic to *A. lycopersici*. Previous studies reported that high or moderate concentrations of fenbutatin oxide, propargite, fenpyroximate, spridomesifen and spirodiclofen caused toxic effects on *A. lycopersici* (Cermelli et al., 1982; Ky & Shepherd, 1988; Atanasov, 1995; Elbert et al., 2005; Spasov et al., 2014). Results of the current study showed that LC_{99} values of bifenazate and hexythiazox (the only mite growth regulator) were found to be higher than their HRC. Lethal concentrations of acequinocyl, tebufenpyrad and bifenazate against *A. lycopersici* were determined for the first time in this study. Van Leeuwen et al. (2010) noted that the effects of bifenazate and acequinocyl which are new acaricidal compounds, are not known against many rust and gall mites, yet. In the same way, some authors have reported that the mite growth regulator acaricide, hexythiazox, are effective against *A. lycopersici* (Arbabi, 2013; Fischer & Klötzli, 2015), but hexythiazox effectiveness was lower compared with the HRCs for other mite pests. The discrepancy may be due to species differences (BKUtarim, 2020).

This study also gave us information about the acute toxic and egg laying reducing effects (side effects) of acaricides at their LC_{99} concentrations (determined for *A. lycopersici*) on *A. swirskii*. According to JM and FM values, the most toxic acaricides were tebufenpyrad, azadirachtin, spirodiclofen and spiromesifen for juveniles and, tebufenpyrad and bifenthrin for females. Based on R ratios, azadirachtin and milbemectin slightly reduced the fecundity of females. According to the side effect scale, tebufenpyrad and azadirachtin were moderately harmful for both juveniles and females. Pyridaben, spiromesifen and spirodiclofen are more detrimental against juveniles compared with females. In agreement with our findings, Momen et al. (1997) showed that two concentrations (0.2 and 0.05%) of a product formulated from Neem seeds decreased the fecundity and increased the mortality of *A. swirskii* females. On the contrary, Audenaert et al. (2014) demonstrated that azadirachtin did not cause mortality on *A. swirskii* under field conditions and it was safe

to use it in combination with this predatory mite. These variations may be a result of different formulations, concentrations and test conditions. Additionally, the quick degradation of azadirachtin in field conditions might be taken into consideration. Similar to our study, several authors reported that tebufenpyrad, pyridaben and pyrethroid acaricides were highly toxic to different strains of *A. swirskii* including an organophosphorus resistant strain (El-Banhawy et al., 2007; Fiedler & Sosnowska, 2012; Fernandez et al., 2017a, b).

Consistent with the findings of Alinejad et al. (2016) who previously reported that HRC of spirodiclofen was very toxic to *A. swirskii*, it was found in this study that only sub-lethal concentrations had fewer side effects on its development and reproduction. In contrast, some authors found that HRC and sublethal concentrations of spirodiclofen and spiromesifen were harmless under the laboratory or field conditions, despite reduced oviposition and life-span of *A. swirskii* females (Audenaert et al., 2014; Fernandez et al., 2017a, b; Döker & Kazak, 2019).

The differences between our findings and the literature records could have arisen from the use of different side effect formulas and scales. In the current study, the side effect value was calculated and evaluated by considering both mortality rates and negative impact on fecundity, whereas other studies included only mortality rates. Since the sensitivity of the formula increases, the value obtained for the negative impact on fecundity is added to the side effect calculation as a multiplier (Fernandez et al*.,* 2017b).

The present study indicated that the LC_{99} values of abamectin, acequinocyl, bifenazate, fenproximate, fenbutatin oxide, hexythiazox, milbemectin and sulphur for *A. lycopersici* were slightly toxic to both females and juveniles of *A. swirskii*. While reducing effects on fecundity of *A. swirskii* were relatively limited for those of abamectin and bifenthrin, the effects of the rest acaricides remained at moderate level. Based on the side effect scale, the concentrations of abamectin, acequinocyl, bifenazate, fenproximate, fenbutatin oxide, hexythiazox, milbemectin and sulphur were found to be slightly harmful. But, among these acaricides, only the concentrations of bifenazate and fenproximate were close to or slightly higher than their HRCs registered for other mite pests in Turkey. Similar to our results, some authors showed the compatibility of acequinocyl, bifenazate, fenproximate and hexythiazox with *A. swirskii* in different agricultural ecosystems (Fiedler & Sosnowska, 2012; Audenaert et al., 2014; Lopez et al., 2015). Although Masui et al. (2014) noted that acequinocyl did not affect the population of *A. swirskii* in field studies in melon fields, the one third of acequinocyl HRC was found as slightly harmful for *A. swirskii* in our study. The reason for discrepancy may be the differences between laboratory and field conditions. Whenever, a lower concentration of abamectin was found to be harmless during this study, the use of the HRC of this acaricide shows a really high toxic effect to *A. swirskii* (Trottin-Caudal et al., 2008; Gradish et al., 2011; Cuthbertson et al., 2012; Fernandez et al., 2017b). Some studies showed that limited side effects on *A. swirskii* were observed from evaporation and dusts arising from application of sulphur (Gazquez et al., 2011; Pijnakker & Ramakers, 2009). However, our experimental concentration for sulphur was quite lower than its HRC. Among acaricides allowed to use in organic farming, the lower concentrations of sulphur and azadirachtin were favorable towards *A. lycopersici*. The determined concentration of azadirachtin was shown to be unfavorable for *A. swirskii* due to its negative effects on the survival and fecundity of the predator. The information about the side effects of the rest of acaricides such as tebufenpyrad, fenbutatin oxide, milbemectin, against *A. swirskii* is limited in the literature.

Consequently, eriophyid mites are tiny arthropods that are very sensitive to pesticides. As in this study, even very low concentrations of some acaricides were able to kill them easily. The results of this comparative toxicological study showed that the use in combination of low concentrations of some acaricides with *A. swirskii* in the control of *A. lycopersici* have potential. Practically, when *A. lycopersici* reaches high populations in a field, the acaricides can be applied, and then the phytoseiid could be released. Conserving the population of the predatory mite, this strategy might be used on tomatoes, but the hypothesis must be confirmed in field conditions in the future.

Acknowledgements

We thank the pesticide companies for purchased acaricides. We also thank to Prof. Dr. Sultan ÇOBANOĞLU for obtained the native *A. swirskii* population. This study is a part of Ayşenur KOLCU's MSc thesis, which was performed at the Graduate School of Natural and Applied Science of Bursa Uludağ University, Entomology Department between the years of 2017 and 2018. This project was supported by TUBITAK-TOVAG, Grant Project No. 117O377.

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