Effects of Selected Insecticides on the Predatory Mite, *Phytoseiulus persimilis* (Acari: Phytoseiidae)[1]

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Abstract The effects of field rates of selected insecticides on the predatory mite, *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae), were evaluated in laboratory bioassays. In topical treatments with lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor, 80–92% of *P. persimilis* adult females survived 168 h after exposure. Females exposed to these four insecticides produced 83–97% as many eggs as did the females in the controls, and eclosion of eggs was not affected. Moreover, the percentage of eggs that hatched and larval survival following direct exposure to these four insecticides were not seriously reduced. Immature *P. persimilis* survived on leaf discs with the residues of lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor, with 86–94% reaching adulthood. Emamectin benzoate, lepimectin, and spirotetramat were highly toxic to *P. persimilis* adult females and larvae. Based on these results, lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor are promising candidates for use in integrated pest management programs where *P. persimilis* is a natural enemy.

Key Words *Phytoseiulus persimilis*, predatory mite, field rates, insecticides, integrated pest management

The twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is an economically important arthropod pest of fruit trees and greenhouse crops in Korea (Cho 2000, Kim and Yoo 2002). Control of *T. urticae* populations in Korea is primarily dependent on repeated applications of acaricides (Choi et al. 2004, Lee and Kim 2015). Owing to its high reproductive potential and short life cycle, sustained use of acaricides has inevitably led to the development of resistance (Ahn et al. 2004, Van Pottelberge et al. 2009). Since resistance to acaricides in *T. urticae* develops rapidly, biological control tactics are crucial to manage spider mite populations (Cheon et al. 2007, Duso et al. 2008, Gerson and Weintraub 2007). Phytoseiid predatory mites are the most important biological control agents of tetranychid phytophagous mites (Argolo et al. 2014, Liburd et al. 2007, McMurtry and Croft 1997). *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) is well known as a predatory mite that specializes on the *Tetranychus* species (McMurtry et al. 2013, Rhodes and Liburd 2006, Steiner et al. 2011). This predatory mite was

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introduced into Korea and evaluated for control of *T. urticae* on strawberries (*Fragaria ananassa* Duchesne), eggplants (*Solanum melongena* L.), and roses (*Rosa hybrida* Hortorum) with promising results (Moon et al. 2006). The key component of biological control of phytophagous mites is the conservation and augmentation of phytoseiid predators in some circumstances (Bostanian et al. 2010, Liburd et al. 2007, Put et al. 2016). However, the influx of other insect pests and pathogens throughout the season necessitates pesticide sprays that could negatively impact the predatory mites and, hence, disrupt the biological control of spider mites (Abraham et al. 2013, Sato et al. 2000, Yorulmaz Salman et al. 2015). Accordingly, knowing the compatibility of pesticides with natural enemies is a prerequisite for implementation of any integrated pest management (IPM) program (Colomer et al. 2011, Gradish et al. 2011). Therefore, the aim of this study was to evaluate the effects of seven insecticides, generally used to control caterpillars, aphids, thrips, and whiteflies in greenhouses and outdoor vegetable crops in Korea, on the survival and reproduction of adult females and the survival of immature *P. persimilis*.

Materials and Methods

Insecticides. All insecticides used in this study were commercial formulations and were selected on the basis of their current use for control of key greenhouse arthropod pests. The products were emamectin benzoate (Affirm® 2.15 EC, Syngenta, Seoul, Korea), lepimectin (Geomtusa® 2 EC, Farm Hannong, Seoul, Korea), lufenuron (Match® 5 EC, Syngenta), novaluron (Rimon® 10 SC, Hankook Samgong, Seoul, Korea), pyrifluquinazon (Fanfare® 10 WG, Kyungnong, Seoul, Korea), spirotetramat (Movento® 22 SC, Bayer, Seoul, Korea), and sulfoxaflor (Straight® 7 WG, Dongbang Agro, Seoul, Korea). The rates tested were recommended field rates in Korean crops.

Colony sources and experimental conditions. The *P. persimilis* colony tested was originally obtained from Biobest (Belgium) for transport to Korea by Korea Beneficial Insects Lab (KBIL). The *P. persimilis* colony tested was established with mites obtained from KBIL in 2012 and has since been reared in the laboratory on kidney bean, *Phaseolus vulgaris* var. *humilis* Alefeld, plants infested with *T. urticae*. The *T. urticae* colony was collected from pear, *Pyrus* sp., trees and maintained on kidney bean plants in a greenhouse. All tests were conducted at 24–26°C at 50–60% relative humidity on an 18-h photophase. An individual test arena was a bean leaf disc (3-cm diameter) placed bottom-side up on moistened cotton in a plastic petri dish (9-cm diameter) with a 1-cm-diameter opening in the center of the top of the petri dish. Each dish was placed in a plastic container (14-cm diameter, 5-cm height) containing water with a 1-cm-diameter opening in its lid. A cotton wick was fitted through the center hole of the petri dish and the plastic container for maintaining moisture in the cotton. Two holes (each 3-mm diameter) were drilled in the upper part of the side wall of the larger container to replenish the water as needed.

Insecticides were applied to run off with a 1-L hand-operated sprayer (Komax Co., Seoul, Korea) held 23 cm away from the leaf disc. The leaf discs were bordered with a barrier of wet cotton (0.3- to 0.4-cm height) on the moistened cotton in each plastic petri dish to prevent the escape of mites (Kim and Yoo 2002).

Effects of insecticides on *P. persimilis*. Topical toxicity of insecticides on the survival and reproduction of adult females of *P. persimilis* and eclosion of eggs deposited by treated females were evaluated in trials with 50 adult females (five replicates with 10 mites per leaf disc). For each insecticide, *P. persimilis* adult females were transferred from the source colony to leaf discs with the aid of a fine brush. Some twospotted spider mites were added to each disc to keep the adult female predators on the leaf discs. The leaf discs with adult female predators were sprayed with aqueous solution of each insecticide or distilled water (control), and then allowed to air-dry for 1 h. A surplus of all stages of *T. urticae* was added to each disc daily to ensure an abundance of food. The survival of adult female predators was recorded at 1, 3, 5, and 7 d after treatment. Predatory mites were considered dead when they did not respond to touches by a fine brush. The eggs on each leaf disc were counted daily and transferred to a separate untreated disc to assess eclosion rates for each treatment.

The ovicidal effects of insecticides were evaluated with 50 eggs (10 eggs per leaf disc). Adult females of *P. persimilis* were placed on leaf discs, allowed to deposit eggs for 24 h, and removed. The number of eggs was then adjusted to 10 per disc on each of five leaf discs for each insecticide tested. The leaf discs with predator eggs were sprayed with aqueous solution of each insecticide or distilled water (control), and then allowed to air-dry for 1 h. Observations on the egg hatch were made daily. To assess the direct larvicidal toxicity of insecticides, adult female predators transferred to each of five leaf discs and allowed to oviposit for 24 h. The *T. urticae* eggs served as the food source for *P. persimilis*. After 24 h, adult female predators were removed and *P. persimilis* eggs were allowed to hatch. At this time, any unhatched *P. persimilis* eggs were removed, and the number of larvae was then adjusted to 10 per disc on each of five leaf discs. Each treatment was replicated five times. The leaf discs with *P. persimilis* larvae were sprayed as described previously. Mortality was evaluated after 24 h.

To evaluate the effects of insecticidal residues on immature predators, the leaf discs were sprayed with aqueous solution of each insecticide or distilled water (control) and then allowed to air-dry for 1 h before being placed in the petri dishes. Fifty eggs of *P. persimilis* (0–24 h old, 10 eggs per leaf disc) were transferred to the leaf discs that had been treated with each insecticide or distilled water. A surplus of all stages of *T. urticae* was placed on each disc when the predator eggs began to hatch. Immature survival to adulthood was observed daily and was assessed by counting the number of subsequent stages. Observations were discontinued when all predators reached adulthood.

Statistical analyses. Data were analyzed using analysis of variance (ANOVA) and Tukey's honestly significant difference test (SAS Institute 2002). Data in the form of percentages were transformed to arcsine values for ANOVA before analysis and were reconverted for reporting.

Results and Discussion

Topical toxicity of the seven insecticides tested on the survival of *P. persimilis* adult females at different time intervals after application is shown in Table 1. Generally, the survival rates of *P. persimilis* adult females in all treatments

Table 1. Survival of adult females of *Phytoseiulus persimilis* on bean leaf discs treated with different insecticides.

Insecticides Treated	Treatment Rate	% Survival (Mean ± SEM) After*			
		24 h	72 h	120 h	168 h
Emamectin benzoate	0.5 ml/L	68.0 ± 4.9 b	4.0 ± 2.5 c	0.0 ± 0 b	0.0 ± 0 c
Lepimectin	0.5 ml/L	26.0 ± 6.8 c	2.0 ± 2.0 c	0.0 ± 0 b	0.0 ± 0 c
Lufenuron	0.5 ml/L	98.0 ± 2.0 a	94.0 ± 2.5 a	88.0 ± 5.8 a	80.0 ± 6.3 b
Novaluron	0.5 ml/L	98.0 ± 2.0 a	94.0 ± 2.5 a	90.0 ± 3.2 a	82.0 ± 4.9 ab
Pyrifluquinazon	0.5 g/L	96.0 ± 2.5 a	92.0 ± 2.0 a	88.0 ± 2.0 a	84.0 ± 2.5 ab
Spirotetramat	0.5 ml/L	64.0 ± 4.3 b	26.0 ± 7.5 b	14.0 ± 5.1 b	4.0 ± 2.5 c
Sulfoxaflor	0.5 g/L	100.0 ± 0 a	96.0 ± 2.5 a	94.0 ± 2.5 a	92.0 ± 3.7 ab
Control	—	100.0 ± 0 a	100.0 ± 0 a	96.0 ± 2.5 a	96.0 ± 2.5 a

* Means in the same column followed by the same letter are not significantly different ($P = 0.05$, Tukey test). Mortality was transformed to arcsine value before analysis of variance. Means of untransformed data are reported.

Table 2. Effects of different insecticides on eggs and larvae of *Phytoseiulus persimilis.*

Insecticides Treated	% Hatchability (Mean ± SEM)*	% Survival of Larvae (Mean ± SEM)*
Emamectin benzoate	100.0 ± 0 a	2.0 ± 2.0 c
Lepimectin	100.0 ± 0 a	6.0 ± 2.5 c
Lufenuron	100.0 ± 0 a	76.0 ± 4.0 b
Novaluron	100.0 ± 0 a	82.0 ± 5.8 b
Pyrifluquinazon	100.0 ± 0 a	84.0 ± 5.1 b
Spirotetramat	100.0 ± 0 a	10.0 ± 4.5 c
Sulfoxaflor	100.0 ± 0 a	90.0 ± 3.2 ab
Control	100.0 ± 0 a	100.0 ± 0 a

* Means in the same column followed by the same letter are not significantly different ($P = 0.05$, Tukey test).

decreased over time after exposure. After 168 h, 80–92% of *P. persimilis* adult females survived in treatments with lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor; these survival rates were not statistically different from the control, except in lufenuron treatment. Based on the International Organization of Biological– established categories (Hassan 1994), these four insecticides tested were in Category 1 (harmless, <30% mortality), indicating that these insecticides had little or no significant effects on the survival of *P. persimilis* in these bioassays. Spirotetramat was toxic to *P. persimilis* adult females and caused 96% mortality after 168 h. Emamectin benzoate and lepimectin were highly toxic, with all adult female predators dying within 5 d of the test. Recently, Bernard et al. (2010) observed that emamectin benzoate was highly toxic to *Euseius victoriensis* (Womersley) (Acari: Phytoseiidae) juveniles. In our test, novaluron was not toxic to *P. persimilis* adult females and larvae, whereas spirotetramat was toxic to adult females and larvae of this predator (Tables 1, 2). In contrast, Beers and Schmidt (2014) reported that novaluron and spirotetramat at their maximum label rate caused 44.0% and 20.8% mortality of *Galendromus occidentalis* (Nesbitt) (Acari: Phytoseiidae) adult females, respectively, but these two insecticides were not toxic to *G. occidentalis* larvae. On the other hand, Lefebvre et al. (2012) documented that novaluron and spirotetramat at their recommended rate caused 4.8% and 40.2% mortality of *Neoseiulus fallacis* (Garman) (Acari: Phytoseiidae) adults, respectively, whereas these insecticides were highly toxic to *N. fallacis* larvae. Lefebvre et al. (2012) and Steiner et al. (2011) referred to the response variability of phytoseiids to insecticide exposure and the need to evaluate insecticides on each species of acarine biocontrol agent.

Pyrifluquinazon and sulfoxaflor did not significantly affect the reproduction of *P. persimilis* adult females (Table 3). Oviposition of the predators exposed to lufenuron and novaluron was less than that of the control; however, treated females produced 83–85% as many eggs as did control females. Egg production by *P. persimilis* adult

Table 3. Reproduction of adult females of *Phytoseiulus persimilis* on bean leaf discs treated with different insecticides and percentages of eclosion.

Insecticides Treated	Number of Eggs per Leaf Disc (Mean ± SEM)*	% Eclosion (Mean ± SEM)*
Emamectin benzoate	15.4 ± 1.4 c	100.0 ± 0 a
Lepimectin	8.8 ± 1.6 c	100.0 ± 0 a
Lufenuron	179.0 ± 11.2 b	100.0 ± 0 a
Novaluron	174.6 ± 7.4 b	100.0 ± 0 a
Pyrifluquinazon	181.6 ± 5.6 ab	100.0 ± 0 a
Spirotetramat	13.4 ± 1.2 c	100.0 ± 0 a
Sulfoxaflor	203.6 ± 8.7 ab	100.0 ± 0 a
Control	209.8 ± 7.5 a	100.0 ± 0 a

* Means in the same column followed by the same letter are not significantly different ($P = 0.05$, Tukey test).

females treated with emamectin benzoate, lepimectin, and spirotetramat was only 4.2–7.3% that of the control females. These results suggest that lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor do not greatly influence the reproduction of surviving adult female predators. All eggs deposited by adult females treated with the insecticides hatched.

Topical toxicity of the insecticides tested on *P. persimilis* eggs and larvae is shown in Table 2. The insecticides tested did not interfere with the hatch of *P. persimilis* eggs. Applications of lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor had low toxicity to *P. persimilis* larvae, with survival rates of 76–90%. However, emamectin benzoate, lepimectin, and spirotetramat were toxic to larvae of *P. persimilis* and caused 90–98% mortality. Emamectin benzoate, lepimectin, and spirotetramat, at their recommended field rates in Korea, caused high mortality of adult females and larvae of *P. persimilis*. Therefore, it is advisable to limit their use as much as possible, thus reducing the chances of predators being affected by these compounds.

The residual effect of insecticides on the immature survival of *P. persimilis* was performed with four insecticides that showed low toxicity to adult females and larvae of this predator. Placement of *P. persimilis* immatures on treated leaf disc surfaces showed that the residues of the insecticides tested did not seriously affect the survival of immatures (Table 4). In treatments with the insecticides tested, 86–94% of immature predators reached adulthood.

These laboratory studies indicate that lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor could be useful in an IPM program designed to utilize this predatory mite. Care should be exercised in translating laboratory tests into predictions of field performance (Lucas et al. 2004, Stark et al. 1995). Thus, field trials are needed to further evaluate the effect of lufenuron, novaluron, pyrifluquinazon, and sulfoxaflor on *P. persimilis*.

Table 4. Effects of different insecticide residues on immatures of *Phytoseiulus persimilis.*

Insecticides Treated	% Mortality (Mean ± SEM) at*			% Survival to Adulthood*
	Egg Stage	Larval Stage	Nymphal Stage	
Lufenuron	0.0 ± 0	4.0 ± 2.5	6.0 ± 2.5	90.0 ± 3.2 ab
Novaluron	0.0 ± 0	10.0 ± 3.2	4.0 ± 2.5	86.0 ± 2.5 b
Pyrifluquinazon	0.0 ± 0	8.0 ± 3.7	6.0 ± 4.0	86.0 ± 2.5 b
Sulfoxaflor	0.0 ± 0	4.0 ± 2.5	2.0 ± 2.0	94.0 ± 2.5 ab
Control	0.0 ± 0	2.0 ± 2.0	0.0 ± 0	98.0 ± 2.0 a

* Means in the same column followed by the same letter are not significantly different ($P = 0.05$, Tukey test).

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