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Selective Toxicity of Three Acaricides to the Predatory Mite, *Neoseiulus womersleyi* and its Prey, *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae)

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Abstract

The comparative toxicity of recommended rates of three acaricides, fluacrypyrim, cyflumetofen and spiromesifen to the predatory mite, *Neoseiulus womersleyi* and its prey, *Tetranychus urticae* was bioassayed in the laboratory. Fluacrypyrim and cyflumetofen were much less toxic to adult females of *N. womersleyi* than to those of *T. urticae*. Adult female predators treated with these two acaricides produced 88~93% as many eggs as did control females. Fluacrypyrim and cyflumetofen did not affect the hatch of *N. womersleyi* eggs or the development of surviving immature predators, and 92~96% of immature predators reached adulthood. Spiromesifen at its treated concentration did not significantly affect the survival and reproduction of adult female predators but caused 100% mortality in larvae of *N. womersleyi*. Adult female predators survived on a diet of spider mites treated with fluacrypyrim and cyflumetofen, and their fecundity was not significantly affected. Moreover, immature predators developed normally on prey treated with these two acaricides. The results indicate that fluacrypyrim and cyflumetofen are promising candidates for use in integrated mite management programs where *N. womersleyi* is the major natural enemy.

Key words *Neoseiulus womersleyi*, *Tetranychus urticae*, acaricides, relative toxicity, integrated management

Introduction

The twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), is an economically important pest of various fruit trees and greenhouse crops in Korea (Kim *et al.*, 1999; Yu *et al.*, 2005). Control of *T. urticae* populations in Korea is primarily dependent on repeated applications of acaricides (Kim and Yoo, 2002; Choi *et al.* 2004). Because of the intensive use of several chemical classes of acaricides, this mite species has developed resistance against most of the available acaricides (Kim and Yoo, 2002; Yu *et al.*, 2005). As chemical control measures turned out increasingly inefficient, biological and integrated pest management were proposed as alternative strategies for the suppression of *T. urticae*. The phytoseiid predators are recognized as the most important biological control agents of phytophagous mites in integrated mite management (IMM) programs of outdoor and greenhouse crops (Van Lenteren and Woets 1988; McMurtry and Croft 1997; Gotoh *et al.*, 2004). Recently, *Neoseiulus womersleyi* Schicha (Acari: Phytoseiidae), a domestic predator of tetranychid mites, has been evaluated for the control of *T. urticae* in apple and pear orchards with promising results (Cho, 2000; Han *et al.*, 2003; Kim *et al.*, 2003).

In view of a growing interest on environmentally-friendly approaches to the control of pests, utilizing this phytoseiid

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predator as a biological control agent has become a useful way of solving acaricide resistance. However, as indicated from several studies, despite the effectiveness of phytoseiid predators for biological control of spider mites, the predators alone may not be able to maintain spider mite populations below an economic threshold for an extended period of time (Trumble and Morse, 1993; Blumel *et al.*, 1999; Ibrahim and Yee, 2000; Shipp *et al.*, 2000; Mochizuki, 2003). Thus, an IMM program with a practicable combination of selective acaricides and biological control agents could be of great use. Compared with other phytoseiid predators, relatively little is known about the selectivity of acaricides to *N. womersleyi*.

The objective of this study was to evaluate the comparative effects of three acaricides currently used in Korea on the survival and reproduction of adult females and immature survival to adulthood of both *N. womersleyi* and *T. urticae*.

Materials and Methods

Colony sources and experimental conditions

The *N. womersleyi* colony was collected from pear trees on the Sunchon National University farm in 2006 and has been reared in the laboratory on kidney bean plants (*Phaseolus vulgaris* var. *humilis* Alefeld) infested with *T. urticae*. The *T. urticae* colony was also collected from pear trees and maintained on kidney bean plants in a greenhouse. All tests were conducted at 24-26°C, 50-60% RH and an 18 h photoperiod. Two test arenas, composed of a bean leaf disc (3 cm in diameter) placed bottom side up on moist cotton in a plastic Petri dish (9 cm in diameter) with a hole (1 cm in diameter) in the center, were placed on a plastic water container (14 cm in diameter, 5 cm in height) with a hole (1 cm in diameter) in the center of the lid. A wick consisting of a strip of cotton was fitted through the center hole of a Petri dish and water container for maintaining the moist cotton. Two holes (each 3 mm in diameter) were drilled in the upper part of the side wall of the water container to refill water using a squeeze bottle. Acaricides were applied until run off with a one liter hand sprayer (Komax co., Seoul, Korea) held 23 cm away from the leaf discs. The leaf discs were properly bordered with wet cotton wall (0.3 to 0.4 cm in height) on moist cotton in a plastic Petri dish to prevent the escape of mites (Kim and Yoo, 2002). Mites of both predator and prey were considered dead when they did not respond to touches by a fine brush. Immature survival of both species was determined by counting the number of subsequent stages.

Acaricides

The acaricides tested are all registered and used for the control of *T. urticae* in Korea. We used commercial formulations of fluacrypyrim 30% suspension concentrate (SC), cyflumetofen 20% SC and spiromesifen 20% SC. These compounds were tested at their maximum recommended rates in Korea.

Effects of acaricides on *N. womersleyi*

The effects of acaricides on the survival and reproduction of adult females of *N. womersleyi* were evaluated in trials with 50 adult females (5 replicates with 10 mites per replicate). For each acaricide, *N. womersleyi* 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 adult female predators on the leaf discs. The leaf discs with adult female predators were sprayed with aqueous solution of each acaricide or distilled water as control, and then allowed to dry for 1 h under room temperature. A surplus of all stages of *T. urticae* was added to each disc daily to ensure an abundance of food. The survival and reproduction of female predators were counted at 1, 3, 5 and 7 days after treatment.

The effects of acaricides on immature predators were evaluated with 50 eggs (10 eggs per replicate). Adult females of *N. womersleyi* 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 5 leaf discs for each acaricide tested. The leaf discs with predator eggs were sprayed with aqueous solution of

each acaricide or distilled water, and then allowed to dry for 1 h. 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. This experiment was discontinued when all predators reached adulthood.

The effects of indirect poisoning (toxicity resulting from feeding on prey treated with acaricides tested) on adult female predators were assessed by providing predators with either twospotted spider mites treated with acaricides, or untreated twospotted spider mites. Adult females of *N. womersleyi* were placed (5 replicates with 10 mites per replicate) on unsprayed leaf discs with immature twospotted spider mites that had been sprayed with aqueous solution of each acaricide or distilled water. Fresh prey of the appropriate treatment was added daily to ensure an abundance of food. Observations on the survival and reproduction of adult female predators were made daily for 7 days. Data for the first 24 h were not used in the analysis in order to exclude the effect of previous feeding. The effects of indirect poisoning on immature predators were assessed in a similar way as it was for adult female predators. Eggs of *N. womersleyi* were placed (5 replicates with 10 eggs per replicate) on unsprayed leaf discs. Newly hatched larvae were fed immature twospotted spider mites that had been sprayed with aqueous solution of each acaricide or distilled water. Abundant prey of the appropriate treatment was provided daily. Immature survival to adulthood was recorded daily. The experiment was discontinued when all immature predators reached adulthood.

Effects of acaricides on *T. urticae*

The effects of acaricides on adult females of *T. urticae* were evaluated in the same way as it was for *N. womersleyi*. Likewise, immature twospotted spider mites were also tested by the same procedure as was used for the immature predators.

Data analysis

All data on survival and reproduction in each experiment were analyzed using analysis of variance (ANOVA) and Tukey test in SAS (SAS Institute 1996). Data in the form of percentages were transformed to arcsine values for ANOVA.

Results and Discussion

The effects of the acaricides tested on the survival of *N. womersleyi* and *T. urticae* adult females at different time intervals after application and their reproduction are shown in Tables 1 and 2, respectively. Treatments with fluacrypyrim, cyflumetofen and spiromesifen had no significant effects on the survival rates of adult female predators throughout the experiment. After 168 h, 90 to

Table 1. Survival of adult females of *N. womersleyi* and *T. urticae* on bean leaf discs treated with fluacrypyrim, cyflumetofen and spiromesifen

Mite species and acaricides treated	Concentration (AI, ppm)	% Survival (Mean SEM) after*			
		24h	72h	120h	168h
N. womersleyi					
Fluacrypyrim	150	98.0 ± 2.00 a	94.0 ± 2.45 a	92.0 ± 3.74 a	90.0 ± 4.46 a
Cyflumetofen	100	100.0 ± 0 a	96.0 ± 2.45 a	94.0 ± 2.45 a	94.0 ± 2.45 a
Spiromesifen	100	100.0 ± 0 a	94.0 ± 2.45 a	92.0 ± 3.74 a	92.0 ± 3.74 a
Control		100.0 ± 0 a	100.0 ± 0 a	100.0 ± 0 a	98.0 ± 2.00 a
T. urticae					
Fluacrypyrim	150	60.0 ± 5.47 b	18.0 ± 4.89 b	6.0 ± 2.45bc	6.0 ± 2.45 b
Cyflumetofen	100	10.0 ± 4.46 c	6.0 ± 3.99 c	0.0 ± 0 c	0.0 ± 0 b
Spiromesifen	100	48.0 ± 5.82 b	18.0 ± 4.89 b	16.0 ± 5.99 b	12.0 ± 4.89 b
Control		100.0 ± 0 a	100.0 ± 0 a	100.0 ± 0 a	96.0 ± 2.45 a

*Means for each species in the same column followed by the same letter are not significantly different (p = 0.05, Tukey test).

94% of adult female predators survived in treatments with the acaricides tested. In contrast, all *T. urticae* adult females exposed to cyflumetofen died at 3 days after treatment. Survival of *T. urticae* adult females treated with fluacrypyrim and spiromesifen declined over time until only 6 to 12% remained alive after 168 h. These results indicate that fluacrypyrim, cyflumetofen and spiromesifen are much less toxic to *N. womersleyi* adult females than to *T. urticae* adult females. Reproduction of adult female predators treated with the acaricides tested was less than that of the control. However, *N. womersleyi* adult females treated with fluacrypyrim, cyflumetofen and spiromesifen produced 88~93% as many eggs as did control females. Reproduction of *T. urticae* adult females was also reduced in all acaricidal treatments. Adult females of *T. urticae* treated with the acricides tested produced only 4~9% as many eggs as normal females. These results suggest that fluacrypyrim, cyflumetofen and spiromesifen have no significant effect on egg production by the surviving adult female predators in each treatment.

The effects of the acaricides tested on the immature survival of *N. womersleyi* and *T. urticae* are summarized in Table 3. Fluacrypyrim and cyflumetofen caused no significant effects on the survival of immature predators. In treatments with these two acaricides, 92 to 96% of immature predators reached adulthood. In contrast, spiromesifen was extremely toxic to larvae of *N. womersleyi* and caused 100% mortality in larvae. Fluacrypyrim, cyflumetofen and spiromesifen were highly toxic to immature twospotted spider mites. In treatments with these three acaricides, all *T. urticae* immatures failed to develop to the nymphal stage. Tables 1-3 showed that fluacrypyrim and cyflumetofen are much less toxic to adult females and immature stages of *N. womersleyi* than to those of *T. urticae.*

In bioassays conducted with spiromesifen, it did not

Table 2. Reproduction of adult females of *N. womersleyi* and *T. urticae* on bean leaf discs treated with fluacrypyrim, cyflumetofen and spiromesifen

Acaricides treated	Concentration (AI, ppm)	Number of eggs per leaf disc (Mean SEM)*	
		N. womersleyi	*T. urticae*
Fluacrypyrim	150	153.6 ± 3.18 a	47.0 ± 6.10 b
Cyflumetofen	100	161.6 ± 7.90 a	27.8 ± 3.75 b
Spiromesifen	100	158.2 ± 7.35 a	61.4 ± 6.01 b
Control		173.8 ± 7.78 a	682.6 ± 16.97 a

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

Table 3. Effects of fluacrypyrim, cyflumetofen and spiromesifen on immature stages of *N. womersleyi* and *T. urticae* on treated bean leaf discs

Mite species and acaricides treated	Concentration (AI, ppm)	% Mortality (Mean SEM) at			% Survival to adulthood*
		Egg stage	Larval stage	Nymphal stage	
N. womersleyi					
Fluacrypyrim	150	0.0 ± 0	4.0 ± 2.45	0.0 ± 0	96.0 ± 2.45 a
Cyflumetofen	100	0.0 ± 0	4.0 ± 2.45	4.0 ± 2.45	92.0 ± 3.74 a
Spiromesifen	100	0.0 ± 0	100.0 ± 0	0.0 ± 0	0.0 ± 0 b
Control		0.0 ± 0	4.0 ± 2.45	0.0 ± 0	96.0 ± 2.45 a
T. urticae					
Fluacrypyrim	150	36.0 ± 5.09	64.0 ± 5.09	0.0 ± 0	0.0 ± 0 b
Cyflumetofen	100	92.0 ± 3.74	8.0 ± 3.74	0.0 ± 0	0.0 ± 0 b
Spiromesifen	100	100.0 ± 0	0.0 ± 0	0.0 ± 0	0.0 ± 0 b
Control		0.0 ± 0	6.0 ± 2.45	0.0 ± 0	94.0 ± 2.45 a

*Means for each species in the same column followed by the same letter are not significantly different (p = 0.05, Tukey test).

significantly affect the survival and reproduction of adult female predators but caused high mortality rate in larvae of *N. womersleyi*. As such, the use of spiromesifen in an IMM program should be carefully evaluated. Recently, Dekeyser (2005) reported that spiromesifen is slightly to moderately harmful to predatory mites but safe to beneficial insects. However, we consider that spiromesifen could be of value in adjusting prey density before the release of *N. womersleyi* adult females.

The effects of indirect poisoning on *N. womersleyi* adult females were tested with fluacrypyrim and cyflumetofen which showed low toxicity to adult females and immature stages of this predator. Adult female predators that fed on twospotted spider mites treated with these two acaricides survived almost as well as those that fed on untreated prey (Table 4). Similarly, the reproductive rates of adult female predators that fed on treated prey were not significantly different from the control. Throughout the entire test period, predators that fed on treated prey produced 95~98% as many eggs as the control. Immature predators that fed on prey treated with fluacrypyrim and cyflumetofen developed normally on this diet. The number of *N. womersleyi* that survived to adulthood was not significantly different from the result of control (Table 5). Thus, a diet of treated prey did not prevent immature predators from developing successfully to adults. Our test of indirect poisoning showed that ingesting treated prey did not influence the survival and egg production of *N. womersleyi* adult females and survival of immature predators. This suggests that *N. womersleyi* populations could maintain themselves in the field on treated prey, which would enhance their ability to prevent resurgences of *T. urticae* populations.

The results of our laboratory tests suggest that fluacrypyrim and cyflumetofen could be used as selective acaricides in an IMM program because they appeared much more toxic to *T. urticae* than to *N. womersleyi*. However, laboratory data may be of limited value to predict compatibility of pesticides and natural enemies in the field (Stark *et al.*, 1995; Lucas *et al.*, 2004). Thus, additional field or semifield trials with fluacrypyrim and cyflumetofen are needed to fully evaluate the potential of these compounds as selective acaricides for integrated management of *T. urticae*.

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Table 4. Survival and reproduction of adult females of *N. womersleyi* fed a diet of *T. urticae* treated with fluacrypyrim and cyflumetofen, compared with females fed a normal diet

Acaricides treated	Concentration (AI, ppm)	% Survival (Mean SEM)*	Number of eggs per leaf disc (Mean SEM)*
Fluacrypyrim	150	94.0 ± 2.45 a	125.4 ± 3.94 a
Cyflumetofen	100	92.0 ± 3.74 a	121.2 ± 5.67 a
Control		96.0 ± 2.45 a	128.2 ± 6.53 a

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

Table 5. Survival of immature stages of *N. womersleyi* fed a diet of *T. urticae* treated with fluacrypyrim and cyflumetofen, compared with immatures fed a normal diet

Acaricides treated	Concentration (AI, ppm)	% Mortality (Mean SEM) at		% Survival to adulthood*
		Larval stage	Nymphal stage	
Fluacrypyrim	150	6.0 ± 3.99	2.0 ± 2.00	92.0 ± 3.74 a
Cyflumetofen	100	4.0 ± 2.45	2.0 ± 2.00	94.0 ± 2.45 a
Control		4.0 ± 2.45	0.0 ± 0	96.0 ± 2.45 a

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

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긴털이리응애(*Neoseiulus womersleyi*)와 점박이응애(*Tetranychus urticae*)에 대한 3종 살비제의 선택독성

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요 약 긴털이리응애와 점박이응애에 대하여 fluacrypyrim, cyflumetofen과 spiromesifen의 권장사용농도로 상대독성을 시험하였다. Fluacrypyrim과 cyflumetofen은 점박이응애보다 긴털이리응애의 자성충에 대하여 독성이 매우 낮았으며, 이들 두 살비제를 처리한 긴털이리응애 암컷성충은 무처리에 비해 88~93%의 산란수를 나타내었다. Fluacrypyrim과 cyflumetofen의 처리는 긴털이리응애 난의 부화나 생존 유·약충의 발육에 영향이 없었으며, 유·약충의 92~96%가 성충으로 우화하였다. Spiromesifen은 시험농도에서 긴털이리응애 암컷성충의 생존율과 산란수에는 큰 영향이 없었으나, 유충에는 100%의 치사율을 나타내었다. Fluacrypyrim과 cyflumetofen을 처리한 먹이를 섭식한 긴털이리응애 자성충은 생존율과 산란수에 큰 영향을 받지 않았다. 또한 이들 살비제를 처리한 먹이를 포식한 긴털이리응애의 유·약충도 성충 우화율에 실질적인 영향을 받지 않았다. 이상의 결과에서 긴털이리응애의 암컷성충과 발육태에 영향이 적게 나타난 fluacrypyrim과 cyflumetofen은 점박이응애의 종합관리체계에서 긴털이리응애와 함께 이용할 수 있을 것으로 생각된다.

색인어 긴털이리응애, 점박이응애, 살비제, 상대독성, 종합관리