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Selection of the Acaricides Selective to *Harmonia axyridis* and Effect of their Application on Phytophagous Mites and Natural Enemies

무당벌레에 선택적인 살비제 선발과 이들 처리가 사과원 식식성 응애류와 천적류에 미치는 영향

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ABSTRACT This study was conducted to select the acaricides selective to *H. axyridis* and examine the effects on phytophagous mites and natural enemies after application of selected acaricides in the apple orchard. All the acaricides tested were more toxic to *T. urticae* and *P. ulmi* than to *H. axyridis*, and also were more toxic to egg than to the larva and adult of *H. axyridis*. Azocyclotin and fenpropathrin were the highest and lowest selective acaricides to *H. axyridis*, respectively. The density of phytophagous mites was high affected by frequency of acaricide application. Significant difference in the changes of the density of natural enemies was not be observed according to frequency of acaricide application and kinds of acaricide. Acaricide treatment showed high effect on the population densities of A. *womersleyi* and *Orius* spp., while less effect on *Chrysopa* spp.

KEY WORDS Selective acaricide, phytophagous mites, *Harmonia axyridis*, natural enemy

초 록 본 연구는 무당벌레에 선택적인 살비제 선발과 이들 처리가 사과원 초식성응애류 및 천적류에 미치는 영향을 조사하기 위하여 수행되었다. 조사된 모든 살비제는 무당벌레 보다는 점박이응애와 사과응애에 더 강한 독성을 보였고, 또 무당벌레의 유충과 성충 보다는 알에 더 높은 독성을 나타냈다. 실내 선택독성실험에서 azocyclotin과 fenpropathrin이 각각 무당벌레에 대해서 선택성이 높은 약제와 낮은 약제로 나타났다. 응애류는 약제 처리횟수에 크게 영향을 받은 반면 천적류는 약제살포횟수 및 약제종류간에 차이가 없었다. 풀잠자리류는 긴털이리응애나 애꽃노린재류와는 달리 약제살포에 비교적 영향이 적었다.

검색어 선택적 살비제, 무당벌레, 초식식성응애류, 천적류

Apple is a major fruit crop in Korea and its cultivation is increasing every year. Among 312 species of the insect and mite pests recorded in the apple orchard, two spider mite species (*Tetranychus urticae* Koch and *Panonychus ulmi* Koch) were the most important species (Anonymous 1986, Lee 1990). There were 41 acaricides registered for controlling spider mites in apple orchard in Korea (Anonymous 1994). However, many of them have failed to provide adequate control after 2-3 yr of use in the field because of the development of resistance induced by intensive use of insecticides and/or acaricides (Cho *et al.* 1993).

Repeated use of insecticides and acaricides has disrupted the control of insects and mites by natural enemies, and also led to outbreaks of secondary pests, resurgence, and the development of widespread resistance to insecticides or acaricides on apple orchards for the past decades (Lee & Yoo 1971, Lee *et al.* 1986, Lee 1990, Cho *et al.* 1993). Therefore, control measurements without relying on insecticide alone should be urgently required (Rajakulendran and Plapp 1982).

Of six predacious natural enemies of spider mites re-

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ported in apple orchard (Lee 1965; Anonymous 1988), the aphidophagus coccinellid (*Harmonia axyridis* Pallas) is an important predator to several crop pests such as aphids and mites. Conservation and use of this predator is an important component in integrated pest management programs (Anonymous 1988). To protect this natural enemy in integrated pest management programs, it would be essential to use the selective insecticides that are toxic against insect pests but relatively safe for the predator (Yu 1988). In examining the effects of pesticide application on the major insect pests and their natural enemies, Lee *et al.* (1994) suggested that *Amblyseiulus womersleyi* is a promising biological control agent to *T. urticae* as it occurred on the apple trees in early season when the prey densities were still low. With selecting the selective insecticides between the aphidophagus coccinellid and aphids, Cho *et al.* (1996) suggested that comparative field evaluation of the possible candidates may be necessary to find out their effects on natural enemy complex.

In our study, we determined the comparative toxicity of some acaricides to the two spider mites (*T. urticae and P. ulmi*) and its coccinellid predator (*H. axyridis*) as an indicator for examining the effect on other major natural enemies in the apple orchard, and investigated the population changes of major insect pests and natural enemies by application of acaricides selected.

MATERIALS AND METHODS

Laboratory Study

Insects: The two spotted spider mite (*Tetranychus urticae* Koch) was collected on apple leaves in Suwon and reared on kidney bean (*Phaseolus vulgaris var. humilis* Alefeld) seedlings (3 wk after germination) in acrylic cages (40 by 40 by 55 cm), and maintained at 25±1°C, 40-60% RH, and a photoperiod of 16:8(L:D) hr for three generations to ensure adequate numbers for testing in the laboratory. The European red mite (*Panonychus ulmi* Koch) was used the very day collected without rearing in the laboratory. The aphidophagous coccinellid (*Harmonia axyridis* Pallas) which collected from the rose of Sharon (*Hibiscus syriacus* L.) was reared on cotton aphid, and maintained under the same rearing conditions as referred above.

Insecticides: The acaricides used in this experiment are as follows: Azocyclotin 25% wettable powder (WP); Pyridaben 20% WP; Dicofol 42% emulsifiable concentrates (EC); Fenpropathrin 5% EC; Fenpyroximate 5% suspension concentrates (SC); These compounds were supplied by local pesticide formulator companies in Korea. They were selected based on their use for controlling the two-spotted spider mite in apple orchard.

Bioassay: The susceptibility of adult mites to acaricides was examined by leaf disk method. Kidney bean and apple leaf disk (ϕ3 cm) were placed upon the small piece of damp cotton pad fitted into plastic petridish (ϕ5.5×H2 cm). Thirty female adults of *T. urticae* and *P. ulmi* were infested on kidney bean and apple leaf disk, respectively. Each treatment was sprayed at the rate of 0.1m*l* per leaf disk by hand sprayer and then was kept under the rearing room as referred above.

0.1 μ*l* of each acaricides per adults and larvae of *H. axyridis* were treated topically on the thoracic sternum. Acetone alone was used for the control. After treatment, the insects were kept in plastic petridish (ϕ10×H7.5 cm) under the same rearing conditions as referred above, providing with the cotton aphids as a food source.

Mortality of mites and aphidophagous beetles was determined 48 hr after treatment, considering dead if their appendages did not move when prodded with a fine brush. Results were analyzed by probit analysis program (Finney 1971, Raymond 1985). The selectivity ratio was obtained by dividing the LC_{50} value of each acaricides to *T. urticae* and *P. ulmi* by the same value for *H. axyridis,* respectively. Values greater than 1 indicate the acaricide was more toxic to the predator than to the pest, and vice versa.

Field Study

Field studies were conducted in a 17-yr-old orchard in Suwon, planted with apple "Fuji" trees in rows' 6m and 3m apart. In all experiments, standard fungicide and herbicide application programs were maintained throughout the growing season. All treatments were applied with an high pressure sprayer equipped with one nozzle, calibrated to deliver 3,500 *l*/ha of liquid according to the company protocols for field application rates (per liter): azocyclotin 0.65 g; fenpropathrin 1.0 m*l*. Two treatments were applied on three-tree plots in a randomized complete block design with three replications. The 1st and 2nd time treatment of the acaricides was applied on July 9 and Aug. 4, 1994, respectively.

Population densities of *T. urticae, P. ulmi, A. womersleyi, Chrysopa* spp. and *Orius* spp. were estimated at 10-d intervals by sampling 30 leaves per each tree at heights of 1.5 to 2.0 m. Mobile stages of them were counted by using a binocular dissecting microscope. In the case of *Chrysopa* spp., the number of eggs was also counted.

RESULTS AND DISCUSSION

The selective toxicity of five acaricides against between *T. urticae* and adult, larva and egg of *H. axyridis* is shown in Table 1. There was considerable variation in the response of these insects to the acaricides tested. All the acaricides tested were more toxic to *T. urticae* than to *H. axyridis*. The range between most toxic (fenpyroximate) and least toxic (dicofol) to *T. urticae* adult at the level of LC_{50} was 21.8-fold. Fenpyroximate that was the most toxic to *T. urticae* was the second toxic compound to *H. axyridis*. Dicofol, which showed the highest selectivity ratio, was by far safer compound for adult and larva of *H. axyridis* than *T. urticae* adult. However, this chemical is not apt for controlling *T. urticae* in the apple orchard because of low control efficacy (unpublished data). Fenpropathrin was the most toxic to adult, larva and egg of *H. axyridis*, and showed the lowest selectivity ratio, excepting for pyridaben in the egg of *H. axyridis*. When considering in various ways, azocyclotin was the highest selective acaricide that was the third toxic to *T. urticae*.

LC_{50} and the selective toxicity of five acaricides to *P. ulmi* and adult, larva and egg of *H. axyridis* are shown in Table 2. All the acaricides tested was more toxic to *P. ulmi* than to *T. urticae*. The response of *P. ulmi* to acaricide varied from high susceptible (1.10 ppm in LC_{50}) to high tolerant (33.18 ppm in LC_{50}). Pyridaben was the most toxic compound to *P. ulmi* and showed the highest selectivity ratio. In addition, this chemical is not apt for controlling *T. urticae* because of low control efficacy (unpublished data), and also not registered for controlling *T. urticae* in the apple orchard in Korea.

Table 1. Selective toxicity of five acaricides for adult of *T. urticae* and different atages of *H. axyridis*

Insecticide	LC_{50}[a](95% FL)				SR[b]
	T. urticae adult	*H. axyridis* egg	*H. axyridis* larva	*H. axyridis* adult	
Azocyclotin	54.50(48.24-60.51)	>650			0.08
Dicofol	411.66(281.18-528.60)	> 50			0.4
Fenpropathrin	22.64(18.10-27.63)	> 12.5			1.8
Fenpyroximate	18.91(13.32-24.12)	>700			0.6
Pyridaben	290.14(160.18-420.14)	> 25			11.6
Azocyclotin			> 40,000		<0.001
Dicofol			> 80,000		<0.005
Fenpropathrin			22.81(3.97-47.97)		1.0
Fenpyroximate			> 12,000		<0.002
Pyridaben			> 25,000		<0.01
Azocyclotin				> 40,000	<0.001
Dicofol				> 80,000	<0.005
Fenpropathrin				263.42(233.54-296.53)	0.1
Fenpyroximate				1811.04(1523.69-2136.44)	0.01
Pyridaben				> 25,000	<0.01

[a]Concentration expressed in ppm as AI.
[b]SR (Selectivity ratio), see Text.

Table 2. Selective toxicity of five acaricides to adult of *P. ulmi* and different stages of *H. axyridis*

Insecticide	LC_{50}[a](95% FL)				SR[b]
	P. ulmi adult	*H. axyridis* egg	*H. axyridis* larva	*H. axyridis* adult	
Azocyclotin	33.18(29.96-36.524)	>650			0.05
Dicofol	28.76(26.51-31.05)	> 50			0.4
Fenpropathrin	5.28(4.46-6.12)	> 12.5			0.4
Fenpyroximate	1.72(1.34-2.07)	>700			0.002
Pyridaben	1.10(0.21-1.95)	> 25			0.04
Azocyclotin			> 40,000		<0.001
Dicofol			> 80,000		<0.0004
Fenpropathrin			22.81(3.97-47.97)		0.2
Fenpyroximate			> 12,000		<0.0001
Pyridaben			> 25,000		<0.00004
Azocyclotin				> 40,000	<0.001
Dicofol				> 80,000	<0.0004
Fenpropathrin				263.42(233.54-296.53)	0.02
Fenpyroximate				1811.04(1523.69-2136.44)	0.009
Pyridaben				> 25,000	<0.00004

[a], [b]For explanation, see Table 1.

Table 3. Phytophagous mites and their natural enemies found in field experiment

Treatmet plot pattern	Total no. mobile stages/30 leaves					
	T. urticae	*P. ulmi*	*Chrysopa* spp.	*Orius* spp.	*A. womersleyi*	*H. axyridis*
HSAT[a]				1.7ab		
Once	736.3b	21.6b	37.3a	1.0b	-	-
Twice	472.2b	4.6b	41.2a		0.9	-
LSAT[b]				2.0ab		
Oncd	471.2b	4.1b	35.1a	0.3b	0.6	-
Twice	498.2b	1.7b	54.1a		0.6	-
				5.6a		
Untreated	2761.1a	168.2a	54.3a		-	-

[a]High selective acaricide treatment.
[b]Low selective acaricide treatment.
* Means with the same letter within a column are not significantly different at P>0.05 by Scheffe's test.

Fenpropathrin, which showed the third in the order of toxicity, was the most toxic compound to all developmental stages of *H. axyridis*, and showed the lowest selectivity ratio. Therefore, azocyclotin and fenpropathrin were the highest and lowest selective acaricide, respectively, and used to examine the effect on phytophagous mites and their major natural enemies in the apple orchard.

Major phytophagous mites and their natural enemies found in field experiment are shown in Table 3. On the whole, the occurrence of natural enemies throughout the growing season was very low because of the long-drawn and the sizzling hot of summer in 1994. Moreover, it was hard to find out *H. axyridis* in the apple orchard used in this experiment. Regardless of acaricide treatment, however, the density of *Chrysopa* spp. was kept much higher than that of other natural enemies.

The population changes of mites and natural enemies after application of azocyclotin that is high selective to *H. axyridis* are shown in Fig. 1. When applied once (Fig. 1A), the population density of mites (*T. urticae* + *P. ulmi*) in treated plot was much lower than that in the control, indicating excellent control efficacy.

The number of mites (*T. urticae* + *P. ulmi*) on July 9, 1994 before treatment is a total of 8.3 per leaf and slowly increased. And then the density on Oct. 19, 1994 was more or less higher than that before treatment. *Amblyseius womersleyi* is an important predator of *T. urticae* (Lee 1965). Lee *et al.* (1994) reported that the density of this predator mite was high in July to September, reaching a peak in August. In this experiment, however, *A. womersleyi* in plots applied once did not occur. Rather, its density in plots applied twice was much higher as a total of 0.6 per 30 leaves before treatment, but never showed since twice treatment. Low density of *A. womersleyi* in this experiment may be due to the long-drawn and the sizzling hot of summer in 1994 rather than effects by acaricide treatment. Thus, the population changes of *A. womersleyi* by treatment of the acaricides selected in this experiment remains to be clarified.

In the case of *Orius* spp., the density before treatment was a total of 0.9 per 30 leaves, and then their occurrence after applying once could not be observed. It may be associated with acaricide treatment. The density of *Chrysopa* spp. before treatment was a total of 2.7 per 30 leaves. Rather, their density after treatment increased as a total of 15.6 per 30 leaves on Aug. 9, and then continued to decrease. It seems that *Chrysopa* spp. were not also dependent upon acaricide treatment. Therefore, *Chrysopa* spp. appear to be promising biological control agent for insect pests such as mites and aphids in the apple orchard.

The density of mites (*T. urticae* + *P. ulmi*) when applied twice (Fig. 1B) was totally much lower than that when applied once, showing excellent control efficacy. And also its density on Oct. 19 was much lower than that when applied once. This result may be due to the occurrence of mites in next year, because *T. urticae* adults moved to the overwintering sites in mid September to November (Lee 1990). Thus, researchers

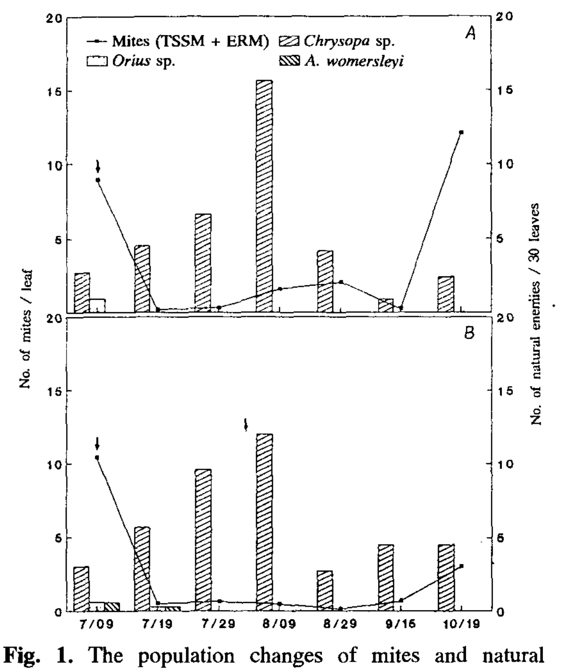

Fig. 1. The population changes of mites and natural enemies after application of azocyclotin which is high selective to *H. axyridis*. A and B indicate those when applied once and twice, respectively. TSSM: Two spotted spider mite; ERM: European red mite. Arrows indicate timing of application.

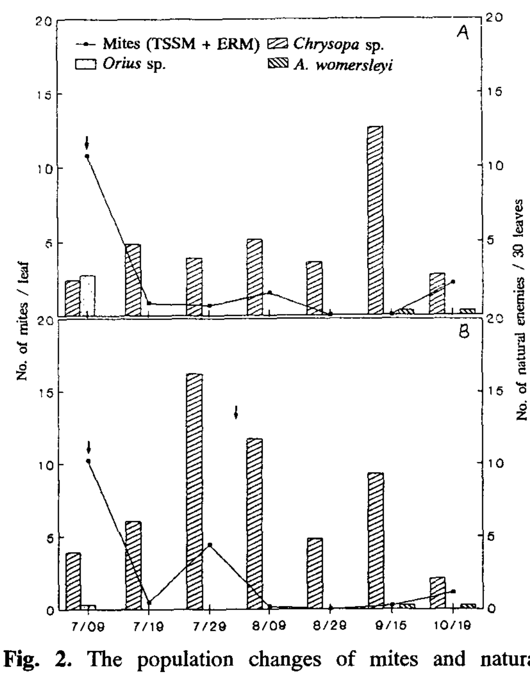

Fig. 2. The population changes of mites and natural enemies after application of fenpropathrin which is low selective to *H. axyridis*. A and B indicate those when applied once and twice, respectively. TSSM: Two spotted spider mite; ERM: European red mite. Arrows indicate timing of application.

should study in several ways to reduce the number of adult mites moved into the overwintering sites. Like the result shown in Fig. 1A, the density changes of natural enemies showed a similar pattern.

The population changes of mites and natural enemies after application of fenpropathrin that is low selective to *H. axyridis* are shown in Fig. 2. When applied once with fenpropathrin (Fig. 2A), *Orius* spp. never occurred after applying one time. The occurrence of *A. womersleyi* was not shown before treatment, but rather shown a total of 0.3 per 30 leaves since Sept. 15. It did not seem that this result may be due to acaricide treatment because its occurrence did not show, even in untreated plot. Fenpropathrin treatment had also no effect on the population density of *Chrysopa* spp, like the results in Fig. 1.

In conclusion, the acaricides for use in integrated mite management programs will, of course, be toxic to the mite but not to the predator. In the absence of such an acaricide, however, the best alternative will be to use acaricides that are the most selective against the predator. In our experiment, the changes of the population density could not be observed according to application frequency and kind of insecticide. Additional data are needed, therefore, to see if the relationship reported here extend to favorable selectivity for other predators and parasites, including comparative field evaluation to ascertain effects of selected pesticides on the whole natural enemy complex.

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