Comparative Toxicity of Selected Insecticides to *Aphis citricola*, *Myzus malisuctus* (Homoptera: Aphididae), and the Predator *Harmonia axyridis* (Coleoptera: Coccinellidae)

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ABSTRACT Response of the apple aphid *Aphis citricola* van der Goot adults to treatment with several classes of insecticides varied from most toxic (esfenvalerate with LC_{50} 0.89 ppm [AI]) to least toxic (monocrotophos with LC_{50} 385.51 ppm [AI]). Esfenvalerate, which was most toxic to *A. citricola*, was also most toxic to the aphidophagus coccinellid *Harmonia axyridis* Pallas. The response of the aphid *Myzus malisuctus* Matsumura adult to different insecticides varied from highly susceptible (deltamethrin with LC_{50} 0.01 ppm [AI]) to highly tolerant (fenpropathrin with LC_{50} 6.95 ppm [AI]). Esfenvalerate, which was 3rd in the order of toxicity to *M. malisuctus*, was the most toxic compound to *H. axyridis*. Alphamethrin, which showed the lowest selectivity ratio, was also much safer to the predator than to the pest. Based on their selectivity ratios, alphamethrin appeared to be the most promising candidate for use in integrated pest management programs where *H. axyridis* is the major natural enemy.

KEY WORDS *Aphis citricola, Myzus malisuctus, Harmonia axyridis,* toxicity, selectivity

APPLE IS A MAJOR FRUIT crop in Korea where increasing cultivation has resulted in increased economic importance (Anonymous 1992). Among 312 species of apple insect pests, the more important species are *Aphis citricola* van der Goot and *Myzus malisuctus* Matsumura (Anonymous 1986, Lee 1990). The aphidophagus coccinellid *Harmonia axyridis* Pallas is an important predator of several crop pests, particularly in apple orchards. Conservation of insect predators can be an important component of integrated pest management (IPM) programs. One approach to protecting this natural enemy in IPM programs involves the use of selective insecticides, which are effective against insect pests but relatively safe for the predator (Yu 1988).

Lee and Kim (1989) reported the selective toxicity between the beetle and 3 aphids at the rate of recommended concentrations of insecticides (acephate, cyhalothrin, and pirimicarb). Several reports have recorded the high toxicity of insecticides to parasites and predators (Bartlett 1966, Lindgren et al. 1972). This greater susceptibility may result from differences in the ability to detoxify insecticides between prey and its predator, but the exact mechanism of insecticide selectivity between prey and predator is unknown.

As part of developing basic techniques for IPM for apple insect pests in Korea, we determined the comparative toxicity of some insecticides to *A. citricola, M. malisuctus,* and their coccinellid predator.

Materials and Methods

Insects. *A. citricola* and *M. malisuctus* were collected from an apple orchard in Suwon and used the same day of collection without rearing in the laboratory. Aphids treated were maintained in apple leaves in the insectary with 25 ± 1°C, 50–60% RH, and a photoperiod 16:8 (L:D) h. An aphidophagous coccinellid, *H. axyridis*, collected from the rose of Sharon, *Hibiscus syriacus* L., was reared on cotton aphid, *Aphis gossypii* Glover, and maintained under the same rearing conditions as described above.

Insecticides. Tested insecticides were provided by the manufacturers and are listed in Table 1. They were selected mostly on the basis of their use, past or current, for the control of *A. citricola* and *M. malisuctus* in apple orchards.

Bioassay. Toxicity measurements for *A. citricola* and *M. malisuctus* were made using the insect-leaf dipping method (to take field conditions into consideration) as modified by Lee and Kim (1989). *A. citricola* and *M. malisuctus* were dipped for 30 s and placed in plastic petri dishes (5.5 by 2.0 cm). Water only was used for the control. Mortality was determined 48 h after treatment. The criterion for death was failure of the aphid to move its legs when stimulated with a fine brush.

Adults and larvae of *H. axyridis* were collected from laboratory cultures and treated topically on the thoracic abdomen with 0.5 μl of each insecticide diluted in acetone. Acetone only was used for

Table 1. Insecticides used in this study

Common name	AI, %		Chemical name
Alphamethrin	2%	EC	A racemate composed of (S)-α-cyano-3-phenoxybenzyl (1R)-cis-3-(2,2-dichloro-vinyl)-2,2-dimethylcyclopropane carboxylate and (R)-α-cyano-3-phenoxybenzyl (1S)-cis-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylate
Deltamethrin	1%	EC	(S)-α-cyano-3-phenoxybenzyl-(1R)-cis(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylate
Esfenvalerate	1.5%	EC	(S)-α-cyano-3-phenoxybenzyl-(S)-2-(4-chlorophenyl)-3-methylbutyrate
Fenpropathrin	5%	EC	(RS)-α-cyano-3-phenoxybenzyl-2,2,3,3-tetramethyl-cyclopropane carboxylate
Methomyl	24.1%	SC	S-methyl N-(methyl carbamoloxy) thioacetimidate
Monocrotophos	24%	SC	Dimethyl(E)-1-methyl-2-methylcarbamoyl vinylphosphate
Phosphamidon	50%	SC	2-chloro-2-diethyl carbmoyl-1-methyl vinyl dimethylphosphate
Pyridaphenthion	30%	EC	0,0-diethyl-0-(3-oxo-2-phenyl-2H-pyridazine-6-yl) phosphorothioate

EC, emulsifiable concentrate; SC, soluble concentrate.

the control. After treatment, the insects were maintained in plastic petri dishes (10 by 7.5 cm) under the same conditions as described above. The test insects were provided cotton aphids as a food source. Mortality was determined 48 h after treatment. The criterion for death was failure of the aphidophagous beetle to move its legs when stimulated with a fine brush. Results were analyzed by probit analysis (Finney 1971, Raymond 1985). Selectivity data were obtained by dividing the LC_{50} value of each insecticide to *A. citricola* and *M. malisuctus* by the same value for *H. axyridis*. Values >1 indicate the insecticide was more toxic to the predator than to the pest. Values <1 indicate the insecticide was more toxic to the pest than to the predator. Thus, the lower the value, the safer an insecticide is for the beneficial insect and, therefore, potentially more appropriate for use in IPM programs.

Results

There was considerable variation in the response of these insects to the insecticides tested (Table 2). For *A. citricola*, the range from most toxic (esfenvalerate) to least toxic (monocrotophos) was >430-fold based on the LC_{50}s. Esfenvalerate, which was the most toxic to *A. citricola*, was also most toxic to *H. axyridis* adults. All insecticides tested were generally more toxic to *A. citricola* than to *H. axyridis*. Alphamethrin, which showed the lowest selectivity ratio, was less toxic to *H. axyridis* adults than *A. citricola*.

Selective toxicities of several classes of insecticides to *A. citricola* adults and *H. axyridis* larvae are shown in Table 3. Deltamethrin was most toxic to *H. axyridis* larvae of the 8 insecticides tested. Alphamethrin, which showed the lowest selectivity ratio, was much safer to *H. axyridis* larvae than *A. citricola*.

The LC_{50}s and the selective toxicity of several classes of insecticides to *M. malisuctus* and *H. axyridis* adults are shown in Tables 4 and 5. *M. malisuctus* was more susceptible to all the insecticides tested than *A. citricola*. The response of *M. malisuctus* adults to treatment with the different insecticides varied from highly susceptible (LC_{50} of <0.01 ppm [AI]) to highly tolerant (LC_{50} of >6.95 ppm [AI]). Esfenvalerate, which was 3rd in the order of toxicity to *M. malisuctus*, was the most toxic

Table 2. Selective toxicity of several classes of insecticides to *A. citricola* adults and *H. axyridis* adults

Insecticide	*A. citricola* adult				*H. axyridis* adult				SR[a]
	n	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	n	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	
Alphamethrin	120	5.19 (3.79– 6.34)	2.14 ± 0.34	0.10	50	100.04 (72.58–138.47)	1.12 ± 0.20	1.21	0.05
Deltamethrin	134	1.08 (0.58– 1.45)	1.60 ± 0.34	2.03	50	89.35 (62.79–129.67)	0.99 ± 0.16	0.23	0.01
Esfenvalerate	119	0.89 (0.08– 2.04)	0.92 ± 0.23	1.46	50	8.09 (3.54– 13.53)	0.65 ± 0.15	0.58	0.11
Fenpropathrin	180	30.60 (24.59– 35.85)	2.46 ± 0.35	0.71	50	263.42 (233.54–296.53)	2.80 ± 0.24	1.00	0.12
Methomyl	122	67.76 (36.36– 96.09)	1.78 ± 0.29	3.95	50	34.95 (31.43– 39.13)	3.54 ± 0.37	3.92	1.94
Monocrotophos	150	385.51 (330.59–436.40)	3.19 ± 0.38	4.47	50	366.70 (337.01–396.27)	6.07 ± 0.68	0.10	1.05
Phosphamidon	112	368.51 (327.94–409.91)	3.73 ± 0.39	4.41	50	44.02 (40.58– 47.58)	5.85 ± 0.59	0.55	8.37
Pyridaphenthion	239	70.65 (36.27–102.27)	1.62 ± 0.27	6.72	50	341.65 (263.83–517.02)	1.30 ± 0.30	0.57	0.21

[a] Selectivity ratios: LC_{50} of *A. citricola* adult/LC_{50} of *H. axyridis* adult. Ratios >1 indicate insecticides more toxic to the predator than to the pest; ratios <1 indicate insecticides more toxic to the pest than to the predator.

Table 3. Selective toxicity of several classes of insecticides to *A. citricola* adults and *H. axyridis* larvae

Insecticide	*A. citricola* adult				*H. axyridis* larva				SR[a]
	n	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	n	LC_{50} ppm (AI) (95% FL)	Slope ± SE	χ^2	
Alphamethrin	120	5.19 (3.79– 6.34)	2.14 ± 0.34	0.10	50	87.93 (60.20–117.93)	1.26 ± 0.16	0.27	0.06
Deltamethrin	134	1.08 (0.58– 1.45)	1.60 ± 0.34	2.03	50	19.65 (14.02– 27.47)	1.07 ± 0.16	0.45	0.05
Esfenvalerate	119	0.89 (0.08– 2.04)	0.92 ± 0.23	1.46	50	30.53 (20.79– 52.67)	0.90 ± 0.16	0.07	0.03
Fenpropathrin	180	30.60 (24.59– 35.85)	2.46 ± 0.35	0.71	50	22.81 (13.97– 47.97)	1.20 ± 0.27	3.29	1.34
Methomyl	122	67.76 (36.36– 96.09)	1.78 ± 0.29	3.95	50	148.26 (137.63–159.80)	6.37 ± 0.61	0.93	0.46
Monocrotophos	150	385.51 (330.59–436.40)	3.19 ± 0.38	4.47	50	208.64 (162.55–255.92)	2.13 ± 0.25	2.29	1.85
Phosphamidon	112	368.51 (327.94–409.91)	3.73 ± 0.39	4.41	50	61.31 (45.67– 74.06)	2.40 ± 0.36	27.68	6.01
Pyridaphenthion	239	70.65 (36.27–102.27)	1.62 ± 0.27	6.72	50	186.70 (166.31–207.07)	3.74 ± 0.39	12.06	0.38

[a] Selectivity ratios: LC_{50} of *A. citricola* adult/LC_{50} of *H. axyridis* larva. Ratios >1 indicate insecticides more toxic to the predator than to the pest; ratios <1 indicate insecticide more toxic to the pest than to the predator.

compound to *H. axyridis*. As a whole, all the synthetic pyrethroids tested in this experiment were more toxic to both *A. citricola* and *M. maliscutus* than several other classes of insecticides. However, deltamethrin showed the lowest selectivity ratio and, also, was much safer to *H. axyridis* than to *M. malisuctus*.

Discussion

Ideal insecticides for use in IPM programs will be toxic to the pest but not to its natural enemies (Plapp and Bull 1978). In the absence of such an insecticide, the best alternative will be to use insecticides that are least selective against the predator. Of the 8 insecticides tested, our data show that almost all insecticides tested were more toxic to the pest than to the predator. Alphamethrin showed the lowest selectivity ratio for larvae and adults of *H. axyridis* compared with *A. citricola* and *M. malisuctus*. These results indicate that all the synthetic pyrethroids tested were highly toxic to *A. citricola* and *M. malisuctus*, but less toxic to *H. axyridis*. This agrees with the findings of Plapp and Bull (1978) and Waddill (1978) who concluded that pyrethroids may be least toxic of available insecticides for both parasites and predators.

The low insecticide susceptibility of *H. axyridis* to the pyrethroids may be the result of its generally high levels of the insecticide detoxifying enzyme activities as compared with the prey (Yu 1987). Use of insecticides that are selectively more toxic to the pest than to the predator has been advocated by several researchers (Plapp and Bull 1978, Coats et al. 1979, Rajakulendran and Plapp 1982). Most of these studies have shown that certain pyrethroids are more toxic to pest insects than to some beneficial insects. This differential insecticide susceptibility may result from biochemical differences between the predator and its prey. In the case of the pyrethroids, these compounds are metabolized by microsomal oxidase and esterases in insects (Shono et al. 1979). Based on our data, it is difficult to determine why *H. axyridis* was less susceptible to the pyrethroids compared with the prey. To do so, additional studies must be done to evaluate detoxification mechanisms, penetration, and target site sensitivity, which could contribute to our understanding of differential toxicity between natural enemies and their prey.

However, based on their selectivity ratios, alphamethrin seems to be the most promising candidate insecticide tested for use in IPM programs where *H. axyridis* is the major natural enemy. Additional data are needed, however, to determine if the relationship reported here extends to favorable selectivity for other predators and parasites. In addition, comparative field evaluation of selected insecticides within this class may be necessary to ascertain their effects on additional natural enemy species, and to evaluate their relative usefulness in

Table 4. Selective toxicity of several classes of insecticides to *M. malisuctus* adults and *H. axyridis* adults

Insecticide	*M. malisuctus* adult				*H. axyridis* adult				SR[a]
	n	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	n	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	
Alphamethrin	453	0.05 (0.01–0.18)	1.07 ± 0.34	6.86	50	100.04 (72.58–138.47)	1.12 ± 0.20	1.21	0.0005
Deltamethrin	492	0.01 (0.01–0.04)	1.00 ± 0.34	8.49	50	89.35 (62.79–129.67)	0.99 ± 0.16	0.23	0.0001
Esfenvalerate	1,131	0.71 (0.15–1.38)	1.15 ± 0.25	2.82	50	8.09 (3.54– 13.53)	0.65 ± 0.15	0.58	0.09
Fenpropathrin	544	6.95 (6.04–8.08)	2.53 ± 0.33	2.58	50	263.42 (233.54–296.53)	2.80 ± 0.24	1.00	0.03
Methomyl	699	2.91 (2.34–3.46)	1.94 ± 0.23	0.91	50	34.95 (31.43– 39.13)	3.54 ± 0.37	3.92	0.08
Monocrotophos	337	3.96 (1.22–6.30)	1.83 ± 0.43	9.80	50	366.70 (377.01–396.27)	6.07 ± 0.68	0.10	0.01
Phosphamidon	765	4.87 (2.93–6.24)	3.15 ± 0.62	1.00	50	44.02 (40.58– 47.58)	5.85 ± 0.59	0.55	0.11
Pyridaphenthion	1,079	0.95 (0.41–1.34)	2.94 ± 0.68	1.94	50	341.65 (263.83–517.02)	1.30 ± 0.30	0.57	0.003

[a] Selectivity ratios: LC_{50} of *M. malisuctus* adult/LC_{50} of *H. axyridis* adult. Ratios >1 indicate insecticides more toxic to the predator than to the pest: ratios <1 indicate insecticides more toxic to the past than to the predator.

Table 5. Selective toxicity of several classes of insecticides to *M. malisuctus* adults and *H. axyridis* larvae

Insecticide	*M. malisuctus* adult				*H. axyridis* larva				SR[a]
	n	LC_{50} ppm (AI) (95% FL)	Slope ± SE	χ^2	*n*	LC_{50}, ppm (AI) (95% FL)	Slope ± SE	χ^2	
Alphamethrin	453	0.05 (0.01–0.18)	1.07 ± 0.34	6.86	50	87.93 (60.20–117.93)	1.26 ± 0.16	0.27	0.0006
Deltamethrin	492	0.01 (0.01–0.04)	1.00 ± 0.34	8.49	50	19.65 (14.02– 27.47)	1.07 ± 0.16	0.45	0.0005
Esfenvalerate	1,131	0.71 (0.15–1.38)	1.15 ± 0.25	2.82	50	30.53 (20.79– 52.67)	0.90 ± 0.16	0.07	0.02
Fenpropathrin	544	6.95 (6.04–8.08)	2.53 ± 0.33	2.58	50	22.81 (13.97– 47.97)	1.20 ± 0.27	3.29	0.3
Methomyl	699	2.91 (2.34–3.46)	1.94 ± 0.23	0.91	50	148.26 (137.63–159.80)	6.37 ± 0.61	0.93	0.02
Monocrotophos	337	3.96 (1.22–6.30)	1.83 ± 0.43	9.80	50	208.64 (162.55–255.92)	2.13 ± 0.25	2.29	0.02
Phosphamidon	765	4.87 (2.93–6.24)	3.15 ± 0.62	1.00	50	61.31 (45.67– 74.06)	2.40 ± 0.36	27.68	0.08
Pyridaphenthion	1,079	0.95 (0.41–1.34)	2.94 ± 0.68	1.94	50	186.70 (166.31–207.07)	3.74 ± 0.39	12.06	0.005

[a] Selectivity ratios: LC_{50} of *M. malisuctus* adult/LC_{50} of *H. axyridis* larva. Ratios >1 indicate insecticides more toxic to the predator than to the pest; ratios <1 indicate insecticides more toxic to the pest than to the predator.

IPM programs. More basic research concerning the biochemistry of beneficial insects is urgently needed to provide a biochemical basis for designing selective insecticides for use in IPM programs.

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