Indirect Effect of Insecticides on Convergent Lady Beetle (Coleoptera: Coccinellidae) in Pecan Orchards

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ABSTRACT Indirect toxicity through feeding on insecticide-treated prey was determined for five insecticides at two concentrations each to larvae and adults of convergent lady beetle, *Hippodamia convergens* Guérin-Méneville. Endosulfan (0.375 and 0.75 g [AI]/liter), carbaryl (1.2 and 2.4 g [AI]/liter), phosmet (0.375 and 0.75 g [AI]/liter), methomyl (0.225 and 0.45 g [AI]/liter), and esfenvalerate (0.015 and 0.03 g [AI]/liter) were toxic to larvae and adults when convergent lady beetles were fed insecticide-treated yellow pecan aphids, *Monelliopsis pecanis* Bissell. Esfenvalerate was a fast-acting insecticide, killing all tested convergent lady beetle life stages 1 h after feeding on treated yellow pecan aphids. Carbaryl and phosmet were slow-acting insecticides, causing the greatest mortality after 48 h. Methomyl was the only insecticide that did not cause 100% mortality to adult convergent lady beetles 48 h after feeding on insecticide-treated yellow pecan aphids, at both rates tested.

KEY WORDS *Hippodamia convergens*, *Monelliopsis pecanis*, toxicity

THE CONVERGENT LADY BEETLE, *Hippodamia convergens* Guérin-Méneville, is a prominent species of the native American fauna of natural enemies in many agroecosystems (Hagen 1962, Edelson & Estes 1987, Elliott & Kieckheffer 1990). *H. convergens* is polyphagous, often showing no preference between aphids (Kring & Gilstrap 1986), but may exhibit a preference between certain aphid species (Garcia & Ribeiro 1983). *H. convergens* is an important predator of pecan aphids, *Monellia caryella* (Fitch) (the blackmargined aphid) and *Monelliopsis pecanis* Bissell (the yellow pecan aphid) (Edelson & Estes 1987). One method of conserving beneficials is to use selective pesticides. However, few selective insecticides are registered for use, or used frequently, on minor crops (Croft 1990). Predators in pecan, *Carya illinoinensis* (Wangenheim) C. Koch, orchards may be affected directly by insecticide spray and contact residue (fresh or dry) or indirectly by consuming treated prey. Carbaryl was toxic to adults of *H. convergens* when beetles contacted dry residue on pecan foliage (Dutcher 1983). Mizell & Schiffhauer (1990) reported that among 15 insecticides used in pecan orchards, lindane was least toxic to *H. convergens*, causing 42% mortality to adults. Insecticides commonly used on other crops, such as celery, *Apium graveolens* L. var. *dulce* (P. Miller) Persoon (Jones et al. 1983); cotton, *Gossypium hirsutum* L. (Wilkinson et al. 1979); and peach, *Prunus persica* (L.) Batsch (Moffitt et al. 1972) caused high mortality of *H. convergens*.

Toxicity may occur through the food chain when predators eat aphids feeding on plants treated with insecticides. For example, adults of *H. convergens* were resistant to demeton, but 51.6% of larvae died after feeding on dead or moribund *Aphis gossypii* Glover that were killed with that insecticide (Ahmed et al. 1954).

This paper reports the toxicity of five contact insecticides commonly used against different pests in pecan orchards to all larval instars and adults of *H. convergens* when fed on insecticide-treated *M. pecanis*.

Materials and Methods

Indirect effect of insecticides on mortality of *H. convergens* was studied in laboratory tests. Adult predators were obtained from Rincon-Vitova (Davis, CA). They were separated by sex, paired, placed in petri dishes, and fed daily on an overabundance of cowpea aphids, *A. craccivora* Koch, in a greenhouse. After 48 h, males were removed from the dishes to preclude egg cannibalism. Coccinellid eggs were collected daily and held in a rearing room at 23 ± 2°C with 50 ± 5% RH and a photoperiod of 16:8 (L:D) h. Eggs were monitored daily for eclosion. Newly hatched larvae were sequestered individually into 29.6-ml transparent plastic graduated medi-

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cine cups that were secured with paper lids. The larvae were fed *A. craccivora* until they reached the proper life stage for the test.

Five insecticides were used, as follows: endosulfan (Thiodan 3E, [Emulsifiable; 360 g (AI)/liter], FMC, Middleport, NY), carbaryl (Sevin 80S [80% Soluble Powder], Rhone-Poulenc, Research Triangle Park, NC), phosmet (Imidan 50WP [50% Wettable Powder], ICI Americas, Wilmington, DE), methomyl (Lannate LV [Low Volume, 286 g (AI)/liter], DuPont, Wilmington, DE), and esfenvalerate (Asana XL, [Xylene, 79 g (AI)/liter], DuPont) at low and high rates. The recommended rates of applications on pecan trees were as follows: 0.75 g (AI)/liter for endosulfan; 2.4 g (AI)/liter for carbaryl; 0.75 g (AI)/liter for phosmet; 0.45 g (AI)/liter for methomyl, and 0.03 g (AI)/liter for esfenvalerate.

M. pecanis was reared on pecan seedlings in growth cabinets in a rearing room as previously described. Leaves bearing aphids were dipped in each insecticide solution or distilled water (control) for 5 s and dried in a fume hood. Insecticide- or water-treated aphids were added twice a day to each cup containing coccinellids. The number of aphid prey added ranged from five for first-instar coccinellids to ≈50 for fourth instars and adults. The treatments were applied in a complete randomized design with five replicates. Six coccinellids per replicate were tested for each larval instar and 3- to 4-d-old adult stage at rates previously described. Adult lady beetles were not separated by sex before the test. Responses of coccinellids to insecticide-treated aphids at these rates were compared with the responses to water-treated aphids. Mortality was recorded 1, 24, and 48 h after the first *M. pecanis* were added to the cups. When the coccinellid's movement was slow and it was unable to right itself when lying on its back, it was called "moribund" and counted as dead. Mortality of the test insects was corrected for control mortality by Abbott's (1925) formula. Percentages were subjected to analysis of variance (ANOVA) and Fisher's least significant difference (LSD) test (SAS Institute 1989).

Results

Endosulfan killed 30% of the fourth instars after 1 h of *H. convergens* feeding on treated *M. pecanis* at the low rate (Table 1). Endosulfan was significantly ($P < 0.05$) more toxic to first and second instars than to fourth instars and was most toxic to adults, causing 100% mortality. Mortality of third and fourth instars increased 24 h after the first insecticide-treated aphids were added to the cups, and almost all larvae died after 48 h. After 1, 24, and 48 h of coccinellid feeding on treated aphids, endosulfan at the high rate caused percentage mortalities of larvae and adults similar to those with endosulfan at the low rate. The only significant ($P < 0.05$) difference in mortality between these rates was found for the first instars after 1 and 24 h of feeding ($F = 8.5$ and 16.0, respectively; df = 1, 9).

Carbaryl at the low rate did not immediately kill coccinellid larvae. No mortality of first instars after 1 h feeding was recorded, but survival decreased sharply, with 89 and 100% mortality after 24 and 48 h of feeding, respectively (Table 1). Mortality of the other instars was also low after 1 h (13–40%), and no increase in mortality was recorded after 24 h of feeding on carbaryl-treated *M. pecanis*. Mortality of the second, third, and fourth instars was <80%. Carbaryl was more toxic to adult *H. convergens* than to larvae, killing 90% of the adults after 1 and 24 h and 100% after 48 h. Generally, toxicity of carbaryl for each rate, to the same instar, and at the same hour, was not significantly different. Significantly ($P < 0.05$) higher mortality at the high rate occurred in first instars after 1 h, third instars after 24 h, and fourth instars after 48 h of feeding on treated aphids ($F = 10.3$, 8.9, and 7.5, respectively; df = 1, 9).

Phosmet at the low rate caused low mortality (10–23%) of first, second, and third instars of *H. convergens* when they fed for 1 h on insecticide-treated *M. pecanis* (Table 1). Higher mortality was recorded for fourth instars and adults, with 43 and 73%, respectively. Significant ($P < 0.05$) increase in mortality of all life stages occurred after 24 h of feeding, and mortality did not change after 48 h. Phosmet at the high rate caused percentage mortality similar to those recorded at the low rate when the same developmental stage and hour were compared, except that first instars had significantly ($P < 0.05$) higher mortality at the high rate after 24 h of feeding ($F = 5.9$; df = 1, 9).

Methomyl at the low rate was toxic to third and fourth instars, with 67 and 73% mortality, respectively, after 1 h of feeding on insecticide-treated aphids (Table 1). First instars and adults were more tolerant of the insecticide after 1 h of feeding, with 30 and 33% mortality, respectively. Second instars were intermediate in their reaction to methomyl. Significant ($P < 0.05$) increase in mortality for first and fourth instars was recorded after 24 h of feeding on treated aphids, and 100% of all instars were dead after 48 h. Methomyl was the only treatment that did not kill all tested adults when they fed 48 h on treated *M. pecanis*. At the low rate, adult mortality reached 60%. The only significant ($P < 0.05$) difference found in mortality between the low and high rates was for the first instars after 24 h feeding, with higher mortality at the high rate ($F = 8.9$; df = 1, 9).

Esfenvalerate was a toxic and fast-acting insecticide to coccinellids at both rates. All larvae and adults died within 1 h of feeding on treated aphids.

Table 1. Indirect toxicity of endosulfan, carbaryl, phosmet, and methomyl to *H. convergens*

Insecticide rate[a] Insecticide	Developmental stage	% mortality of coccinellids ± SEM at indicated rates and hours							
		Low				High			
		1 h	24 h	48 h	F^b	1 h	24 h	48 h	F^b
Endosulfan	1st instar	63 ± 8bB* (19)[c]	67 ± 5cB* (20)	97 ± 3aA (29)	9.6	90 ± 4aA (27)	93 ± 4abA (28)	96 ± 4aA (29)	0.5
	2nd instar	67 ± 5bB (20)	79 ± 7bcB (24)	100 ± 0aA (30)	11.1	73 ± 6bA (24)	83 ± 9bA (25)	93 ± 4aA (28)	2.3
	3rd instar	50 ± 7bcB (15)	93 ± 4abA (28)	97 ± 3aA (29)	24.4	50 ± 5cB (14)	93 ± 4abA (27)	100 ± 0aA (30)	49.7
	4th instar	30 ± 9cB (9)	90 ± 7abA (27)	100 ± 0aA (30)	31.0	27 ± 8dB (8)	97 ± 3abA (29)	100 ± 0aA (30)	61.7
	Adult	100 ± 0aA (30)	100 ± 0aA (30)	100 ± 0aA (30)	—	100 ± 0aA (30)	100 ± 0aA (30)	100 ± 0aA (30)	—
	F^d	13.8	6.3	0.7		28.1	1.5	1.4	
Carbaryl	1st instar	0 ± 0dC* (0)	89 ± 4aB (27)	100 ± 0aA (30)	467.9	40 ± 12bcB (12)	85 ± 9abA (25)	100 ± 0aA (30)	12.4
	2nd instar	40 ± 16bB (12)	43 ± 14bB* (13)	80 ± 10abA (24)	2.6	60 ± 7bC (18)	83 ± 5abB (25)	100 ± 0aA (30)	16.8
	3rd instar	13 ± 8cdB (4)	50 ± 14bAB* (15)	73 ± 13bA (22)	6.1	27 ± 7cB (8)	93 ± 4aA (28)	100 ± 0aA (30)	80.7
	4th instar	26 ± 6bcB (8)	37 ± 17bB (11)	77 ± 8abA* (23)	5.2	30 ± 8cC (9)	73 ± 4bB (22)	100 ± 0aA (30)	44.9
	Adult	90 ± 4aA	90 ± 4aA (27)	100 ± 0aA (27)	3.0 (30)	93 ± 4aA	93 ± 4aA (28)	100 ± 0aA (28)	1.3 (30)
	F^d	15.2	4.6	2.4		11.5	2.2	—	
Phosmet	1st instar	17 ± 5cB (5)	89 ± 5bA* (25)	100 ± 0aA (27)	123.7	20 ± 6cB (6)	100 ± 0aA (28)	100 ± 0aA (28)	164.6
	2nd instar	10 ± 7cB (3)	100 ± 0aA (30)	100 ± 0aA (30)	182.2	17 ± 7cB (5)	100 ± 0aA (30)	100 ± 0aA (30)	125.0
	3rd instar	23 ± 8cB (7)	97 ± 3aA (29)	100 ± 0aA (30)	67.6	33 ± 16bcB (10)	97 ± 3aA (30)	100 ± 0aA (30)	16.2
	4th instar	43 ± 4bB (13)	100 ± 0aA (30)	100 ± 0aA (30)	192.7	60 ± 10abB (18)	100 ± 0aA (30)	100 ± 0aA (30)	16.0
	Adult	73 ± 7aB (22)	100 ± 0aA (30)	100 ± 0aA (30)	16.0	80 ± 3aB (24)	100 ± 0aA (30)	100 ± 0aA (30)	36.0
	F^d	15.9	3.7	—		8.1	1.0	—	
Methomyl	1st instar	30 ± 3bC (9)	67 ± 7bcB* (21)	100 ± 0aA (30)	55.2	47 ± 10bB (16)	93 ± 4aA (28)	100 ± 0aA (30)	18.9
	2nd instar	47 ± 11abB (14)	63 ± 12cB (20)	100 ± 0aA (30)	8.2	37 ± 3bC (11)	77 ± 7bB (23)	100 ± 0aA (30)	55.4
	3rd instar	73 ± 15aA (22)	97 ± 3aA (29)	100 ± 0aA (30)	2.5	73 ± 7aB (22)	97 ± 3aA (29)	100 ± 0aA (30)	11.4
	4th instar	67 ± 0aB (20)	93 ± 4abA (28)	100 ± 0aA (30)	56.0	70 ± 3aB (21)	93 ± 4aA (28)	100 ± 0aA (30)	26.8
	Adult	33 ± 10bA (10)	53 ± 13cA (16)	60 ± 12bA (18)	1.3	43 ± 7bB (13)	43 ± 7cB (15)	80 ± 12bA (24)	5.6
	F^d	3.9	4.5	10.3		6.7	18.0	2.5	

Lowercase letters within each column are for mean percentage mortality of larval and adult stages at the same hour for each rate; uppercase letters within the same row are for mean percentage mortality of the same stage at 1, 24, and 48 h at the low and high rates. Asterisks indicate significant differences ($P < 0.05$) between percentage mortality at the low and high rates at the same stage and hour. Means were separated ($P < 0.05$) using Fisher's protected least significant difference.

[a] Low and high insecticide rates are as follows: endosulfan (0.375 and 0.75 g [AI]/liter), carbaryl (1.2 and 2.4 g [AI]/liter), phosmet (0.375 and 0.75 g [AI]/liter), methomyl (0.225 and 0.45 g [AI]/liter), and esfenvalerate (0.015 and 0.03 g [AI]/liter).

[b] *F* values for means separation for each stage at different time periods.

[c] Numbers in parentheses are cumulative numbers of dead coccinellids, $n = 30$.

[d] *F* values for means separation for all stages at each time period.

Discussion

All tested insecticides were toxic to larvae and adults of *H. convergens* and caused similar mortality at the low and high rates after 48 h feeding on insecticide-treated *M. pecanis*. Reduced rates of insecticides conserve natural enemies (Mizell & Schiffhauer 1990). In our study, all of the tested insecticides were toxic to all developmental stages of *H. convergens,* even at the low rate. Esfenvalerate was a fast-acting insecticide that killed all coccinellids within 1 h of feeding on treated aphids. Other pyrethroids applied directly were also highly toxic to *H. convergens* (Wilkinson et al. 1979, Jones et al. 1983, Mizell & Schiffhauer 1990). In contrast, carbaryl and phosmet acted slowly, causing the highest mortality of larvae after 48 h. Methomyl was the only insecticide that did not kill all adult *H. convergens* after 48 h.

Adult *H. convergens* were tolerant of the systemically acting insecticide demeton when fed on dead or moribund cotton aphids (Ahmed et al.

1954). Percentage mortality of the first instars was 15.5 and 51.6% when they fed on demeton-treated aphids after 48 h and 7 d, respectively. In our tests, adults fed on *M. pecanis* treated with various contact insecticides were susceptible to those insecticides. The tested insecticides killed ≈100% of all larvae, regardless of instar, within 48 h of feeding on treated aphids. Demeton exhibited differential indirect toxicity to larvae of various coccinellid species, with mortality ranging from 3.6% in *Coleomegilla maculata* (De Geer) to 100% in *Scymnus haemorrhous* LeConte. Insecticides are widely used in Georgia pecan orchards. In 1991, 281,144 kg of insecticides were used at 4.2 kg/ha (Anonymous 1992), most of which are toxic to *H. convergens* (Dutcher 1983, Mizell & Schiffhauer 1990). All insecticides tested in our study were toxic to *H. convergens*.

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