EFFECT OF INSECTICIDES ON TWO PREDATORS OF THE COLORADO POTATO BEETLE (COLEOPTERA: CHRYSOMELIDAE)

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ABSTRACT

The effect of insecticides currently used in commercial eggplant fields to control the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) on two egg predators, *Coleomegilla maculata* DeGeer and *Chysoperla carnea* (Stephens) was evaluated. Mortality from contact exposure to leaf residues, topical applications, and ingestion of contaminated eggmasses was compared for the following insecticides: esfenvalerate alone and in combination with piperonyl butoxide (PBO); oxamyl; PBO; and rotenone alone and in combination with PBO. Topical exposure and feeding studies were conducted using concentrations 1.00, 0.90, 0.80, 0.70, 0.60, 0.50, 0.40, 0.30, 0.20, and 0.10X the maximum labeled dose; leaf exposure studies were conducted using concentrations 1.00, 0.75, 0.50, and 0.25X the maximum labeled dose. Mortality of *C. maculata* adults and larvae from topical exposure was high after 48 h of exposure for all chemicals and doses. Mortality from topical exposure was low for *C. carnea* larvae in all cases when compared to PBO alone. Mortality from exposure to leaf residues was low in all cases for *C. maculata* adults but varied, depending on dose and chemical, for both *C. maculata* and *C. carnea* larvae. For all treatments, ingestion of treated eggs negatively affected the feeding and survival of *C. maculata* adults and larvae and *C. carnea* larvae. Esfenvalerate combined with PBO had the greatest effect on *C. maculata* adults; rotenone combined with PBO had the greatest effect on *C. maculata larvae*; esfenvalerate combined with PBO affected *C. carnea* larvae the most.

Key Words: *Coleomegilla maculata*, *Chrysoperla carnea*, insecticides, eggplant, IPM, *Leptinotarsa decemlineata*

RESUMEN

Fue evaluado el efecto de los insecticidas comunmente usados en campos comerciales de berenjena para el control del escarabajo de Colorado, *Leptinotarsa decemlineata* (Say), sobre dos depredadores de huevos, *Coleomegilla maculata* DeGeer y *Chysoperla carnea* (Stephens). Fue comparada la mortalidad por exposición a residuos en las hojas, aplicaciones tópicas, e ingestión de masas de huevos contaminadas con los siguientes insecticidas: esfenvalerate solo y en combinación con piperonyl butoxide (PBO); oxamyl; PBO; y rotenone solo y en combinación con PBO. Los ensayos de exposición tópica fueron efectuados utilizando concentraciones de 1.00, 0.90, 0.80X, 0.70, 0.60, 0.50, 0.40, 0.30, 0.20, y 0.10X de la dosis máxima recomendada para los productos. Los estudios de exposición de las hojas fueron conducidos usando concentraciones de 1.00, 0.75, 0.50, y 0.25X de la dosis máxima recomendada. La mortalidad de los adultos y larvas de *C. maculata* mediante exposición tópica fue alta luego de 48 horas de exposición a todos los productos y dosis. La mortalidad de las larvas de *C. carnea* mediante exposición tópica fue baja en todos los casos cuando se comparó con con el PBO solo. La mortalidad mediante exposición a residuos en las hojas fue baja en todos los casos para los adultos de *C. maculata* pero varió con la dosis y el producto en las larvas de *C. maculata* y *C. carnea*. En todos los tratamientos, la ingestión de huevos tratados afectó negativamente la alimentación y sobrevivencia de los adultos y larvas de *C. maculata* y de las larvas de *C. carnea*. El esfenvalerate combinado con PBO tuvo el mayor efecto en los adultos *C. maculata*, el rotenone combinado con PBO tuvo el mayor efecto en las larvas de *C. maculata*, el esfenvalerate combinado con PBO fue el producto que más afectó a las larvas de *C. carnea*.

In New Jersey, the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is a key pest in eggplant and, if left uncontrolled, subsequent defoliation can completely destroy the crop (Cotty & Lashomb 1982). Colorado potato beetle populations have become resistant to most chemical insecticides resulting in difficulty in protecting the crop (Forgash 1985). During the late 1980s, a biological control intensive pest management program (BCIPM), using the egg parasitoid *Edovum puttleri* Grissell (Hymenoptera: Eulophidae), was implemented to reduce grower reliance on insecticides (Lashomb 1989). This program uses field scouting, weekly parasitoid releases, and insecticide applications pre- and post-release if either eggmass or larva/adult economic thresholds are reached.

A side benefit to this successful program has been increased populations of several indigenous natural enemies of Colorado potato beetle including *Coleomegilla maculata* DeGeer and *Chrysoperla carnea* (Stephens) (Lashomb unpublished) not found in non-BCIPM fields. Fields not utilizing biocontrol are repeatedly treated with various insecticides including esfenvalerate, oxamyl and rotenone (Hamilton 1995). The lack of natural enemies suggests that insecticide usage may be adversely affecting non-target species such as *C. maculata* and *C. carnea*. Several studies have documented the effect of various insecticides on *C. maculata* and *C. carnea*; however, these materials are not used in eggplant. This study evaluated the effect of insecticides commonly applied to eggplants for Colorado potato beetle control on *C. maculata* and *C. carnea*.

MATERIALS AND METHODS

C. maculata DeGeer (larvae and adults) and *C. carnea* (Stephens) (larvae) were used in all studies. *C. maculata* adults and larvae were obtained from the USDA Beneficial Insect Laboratory (Mission, TX); *C. carnea* from Rincon-Vitova Insectaries, Inc. (Ventura, CA). Before each study, all individuals were held in a Precision® growth chamber maintained at 26 ± 1°C, 45 ± 5% RH and a photoperiod of 15:9 [L:D].

Three commonly used insecticides, esfenvalerate (Asana XL®, E. I. Dupont, Wilmington, DE), oxamyl (Vydate L®, E.I. Dupont, Wilmington, DE), and rotenone (Rotenox®, Fairfield American, Frenchtown, NJ) and 1 synergist, piperonyl butoxide (PBO) (Butoxide®, Fairfield American, Frenchtown, NJ) were tested. Combinations of esfenvalerate and PBO, and rotenone and PBO were also tested. The topical exposure and egg feeding studies were conducted using concentrations [g (AI) per liter] of approximately 1.0, 0.90, 0.80, 0.70, 0.60, 0.50 0.40, 0.30 and 0.20X of the maximum labeled dose recommended for controlling Colorado potato beetle (esfenvalerate - 0.12, 0.11, 0.096, 0.08, 0.07, 0.06, 0.05, 0.036, and 0.02X respectively; oxamyl - 1.20, 1.08, 0.96, 0.84, 0.72, 0.60, 0.48, 0.36, and 0.24X, respectively; PBO - 2.39, 2.15, 1.91, 1.67, 1.43, 1.20, 0.96, 0.72, and 0.48X, respectively; rotenone - 7.66, 6.89, 6.13, 5.34, 4.60, 3.83, 3.06, 2.30, and 1.53X, respectively) and a water control. Leaf exposure studies were conducted using concentrations [g (AI) per liter] of approximately 1.0, 0.75, 0.50 and 0.25X of the maximum labeled dose recommended for controlling Colorado potato beetle (esfenvalerate - 0.12, 0.09, 0.06, and 0.03X, respectively; oxamyl - 1.20, 0.90, 0.60, and 0.30X, respectively; PBO - 2.39, 1.79, 1.20, and 0.60X, respectively; rotenone - 7.66, 5.75, 3.83, and 1.92X, respectively) and a water control.

Topical Exposure Tests

The effect of topically applied insecticides on *C. maculata* adults and larvae, and on *C. carnea* larvae was evaluated. For each material and dose, 100 *C. maculata* adults were treated with 10 µl of insecticide using a Burkhardt® metered micro-syringe applicator. Treated individuals were then placed into vented 9-cm petri dishes (10 per dish) containing moistened filter paper and held for 48 h. Mortality was recorded at 24 and 48 h post exposure. All individuals were removed after 48 hours, recounted, and the mean percent mortality was determined. This procedure was repeated for both *C. maculata* and *C. carnea* larvae with the exception that treatments were made using 1 µl of insecticide.

Leaf Exposure Tests

The effect of insecticide leaf residues on *C. maculata* adults and larvae, and *C. carnea* larvae was evaluated using treated leaf disks. For each material, dose and species, 10 eggplant leaves were excised and the petioles inserted into an Oasis® rootcube moistened with water and trimmed to 63.5 cm^2 leaf disks using a 9-cm plastic petri dish placed over the midrib. Each leaf disk was dipped into 100 ml of the respective concentration for each material, air dried, and placed into vented 9-cm petri dishes. Ten individuals were introduced into each petri dish and held for 48 hours. Mortality was recorded at 24 and 48 h post exposure. All individuals were removed after 48 hours, recounted, and the mean percent mortality was determined.

Feeding and Survival Tests

The effect of insecticides topically applied to *L. decemlineata* eggmasses on feeding and survival of *C. maculata* adults and larvae, and *C. carnea* larvae was determined. Eggmasses were obtained by rearing Colorado potato beetle larvae to adults and allowing them to lay eggs on caged potato plants maintained in the greenhouse under

25.0 ± 2.0°C temperature and a photoperiod of 12:12 (L:D). Eggmasses were collected from plants and trimmed to 10 eggs per mass. For each species, one hundred trimmed eggmasses per concentration per chemical were treated with 10 µl of material per eggmass using a Burkhardt® metered micro-syringe applicator, allowed to air dry, and transferred to sealed Solo® plastic condiment cups (59.1 ml) (1 eggmass per cup). A single individual was then placed into each cup. Each day following the initiation of the test, all eggmasses were removed from cups, examined for evidence of feeding, and replaced with freshly treated eggs. Daily monitoring continued until either pupation or mortality occurred. The mean number of eggs fed upon and the survival rate of individuals was determined.

Statistical Analysis

Topical and leaf exposure percent mortality data were corrected using Abbott's (1925) and analyzed using probit analysis (Robertson & Preisler 1992, SAS 1987); feeding and survival data were transformed to SQRT(X + 1) (Snedecor and Cochran 1978) and analyzed using linear regression (SAS 1987).

Results and Discussion

Topical Exposure Tests

Topical exposure of *C. maculata* adults and larvae and *C. carnea* larvae to all materials tested resulted in mortality in all cases (Table 1). Mortality levels were consistently higher at 48 h post-exposure than at 24 h post-exposure. *C. maculata* adults were most sensitive to topical applications of esfenvalerate in combination with PBO after both 24 h and 48 h when compared to PBO alone (Table 2). Exposure to rotenone alone resulted in the lowest toxicity ratios observed. Overall, toxicity ratios for esfenvalerate alone and in combination with PBO for *C. maculata* larvae were higher than those observed for adults but lower for all other materials. Similar levels of mortality have been reported when *C. maculata* was topically exposed to cypermethrin, carbaryl, fenvalerate, malathion and permethrin (Coats et al. 1979, Lecrone & Smilowitz 1980, Roger et al. 1994). *C. carnea* larvae were least affected by topical applications when compared to PBO, thus supporting evidence that *C. carnea* is tolerant of certain pyrethroid and carbamate insecticides (Shour & Crowder 1980, Ihaaya & Casida 1981, Grafton-Cardell & Hoy 1985, 1986, Pree et al. 1989). Toxicity ratios at 48 h post-exposure were highest for esfenvalerate in combination with PBO, followed by oxamyl.

Leaf Exposure Tests

Exposure to foliar residues of the insecticides also resulted in high levels of mortality (Table 3). For each insecticide, mortality was highest at 48 h post-exposure. *C. maculata* adults, however, showed no response to low levels (0.25) of esfenvalerate alone, rotenone alone or in combination with PBO, or oxamyl. Exposure to leaves treated with esfenvalerate in combination with PBO resulted in the highest toxicity ratios observed for each species, followed by esfenvalerate alone and oxamyl (Table 2). *C. maculata* adults were least affected by exposure to the insecticides tested when compared to larvae. These findings contradict the work by Plapp & Bull (1978) that showed *C. carnea* to be less susceptible to contact residues of pyrethroid insecticides

TABLE 1. RESPONSE OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* TO TOPICAL EXPOSURE TO SELECTED INSECTICIDES.

	Mortality after 24 h			Mortality after 48 h		
Insecticide	b ± SE[1]	LD_{50}, g/liter (95% FL)	LD_{90}, g/liter (95% FL)	b ± SE[1]	LD_{50}, g/liter (95% FL)	LD_{90}, g/liter (95% FL)
Coleomegilla maculata adults						
Esfenvalerate	0.86 ± 0.32	0.07 (0.04 - 0.29)	2.18 (1.41 - 2.31)	1.03 ± 0.37	0.01 (0.005 - 0.03)	0.19 (0.10 - 0.49)
Esfenvalerate & PBO	2.06 ± 0.55	0.02 (0.001 - 0.03)	0.07 (0.05 - 0.15)	3.86 ± 0.75	0.01 (0.007 - 0.02)	0.03 (0.02 - 0.04)
Rotenone	3.10 ± 0.35	6.07 (5.41 - 7.07)	15.72 (11.98 - 24.84)	2.42 ± 0.28	4.14 (3.62 - 4.73)	14.02 (10.57 - 22.56)
Rotenone & PBO	1.96 ± 0.41	0.97 (0.28 - 1.53)	4.34 (3.38 - 6.54)	1.22 ± 0.30	0.009 (0.0003 - 0.06)	2.12 (1.20 - 2.79)
Oxamyl	2.54 ± 0.22	0.36 (0.31 - 0.40)	1.15 (1.01 - 1.35)	3.02 ± 0.30	0.20 (0.16 - 0.23)	0.53 (0.48 - 0.59
PBO	6.15 ± 1.16	3.38 (2.92 - 4.59)	5.43 (4.16 - 9.78)	1.73 ± 0.40	6.26 (3.64 - 7.15)	34.43 (11.15 - 57.71)
Coleomegilla maculata larvae						
Esfenvalerate	0.99 ± 0.23	0.003 (0.002 - 0.007)	0.06 (0.04 - 0.08)	—[2]	—	—
Esfenvalerate & PBO	1.91 ± 0.66	0.003 (0.0007 - 0.01)	0.02 (0.004 - 0.03)	—[2]	—	—
Rotenone	1.01 ± 0.21	12.20 (8.64 - 25.76)	229.35 (72.43 - 386.27)	1.22 ± 0.20	2.41 (1.79 - 2.91)	26.94 (16.75 - 65.71)
Rotenone & PBO	33.36 ± 0.13	1.40 (1.90 - 0.90)	1.53 (1.28 - 1.78)	31.32 ± 0.17	1.36 (0.95 - 1.77)	1.48 (1.15 - 1.63)
Oxamyl	4.22 ± 0.92	0.13 (0.07 - 0.17)	0.26 (0.21 - 0.30)	33.85 ± 0.13	0.22 (0.19 - 0.25)	0.24 (0.18 - 0.26)
PBO	2.09 ± 0.24	0.36 (0.25 - 0.45)	1.473 (1.30 - 1.73)	2.52 ± 0.61	0.20 (0.03 - 0.35)	0.54 (0.38 - 0.84)
Chrysoperla carnea larvae						
Esfenvalerate	2.01 ± 0.24	0.15 (0.13 - 0.19)	0.65 (0.42 - 1.29)	0.90 ± 0.19	0.14 (0.10 - 0.25)	3.71 (1.13 - 6.23)
Esfenvalerate & PBO	2.48 ± 0.26	0.11 (0.10 - 0.14)	0.38 (0.29 - 0.59)	1.45 ± 0.26	0.11 (0.09 - 0.18)	0.87 (0.40 - 1.34)

[1]n = 100.
[2]Analysis not conducted due to 100% mortality at all doses.

TABLE 1. (CONTINUED) RESPONSE OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* TO TOPICAL EXPOSURE TO SELECTED INSECTICIDES.

	Mortality after 24 h			Mortality after 48 h		
Insecticide	b ± SE[1]	LD_{50}, g/liter (95% FL)	LD_{90}, g/liter (95% FL)	b ± SE[1]	LD_{50}, g/liter (95% FL)	LD_{90}, g/liter (95% FL)
Rotenone	6.25 ± 0.59	7.46 (7.07 - 7.99)	11.96 (10.65 - 14.12)	4.06 ± 0.88	7.88 (6.50 - 12.49)	16.30 (10.94 - 27.24)
Rotenone & PBO	3.12 ± 0.45	13.03 (10.61 - 18.60)	33.55 (22.34 - 69.17)	1.70 ± 0.24	12.49 (9.77 - 18.90)	70.88 (41.15 - 103.13)
Oxamyl	0.92 ± 0.20	0.15 (0.05 - 0.24)	3.72 (2.10 - 4.33)	0.98 ± 0.21	0.10 (0.03 - 0.18)	2.06 (1.37 - 5.28)
PBO	1.86 ± 0.22	2.16 (1.90 - 2.59)	10.53 (7.11 - 19.62)	1.27 ± 0.20	2.03 (1.71 - 2.65)	20.90 (10.68 - 31.11)

[1]n = 100.
[2]Analysis not conducted due to 100% mortality at all doses.

TABLE 2. TOXICITY RATIOS BASED ON TOPICAL AND FOLIAR RESIDUE EXPOSURE TO SELECTED INSECTICIDES FOR *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA*.

	Toxicity Ratio[1] (Topical)				Toxicity Ratio[1] (Leaf Residues)			
	24 h Post-Exposure		48 h Post-Exposure		24 h Post-Exposure		48 h Post-Exposure	
Insecticide	LD_{50}	LD_{90}	LD_{50}	LD_{90}	LD_{50}	LD_{90}	LD_{50}	LD_{90}
Coleomegilla maculata adults								
Esfenvalerate	48.29	2.49	626.00	181.21	16.95	31.27	14.61	38.55
Esfenvalerate & PBO	169.00	77.57	626.00	1,147.67	21.87	2.77	37.57	17.26
Rotenone	0.56	0.35	1.51	2.46	0.39	1.14	0.27	0.74
Rotenone & PBO	3.48	1.25	695.56	16.24	0.66	1.78	0.36	1.05
Oxamyl	9.39	4.72	31.30	64.96	3.66	10.49	2.12	1.00
PBO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Coleomegilla maculata larvae								
Esfenvalerate	120.00	24.50	—	—	26.50	38.33	28.00	21.00
Esfenvalerate & PBO	120.00	73.50	—	—	53.00	11.50	—	—
Rotenone	0.03	0.01	0.08	0.02	0.03	0.01	0.14	0.04
Rotenone & PBO	0.26	0.96	0.15	0.43	0.14	0.08	0.23	0.08
Oxamyl	2.77	5.65	0.91	2.67	1.71	0.70	5.60	0.85
PBO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chrysoperla carnea larvae								
Esfenvalerate	14.40	16.20	14.50	5.63	50.08	1.40	176.67	20.75

1Toxicity relative to PBO = $LD_{PBO}/LD_{insecticide}$ = Toxicity Ratio.

TABLE 2. (CONTINUED) TOXICITY RATIOS BASED ON TOPICAL AND FOLIAR RESIDUE EXPOSURE TO SELECTED INSECTICIDES FOR *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA*.

	Toxicity Ratio[1] (Topical)				Toxicity Ratio[1] (Leaf Residues)			
	24 h Post-Exposure		48 h Post-Exposure		24 h Post-Exposure		48 h Post-Exposure	
Insecticide	LD_{50}	LD_{90}	LD_{50}	LD_{90}	LD_{50}	LD_{90}	LD_{50}	LD_{90}
Esfenvalerate & PBO	19.64	27.71	18.45	24.02	651.00	1,530.00	1,855.00	671.88
Rotenone	0.29	0.88	0.26	1.28	1.54	0.91	11.28	3.23
Rotenone & PBO	0.17	0.31	0.16	0.29	2.26	7.20	8.10	2.85
Oxamyl	14.40	2.83	20.30	10.15	15.88	28.75	148.40	7.25
PBO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

1Toxicity relative to PBO = $LD_{PBO}/LD_{insecticide}$ = Toxicity Ratio.

TABLE 3. RESPONSE OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* EXPOSED TO FOLIAR RESIDUES OF SELECTED INSECTICIDES.

	Mortality after 24 h			Mortality after 48 h		
Insecticide	b ± SE[1]	LC_{50}, g/liter (95% FL)	LC_{90}, g/liter (95% FL)	b ± SE[1]	LC_{50}, g/liter (95% FL)	LC_{90}, g/liter (95% FL)
Coleomegilla maculata adults						
Esfenvalerate	0.88 ± 0.26	0.40 (0.22 - 0.62)	1.71 (0.57 - 2.28)	1.30 ± 0.24	0.18 (0.14 - 0.27)	0.47 (0.30 - 0.57)
Esfenvalerate & PBO	0.31 ± 0.13	0.31 (0.15 - 0.47)	19.32 (1.52 - 37.12)	0.47 ± 0.12	0.07 (0.05 - 0.10)	1.05 (0.81 - 1.28)
Rotenone	1.30 ± 0.36	17.56 (11.76 - 23.36)	47.10 (22.46 - 69.56)	1.38 ± 0.39	9.64 (8.88 - 10.40)	24.41 (23.65 - 25.17)
Rotenone & PBO	1.20 ± 0.37	10.33 (9.60 - 11.06)	30.06 (29.33 - 30.79)	1.49 ± 0.39	7.28 (6.52 - 8.04)	17.24 (16.48 - 18.00)
Oxamyl	1.26 ± 0.37	1.85 (1.50 - 2.58)	5.10 (4.37 - 5.83)	1.45 ± 0.34	1.24 (0.57 - 1.91)	3.01 (2.34 - 3.68)
PBO	0.62 ± 0.16	6.78 (3.93 - 9.63)	53.48 (15.74 - 91.58)	0.66 ± 0.13	2.63 (2.05 - 4.23)	18.12 (8.61 - 27.72)
Coleomegilla maculata larvae						
Esfenvalerate	9.30 ± 0.02	0.02 (-0.02 - 0.06)	0.03 (-0.01 - 0.07)	9.03 ± 0.20	0.02 (-0.26 - 0.32)	0.03 (-0.36 - 0.42)
Esfenvalerate & PBO	0.59 ± 0.19	0.01 (-0.37 - 0.37)	0.10 (-0.28 - 0.48)	—[2]	—	—
Rotenone	0.48 ± 0.14	15.28 (9.37 - 21.29)	218.90 (53.99 - 383.81)	0.85 ± 0.28	3.93 (3.38 - 4.48)	17.67 (17.01 - 18.25)
Rotenone & PBO	0.95 ± 0.13	3.75 (3.21 - 4.29)	14.41 (10.84 - 23.11)	1.05 ± 0.13	2.39 (1.92 - 2.79)	8.12 (6.71 - 10.88)
Oxamyl	0.77 ± 0.28	0.31 (-0.24 - 0.55)	1.65 (1.10 - 2.20)	0.64 ± 0.16	0.10 (0.02 - 0.18)	0.74 (0.57 - 1.11)
PBO	1.66 ± 0.42	0.53 (-0.29 - 1.35)	1.15 (0.33 - 1.97)	9.03 ± 0.20	0.56 (0.17 - 1.29)	0.63 (0.24 - 1.02)
Chrysoperla carnea larvae						
Esfenvalerate	0.21 ± 0.13	0.39 (0.30 - 0.48)	153.37 (129.24 - 177.5)	0.90 ± 0.12	0.21 (0.18 - 0.24)	2.59 (2.25 - 2.84)
Esfenvalerate & PBO	0.96 ± 0.13	0.03 (0.02 - 0.04)	0.14 (0.11 - 0.19)	1.04 ± 0.35	0.02 (0.01 - 0.03)	0.08 (0.05 - 0.11)

[1]n = 100.
[2]Analysis not conducted due to 100% mortality at all doses.

TABLE 3. (CONTINUED) RESPONSE OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* EXPOSED TO FOLIAR RESIDUES OF SELECTED INSECTICIDES.

Insecticide	Mortality after 24 h			Mortality after 48 h		
	b ± SE[1]	LC_{50}, g/liter (95% FL)	LC_{90}, g/liter (95% FL)	b ± SE[1]	LC_{50}, g/liter (95% FL)	LC_{90}, g/liter (95% FL)
Rotenone	0.44 ± 0.13	12.68 (8.05 - 17.31)	236.23 (53.92 - 418.54)	0.79 ± 0.13	3.29 (2.66 - 3.87)	16.64 (11.62 - 32.21)
Rotenone & PBO	1.04 ± 0.31	8.65 (7.61 - 9.64)	29.74 (25.44 - 34.04)	0.91 ± 0.13	4.58 (3.97 - 5.33)	18.84 (13.33 - 34.32)
Oxamyl	0.71 ± 0.13	1.23 (0.99 - 1.81)	7.45 (3.88 - 9.98)	0.38 ± 0.12	0.25 (0.04 - 0.39)	7.41 (2.76 - 12.06)
PBO	0.53 ± 0.20	19.53 (6.51 - 32.55)	214.20 (26.46 - 401.94)	0.26 ± 0.14	37.10 (34.15 - 40.50)	53.75 (48.86 - 58.64)

[1]n = 100.
[2]Analysis not conducted due to 100% mortality at all doses.

TABLE 4. SURVIVAL OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* FED ON EGGS TREATED WITH SELECTED INSECTICIDES.

		Number of Eggs Eaten per Day			Number of Days Survived		
Insecticide	n	a ± 95% CL	b ± 95% CL	r^2	a ± 95% CL	b ± 95% CL	r^2
Coleomegilla maculata adults							
Esfenvalerate	100	1.30 ± 0.21	-1.40 ± 0.35	0.67*	4.83 ± 0.40	-4.28 ± 0.65	0.84*
Esfenvalerate & PBO	100	1.98 ± 0.50	-2.62 ± 0.80	0.57*	3.14 + 0.40	-3.57 ± 0.64	0.79*
Rotenone	100	2.59 ± 0.18	-2.17 ± 0.29	0.88*	3.18 ± 0.36	-2.98 ± 0.58	0.77*
Rotenone & PBO	100	2.63 ± 0.33	-2.61 ± 0.54	0.75*	3.97 ± 0.41	-3.26 ± 0.66	0.75*
Oxamyl	100	2.11 ± 0.30	-2.19 ± 0.49	0.71*	5.05 ± 0.45	-4.90 ± 0.73	0.85*
PBO	100	2.25 ± 0.39	-2.84 ± 0.63	0.72*	4.16 ± 0.48	-4.79 ± 0.77	0.83*
Coleomegilla maculata larvae							
Esfenvalerate	100	1.82 ± 0.25	-1.40 ± 0.41	0.60*	2.94 ± 0.12	-0.53 ± 0.20	0.47*
Esfenvalerate & PBO	100	1.06 ± 0.36	-0.98 ± 0.59	0.26	3.29 ± 0.22	-1.74 ± 0.36	0.74*
Rotenone	100	4.15 ± 0.46	-1.53 ± 0.75	0.34	5.85 ± 0.17	-1.62 ± 0.27	0.81*
Rotenone & PBO	100	2.76 ± 0.26	-2.15 ± 0.42	0.77*	4.42 ± 0.08	-0.40 ± 0.13	0.55*
Oxamyl	100	3.36 ± 0.15	-1.94 ± 0.24	0.89*	4.33 ± 0.12	-1.36 ± 0.19	0.87*
PBO	100	2.69 ± 0.18	-1.31 ± 0.29	0.71*	5.37 ± 0.10	-1.16 ± 0.16	0.87*
Chrysoperla carnea larvae							
Esfenvalerate	100	4.50 ± 0.12	-1.32 ± 0.19	0.86*	6.29 ± 0.06	-0.25 ± 0.09	0.48*
Esfenvalerate & PBO	100	2.63 ± 0.13	-1.69 ± 0.21	0.89*	5.76 ± 0.14	-1.15 ± 0.23	0.75*
Rotenone	100	3.64 ± 0.05	-0.70 ± 0.05	0.90*	6.58 ± 0.07	-0.72 ± 0.11	0.85*

*Significant at $P \leq 0.05$.

TABLE 4. (CONTINUED) SURVIVAL OF *COLEOMEGILLA MACULATA* AND *CHRYSOPERLA CARNEA* FED ON EGGS TREATED WITH SELECTED INSECTICIDES.

	Number of Eggs Eaten per Day				Number of Days Survived		
Insecticide	n	a ± 95% CL	b ± 95% CL	r^2	a ± 95% CL	b ± 95% CL	r^2
Rotenone & PBO	100	3.67 ± 0.09	-1.63 ± 0.14	0.94*	6.78 ± 0.08	-0.66 ± 0.14	0.74*
Oxamyl	100	1.81 ± 0.09	-0.64 ± 0.14	0.72*	6.46 ± 0.08	-0.82 ± 0.13	0.84*
PBO	100	4.81 ± 0.17	-1.43 ± 0.28	0.77*	6.98 ± 0.06	-0.50 ± 0.10	0.75*

*Significant at $P \leq 0.05$.

when compared to various carbamate and organophosphate materials. The data also suggest that field applications of rotenone could have a detrimental effect on the larval populations of both predators.

Feeding and Survival Tests

All insecticide treatments negatively affected the feeding and survival of *C. maculata* and *C. carnea* (Table 4). Significant linear relationships ($P \leq 0.05$) between dose and feeding were found for all insecticides and species tested with the exception of *C. maculata* larvae exposed to eggs treated with rotenone ($r^2 = 0.34$) and esfenvalerate combined with PBO ($r^2 = 0.26$). Esfenvalerate combined with PBO and PBO alone had the greatest effect on feeding by *C. maculata* adults (b = -2.62 and -2.84, respectively), whereas rotenone combined with PBO had the greatest effect on *C. maculata* larvae (b = -2.15), followed by oxamyl alone (b = -1.93). Feeding by *C. carnea* larvae was most affected by esfenvalerate in combination with PBO and rotenone in combination with PBO (b = -1.69 and -1.63, respectively). Overall, survival of larvae for both species was most affected by esfenvalerate combined with PBO. *C. maculata* adult survival was most affected by oxamyl (b = -4.90). PBO alone, however, had little impact on the survival of *C. maculata* and *C. carnea* larvae but greatly reduced the survival of *C. maculata* adults (b = -4.79). Egg mortality, as the result of insecticide treatments, may in part explain the decreased feeding levels and subsequent reduced survival observed. Insecticide repellency might also account for the drop in egg consumption. Finally, mortality of individuals from ingestion of surface residues could be responsible for reduced feeding. Adverse effects from the ingestion of treated food items have been reported for other insecticides. Singh & Varma (1986) found reductions in *C. carnea* survival from ingestion of *Corcyra cephalonica* Stainton eggs treated with several insecticides including, endosulfan, carbaryl, and cypermethrin. Giroux et al. (1994) demonstrated that ingestion of Colorado potato beetle eggs by *C. maculata* was reduced when eggs were treated with *Bacillus thuringiensis* var. *san diego*. Reduced survival due to ingestion of treated food material has also been reported for other coccinellids such as *Hippodamia convergens* Guérin-Méneville (Hurej & Dutcher 1994).

Our results show that *C. maculata* adults and larvae, and *C. carnea* larvae are susceptible to chemical insecticides commonly used to control Colorado potato beetle. This finding is important in terms of the design of a pest management program. It suggests that changing the types of insecticides applied may allow predator survival in fields thereby helping to reduce pest populations.

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