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INFLUENCE OF ACEPHATE AND CARBARYL INGESTED FROM PREY ON DEVELOPMENT, MORTALITY, AND SURVIVAL OF THE SPINED SOLDIER BUG, *PODISUS MACULIVENTRIS* (SAY) (HEMIPTERA: PENTATOMIDAE)

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ABSTRACT—The toxicities of acephate and carbaryl were evaluated for the spined soldier bug, *Podisus maculiventris* (Say), to determine the potential use of this predator in an integrated pest management program for snapbeans. Acephate (Orthene 75 S) at 3.0 g (ai)/1 and 0.59 g (ai)/1 and carbaryl (Sevin 50 WP) at 7.5 g (ai)/1 and 1.5 g (ai)/1 were ingested by larvae of the Mexican bean beetle, *Epilachna varivestis* Mulsant, that fed on treated snapbean foliage. Second, third, fourth, and fifth instars of the spined soldier bug were reared on pesticide-fed Mexican bean beetle larvae to determine developmental times, mortality, survival, and any aberrant adult morphology. Both concentrations of acephate, ingested by prey and subsequently fed to spined soldier bug nymphs, induced greater mortality ($P = 0.05$) than in nymphs exposed to carbaryl through their prey. There was no significant difference between predator mortality in carbaryl and control treatments. Developmental times for nymphs ingesting both pesticides at each formulation were significantly longer ($P = 0.05$) than nymphs in the control treatment. Adults in control treatments were slightly larger than adults from pesticide treatments.

While pesticides remain the cheapest, fastest, and most reliable means of suppressing arthropod pests, more emphasis should be placed on ecologically based tactics that promise great potential for suppression of pest species populations, while leaving natural enemy populations intact (Watson, 1975). Tabashnik (1986) inferred that where chemicals are used in agricultural systems, natural enemies have the ability to develop pesticide resistance if provided an adequate supply of prey that have ingested pesticides. When pest populations are severely reduced by spraying, natural enemies starve, emigrate, or are eliminated through mortality directly attributable to pesticide action. It is therefore necessary to consider the effects on beneficial arthropods that feed on prey exposed to pesticides.

Arthropod predators and parasites are considered vital in suppressing arthropod pests in agricultural ecosystems. The spined soldier bug, *Podisus maculiventris* (Say), is a polyphagous predator commonly occurring in North America east of the Rocky Mountains, and is considered an important predator of economic insect pests due to its diversity in prey preference (McPherson, 1980). This predator has been studied as a biological control agent in a variety of agroecosystems including orchards, forests, and field crops (Morris, 1963; LeRoux, 1964; Mukerji and LeRoux, 1965; Waddill and Shepard, 1975; Ignoffo et al., 1977; Marston et al., 1978; Ables and McCommas, 1982; Lambdin and Baker, 1986; O'Neil and Wiedenmann, 1987; O'Neil, 1997).

Integration of chemical and biological control programs is severely hampered by resistance in pests and lack of resistance in beneficial arthropods (Tabashnik, 1986; Hoy, 1986). Successful incorporation of *P. maculiventris* in an integrated pest management (IPM) program to control the Mexican bean beetle, *Epilachna varivestis* Mulsant, on snapbeans requires knowledge of predator susceptibility to recommended insecticides.

Two pesticides, acephate (Orthene 75S) and carbaryl (Sevin 50WP), are among those recommended for use in Tennessee for control of insect pests on snapbeans (Yanes et al., 1986). Only a few studies are available on the effects of acephate on beneficial arthropods. However, carbaryl has been used in a variety of control programs since the late 1950s, and has been tested against *P. maculiventris* for selectivity to pesticides (Wilkinson et al., 1979).

Turnipseed et al. (1974) achieved 83% control of adults and 95% control of *E. varivestis* larvae using reduced rates of carbaryl with acceptable levels of mortality of beneficial arthropods. In tests using sulprofos, profenfos, permethrin, and fenvalerate, Wilkinson et al. (1979) determined that the two organophosphates (sulprofos and profenfos) were extremely toxic to *P. maculiventris* and the convergent lady beetle, *Hippodamia convergens* Guérin. However, Elsey and Cheatham (1976) reported that both carbaryl and acephate were relatively non-toxic to the predatory stilk bug, *Jalysus spinosus* (Say). Reduced pesticide application rates that produce less than 100% mortality of the pest species may enhance the retention of beneficials in an agroecosystem, and provide a reservoir for migration into other feeding areas. Reduced pesticide application rates also may decrease the development of resistance in pest populations. In laboratory and microplot tests, Hough-Goldstein and McPherson (1997) found both *P. maculiventris* and the two-spotted stink bug, *Perillus bioculatus* (F.), were equally effective in feeding on eggs and larvae of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say). Also, O'Neil (1997) reported the searching strategy and level of attack for *P. maculiventris* remains consistent regardless of predator, prey, or crop.

Differences in physiological selectivity are particularly evident when comparing the effects of pesticides on herbivorous and carnivorous arthropods. Gordon (1961) suggested phytophagous species are preadapted to detoxify pesticides through feeding antecedents that produce elevated levels of detoxification enzymes from exposure to dietary allelochemicals in host plants. This hypothesis is supported through discovery and isolation of enzymes in herbivores that act on specific plant allelochemicals (Mullin and Croft, 1983). The absence of these enzymes in predaceous insects significantly decreases the predator's ability to detoxify pesticides (Hull and Beers, 1985).

The objective of this study was to evaluate the impact of ingesting *E. varivestis* that had fed on snapbean foliage treated with carbaryl and acephate by the nymphs and adults of *P. maculiventris.*

MATERIALS AND METHODS

Mexican bean beetles were obtained from a greenhouse colony maintained on snapbeans 'Bush blue lake' at 28 ± 5°C, 60–90% relative humidity, and a 16:8 (L:D) photoperiod. Foliage of snapbean plants at the pre-bloom stage was treated with either acephate, carbaryl, or distilled H_20, and allowed to dry for 24 h before Mexican bean beetle larvae were placed on the leaves to feed. Acephate (Orthene 75S) and carbaryl (Sevin 50 WP) were applied at the manufacturer's recommended rates as well as at a rate determined to be 1/5 the recommended rate (acephate 2.996 g (ai)/l max. rec. rate and 0.593 g (ai)/l min. rec. rate, carbaryl at 7.49 g (ai)/l max. rec. rate and 1.498 g (ai)/l min. rec. rate). After each 7-day period, fresh plants were treated and previously treated plants were discarded. Third and fourth instar nymphs were removed from the population and starved for 12 h before being placed on chemically-treated snapbean plants. Larvae were allowed to feed until they suspended themselves from the leaf surface by the base of the abdomen. This time was determined to be sufficient to ingest the pesticide without inducing immediate mortality.

Podisus maculiventris nymphs were maintained under laboratory conditions of 27 ± 2°C, 40–70% relative humidity, and a 16:8 (L:D) photoperiod. Second, third, fourth, and fifth instars of *P. maculiventris* were evaluated in four separate tests, each using a completely randomized design consisting of five treatments, each with 20 *P. maculiventris* nymphs. Data were recorded to determine the effects of carbaryl and acephate on mortality, developmental time per stadium, survival time of treatment groups, and morphology of adults. If a specimen died between molts, it was excluded from consideration in the stadium during which it died. Each predator was maintained in a 5.5 cm plastic petri dish lined with a 5.5 cm filter paper and containing a cotton-plugged shell vial (12 × 35 mm) filled with distilled H_2O. Prey were provided *P. maculiventris* at 24 h intervals, and filter paper and H_2O vials were changed daily to reduce the possibility of predator mortality from tarsal contact with pesticides brought in by the prey.

Data on mortality and duration of each stadium between molts were taken at 12 h intervals until emergence of the adult. After emergence (24–48 h), lengths (from apex of wings to apex of head) and widths (across the humeral spines of the pronotum) of adults were measured using an ocular micrometer. Because of unequal sample size, all data were submitted to the General Linear Models procedure (SAS Institute, 1985). The Waller-Duncan K-ratio *t*-test was used for mean separation tests to assess the total developmental time.

RESULTS

The spined soldier bug has five developmental stages consisting of four nymphal stages and the adult stage. This is a bisexual species with several generations per year. For data in all tables for third, fourth, and fifth instars, numbers in columns for developmental stage reflect mean preadult development time for individuals surviving through that instar. Numbers in the total column for all tables are mean hours survival time for each group, incorporating all hours survived by a single individual until it died or molted to an adult. In the carbaryl treatments and control group, total means reflect developmental time of that group before emergence of the adult and the expected survivability of the treatment group as a whole.

Second instar nymphs exhibited a higher degree of overall mortality than did third, fourth, and fifth instars (Table 1). A significant difference (P = 0.05) was found between all treatments for development in nymphs through the second and third instars. No significant differences were indicated for development of nymphs surviving through the fourth and fifth instar stages in the two carbaryl treatments and the control group. The greatest difference in mortality and development was found among treatments of acephate compared with carbaryl treatments and the control group as reflected in mortality of individuals and total mean survival time. Within the two treatments of acephate, a higher mortality was observed for the corresponding higher dosage. There was little difference in overall mortality among treatments of carbaryl and the control group. Also, nymphs in carbaryl treatments molted sooner than those of the control group. In later preadult stages in all tests, the control group exhibited a significantly faster rate of development.

Third instar nymphs provided chemically treated *E. varivestis* larvae successfully survived initial handling as well as consumption of prey that had ingested the pesticide treated leaves (Table 1). Significant differences (P = 0.05) were found among treatments for development and mortality of nymphs in the third and fourth instars. Nymphal mortality in acephate treatments was reduced, and more nymphs survived into successive developmental stages, but less than for nymphs in the carbaryl treatments or control. Eleven nymphs ingesting prey from the high acephate treatment survived to become fourth instars, but died during that stadium. Nymphs ingesting the low acephate-treated prey and surviving through the fourth instar treatment died before molting into fifth instars. There were no significant differences in mortality, developmental time, and total survival time among nymphs in the carbaryl and control treatments. While some mortality occurred in both carbaryl groups, it was reflected only in survival time of the group.

Those specimens in the reduced formulation treatment of acephate survived ingestion of treated prey and developed slightly more rapidly as third instar nymphs than nymphs provided *E. varivestis* larvae that ingested the higher concentration of acephate. Also, survival time of nymphs ingesting larvae fed a more concentrated formulation of acephate was significantly reduced. Nymphs that fed on *E. varivestis* larvae that had consumed the concentrated carbaryl formulation developed faster than those in the lower carbaryl formulation and the control group, except for the fourth instar stage. Mean total survival times were not significantly different among the carbaryl and control treatment groups.

Fourth instar nymphs exhibited less mortality among all

TABLE 1. Mean developmental time (h), mortality, and survival time of *Podisus maculiventris* nymphs ingesting acephate and carbaryl treated *Epilachna varivestis* larvae.

Treatment (g ai/l)	2nd Instar	3rd Instar	4th Instar	5th Instar	Survival time (h)
SECOND INSTAR					
Acephate (0.59)	96.1 (17)[1]	115.6 (1)	192.0 (1)	—	228.8 (20)c[2]
Acephate (3.0)	97.4 (7)	120.0 (1)	—	—	108.3 (20)d
Carbaryl (1.5)	99.2 (19)	112.8 (18)	131.8 (17)	184.7 (17)	475.3 (20)a
Carbaryl (7.5)	85.8 (16)	106.5 (16)	125.8 (14)	192.9 (14)	380.9 (20)b
Control	121.8 (16)	91.5 (15)	132.2 (15)	189.1 (15)	448.3 (20)ab
THIRD INSTAR					
Acephate (0.59)		102.2 (20)[1]	119.7 (10)	—	246.8 (20)b[2]
Acephate (3.0)		127.3 (11)	—	—	131.7 (20)c
Carbaryl (1.5)		106.4 (19)	139.8 (19)	182.7 (19)	411.1 (20)a
Carbaryl (7.5)		107.4 (18)	115.3 (18)	186.0 (18)	381.7 (20)a
Control		104.1 (20)	147.5 (20)	168.6 (20)	420.2 (20)a
FOURTH INSTAR					
Acephate (0.59)			114.7 (13)[1]	168.7 (3)	153.2 (20)c[2]
Acephate (3.0)			105.9 (15)	173.0 (1)	174.1 (20)c
Carbaryl (1.5)			124.5 (20)	181.1 (20)	305.5 (20)a
Carbaryl (7.5)			117.8 (20)	168.1 (20)	280.9 (20)a
Control			96.1 (20)	136.1 (19)	226.4 (20)b
FIFTH INSTAR					
Acephate (0.59)				172.1 (17)[1]	170.2 (20)a[2]
Acephate (3.0)				188.5 (4)	128.9 (20)b
Carbaryl (1.5)				173.2 (20)	173.2 (20)a
Carbaryl (7.5)				176.5 (20)	176.5 (20)a
Control				134.7 (20)	134.7 (20)b

[1] Number of surviving nymphs in each stage.

[2] Means within columns for each instar with same letter do not differ significantly ($P = 0.05$, Waller-Duncan).

treatment groups than did the previous instars (Table 1). Increased survival rate of nymphs in the two treatments of acephate was indicated by the number of individuals surviving each development stage and reduced disparity among total survival times among all treatment groups. A significantly ($P = 0.05$) higher total survival time was indicated between the fourth and fifth instars of the carbaryl treatment groups. The nymphs in the control group developed significantly faster than those in the carbaryl treatments.

Fifth instar adults administered acephate treated *E. varivestis* exhibited significantly higher mortality ($P = 0.05$) than specimens in the other treatments (Table 1). The higher rate of acephate caused the highest mortality rate compared to all other treatments. Significant differences in the time of development for fifth instars and total survival of treatment groups were indicated.

Morphological Effects—In addition to extended development times in treatment groups where nymphs were subjected to dietary stresses through feeding on pesticide-treated *E. varivestis,* it was anticipated that there would be morphological differences between control and treatment groups (Table 2). Substantial mortality was observed in some specimens in pesticide treatment groups due to unsuccessful molting. Physiological impairments were manifested in distended abdomens observed among nymphs treated with acephate. In general, nymphal development of the predator on pesticide-fed prey appeared to result in individuals being slightly smaller (Table 2) and less aggressive than those in the control group.

The adults in carbaryl treatments and control groups were slightly larger than adults in the acephate treatments (Table 2). No discoloration among the specimens was observed. Also, the lowest number of specimens surviving to adults occurred in the highest acephate treatment. Although the adults may live up to two months, life spans of males and females were found to differ (Baker and Lambdin, 1985).

DISCUSSION

Mukerji and LeRoux (1969) reported differences in developmental times of *P. maculiventris* nymphs reared on different dietary proportions of the same prey. Those individuals subjected to dietary stresses in the form of insufficient prey needed a greater amount of time to complete each stadial instar and molted into smaller adults than those which developed on a diet determined to be adequate. A similar phenomenon was noted for *P. maculiventris* nymphs reared on different prey by Drummond et al. (1984). Nymphal developmental rate was fastest on the greater wax moth, *Galleria mellonella* (Say), followed by *E. varivestis* and *Leptinotarsa decemlineata* (Say), respectively. They also observed that a diet of *L. decemlineata* caused a significant degree of mortality among nymphs, whereas the *E. varivestis* diet pro-

TABLE 2. The size of insecticide-treated *Podisus maculiventris* surviving to adult.[1]

Treatment (g ai/l)	2nd Instar		3rd Instar		4th Instar		5th Instar	
	L	W	L	W	L	W	L	W
Acephate (0.59)	—	—	—	—	10.2	6.2 (3)[2]	10.8	6.5 (17)
Acephate (3.0)	—	—	—	—	10.6	6.1 (1)	10.3	5.9 (4)
Carbaryl (1.5)	11.2	6.7 (17)	10.9	6.5 (19)	11.1	6.7 (20)	11.1	6.6 (20)
Carbaryl (7.5)	10.6	6.5 (14)	10.6	6.4 (18)	10.7	6.5 (20)	11.0	6.6 (20)
Control	11.4	6.7 (15)	11.4	6.7 (20)	11.3	6.9 (19)	10.9	6.6 (19)

[1] Length (L) and width (W) measurements (mm) from anterior tip of rostrum to tip of membranous wings.
[2] Numbers in parentheses indicate the number of individuals measured.

duced a high survival rate. The authors hypothesized that the low quality of *L. decemlineata* as prey could be attributable to toxins ingested from its host plants in the family Solanaceae. The effects of acephate on *P. maculiventris* would apparently preclude its consideration for use in IPM strategies designed to control pests of snapbean through chemical applications and inundative releases of this predator. Even at a greatly reduced concentration, acephate caused significant mortality as well as slower development of *P. maculiventris* nymphs. Detrimental effects did not significantly differ among second, third, fourth, or fifth instars, although mortality rates were decreased slightly in the later instars. Further, adult size was smaller in the acephate treatment groups than in the other groups. Thus, our hypothesis that ingestion of pesticide-treated prey would have a detrimental impact on development, survival, and morphology of the predator was verified.

Since one of the tools of IPM is the use of chemicals that do not effectively impair biological control agents, carbaryl may be a candidate for use on snapbean. Carbaryl has been shown to be as effective or better than acephate in suppressing populations of *E. varivestis* at recommended rates (Dobrin and Hammond, 1983) and at reduced rates (Turnipseed et al., 1974). Its effect on the predator through ingestion was minimal in this study. The relative non-toxicity of carbaryl was not expected, but could be attributed, at least in part, to the reversible nature of its bonding with acetylcholinesterase in the insect's nervous system.

In general, developmental time was longer for third, fourth, and fifth instars in the carbaryl treatments than for nymphs and adults in the control group. It was not determined what effect ingestion of the pesticides had on the predator's behavior, particularly as it relates to its ability to search for prey. However, increased developmental time for *P. maculiventris* nymphs is not necessarily a negative effect. Since nymphs are wingless, they are more likely to remain in the release areas whereas adults are able to move to other areas. An increased developmental time associated with ingestion of pesticide through prey, as long as there were no other detrimental effects due to diminished predaceous behavior, would extend the control period by the predator.

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