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Mortality, development and morphological effects of carbaryl and acephate on Podisus maculiventris (SAY)

Jane Byrne Horton

To the Graduate Council:

I am submitting herewith a thesis written by Jane Byrne Horton entitled "Mortality, development and morphological effects of carbaryl and acephate on Podisus maculiventris (SAY)." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.

Paris L. Lambdin, Major Professor

We have read this thesis and recommend its acceptance:

Vernon Reich, Jaime Yanes

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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C W Minkel

Vice Provost
and Dean of The Graduate School

MORTALITY, DEVELOPMENT AND MORPHOLOGICAL EFFECTS OF CARBARYL AND ACEPHATE ON *Podisus maculiventris* (SAY)

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Jane Byrne Horton

June 1987

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Finally, a special thanks to my parents, who are now breathing a great sigh of relief, without whose good humour, encouragement and wonderful friendship none of this would have been possible - and to Jim and Peg Girard who provided me with a home away from home.

ABSTRACT

Successful incorporation of *Podisus maculiventris* (Say) in an integrated pest management program requires testing of recommended insecticides for selectivity to the predator. Acephate (Orthene 75 S) at 0.59 g (AI)/l and 3.0 g (AI)/l and carbaryl (Sevin 50 WP) at 1.5 g (AI)/l and 7.5 g (AI)/l were injested by *Epilachna varivestis* Mulsant larvae from treated snapbean foliage. Second, third, fourth, and fifth instar *P. maculiventris* nymphs were reared on the pesticide treated larvae to determine mortality and development times of nymphs and morphology of adults. Both concentrations of acephate, as injested by prey subsequently fed to predators, induced significantly greater mortality ($P < 0.05$) than the carbaryl. There was no significant difference in mortality of nymphs in carbaryl and control treatments. Developmental times for nymphs injesting both toxins at each formulation were significantly longer ($P < 0.05$) than nymphs in the control treatment. Adults in control treatments were somewhat larger than adults from pesticide treatments.

Mortality of nymphs in carbaryl treatments was not significantly different from those in the control treatments thus making it a candidate for incorporation in an integrated pest management program.

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I. INTRODUCTION

Podisus maculiventris (Say) is a polyphagus pentatomid predator commonly occurring in North America east of the Rocky Mountains. It is known to feed on over 100 species of insects (McPherson 1980, 1982) and has been observed feeding on plants (Morris 1963, Ruberson et al. 1986). It is considered an important predator of economically important insect pests (Morrill 1906, Couturier 1938) and by virtue of its diversity in prey preference 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, Martston et al. 1978, Ables and McCommas 1982, Lambdin and Baker 1986).

Successful incorporation of P. maculiventris in an integrated pest management program to control Epilachna varivestis Mulsant on snapbean requires a knowledge of predator susceptibility to recommended insecticides. Two pesticides, carbaryl (Sevin 50WP) and acephate (Orthene 75S), are among those recommended for use in Tennessee for control of the pest on snapbean (Yanes et al. 1986). Turnipseed et al.(1974) achieved 83% control of adults and 95% control of larvae of E. varivestis using 1.6 oz. (AI)/a of carbaryl while also maintaining the population integrity of beneficial arthropods. Reducing pesticide concentrations serves several purposes. Given less than 100% mortality of pest species, beneficials surviving applications will remain in a given agroecosystem as well as immigrate from other areas to feed. Reduced concentrations of toxins also decrease the development of resistance and pesticide tolerance in pest populations.

The purpose of this test was to evaluate susceptibility of P. maculiventris to carbaryl and acephate through exposure to toxins by injestion of prey, E. varivestis, fed on snapbean foliage treated with the pesticides.

II. LITERATURE REVIEW

INTEGRATED PEST MANAGEMENT

Arthropod predators and parasites are considered vital in suppressing economically significant arthropod pests in agricultural ecosystems (Ripper 1944, Clausen 1958, Huffaker 1971). Cases of successful reduction and suppression of harmful insects through importation or augmentation of natural enemies are documented by researchers in orchards and monocultures (Clausen 1958, DeBach 1974, Zungoli et al. 1983, Croft and Strickler 1983, Hoy 1986). The efficacy of arthropod predators in a variety of ecosystems including agricultural areas is also explained through mathematical modeling of insect predator/prey interactions (Hollings 1966, Hassell 1978).

Implementation of a biological control program requires successful establishment and/or augmentation of one or more beneficial arthropods. Practices which interfere with a program include the destruction of diversified vegetation peripheral to vast monocultures (Altieri and Letourneau 1982) resulting in habitat loss for a variety of beneficial arthropods (van Emden 1981), or the more destructive natural enemy mortality associated with the use of broad spectrum insecticides.

Primary pest resurgence and secondary pest outbreaks are consequences of pesticide induced natural enemy disruption which are likely to persist until effective and safe alternatives to chemical control are found (Woglum et al. 1947, Tothill 1958, Bartlett and Lagace 1960, Bartlett 1964, Smith and van den Bosch 1967). A problem associated with use of broad spectrum pesticides is the rapid development of resistance in pests as well as elimination of natural enemies. This problem is the primary focus of toxicological research, the emphasis being on pest response and development of resistance rather than the disruptive effects of pesticides on beneficials arthropods (Croft and Brown 1975).

PESTICIDE EFFECTS

Selectivity of pesticides are grouped into two basic categories: physiological selectivity and ecological selectivity (Watson 1975). Physiological selectivity refers to the properties of a compound, which under similar conditions and rates produce different mortality rates in two taxa of arthropods. Specifically, it refers to the differential toxicity of a pesticide as it reacts with an organism's biochemical processes (Hull and Beers 1985). Differences in physiological selectivity are particularly evident when comparing the effects of pesticides on herbivorous and carnivorous arthropods. Gordon (1961) suggests that phytophagus 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 which act on specific plant allelochemicals (Mullin and Croft 1983). Their absence in carnivorous insects significantly decreases their ability to detoxify pesticides (Hull and Beers 1985).

Ecological selectivity pertains to the judicious use of pesticides through practices such as critical selection, dosage and formulation regulation, and timing and placement of broad spectrum insecticides (Hull and Beers 1985). While pesticides remain the cheapest, fastest and most reliable means of suppressing arthropod pests (Metcalf 1982), the emphasis on ecological tactics, rather than anticipating the development of selective pesticides, promises the greatest potential for achieving a selectivity which targets pest species while leaving natural enemy populations intact (Watson 1975).

Integration of chemical and biological control programs is severely hampered by resistance in pests and lack of resistance in beneficials (Stern et al. 1959, Smith 1970, Tabashnick 1986, Hoy 1986, Georghiou 1986). Two theories advanced to understand why pests develop resistance more readily than natural enemies are the feeding preadaptation hypothesis and the "food limitation" hypothesis. The first is a correlate of the physiological selectivity factor that assumes a biochemical and genetic preadaptation in pests to detoxify chemicals. (Croft and Morse 1979, Gordon 1961, Hull and Beers 1985). The "food limitation hypothesis" (Tabashnick 1986), is the integration of Huffaker's (1971) and Georghiou's (1972) observations on natural enemy - pest population dynamics. It infers that in agricultural systems where chemicals are used, natural enemies have the ability to develop resistance, given an adequate supply of prey. The hypothesis also assumes that pests have developed a substantial degree of resistance and are not readily suppressed by pesticides (Croft and Morse 1979). When pest populations are severely reduced by spraying, natural enemies starve, emigrate to other areas, or are eliminated through mortality directly attributable to pesticide action (Tabashnick 1986).

HISTORICAL ANTECEDENTS

Early research on beneficial arthropods focused primarily on assessing impacts of pesticides in field conditions where empirical evidence supported the theoretical view of long term impacts of insecticides (Woglum et al. 1947, Newsom and Smith 1949, Campbell and Hutchins 1952, Ahmed et al. 1954, van den Bosch et al. 1956, Stern et al. 1959, Bartlett and Legace 1960). Van den Bosch et al. (1956) determined relative toxicity rates of some widely used organophosphates and chlorinated hydrocarbons on indigenous populations of Hippodamia sp., *Geocoris* sp., *Orius* sp. *Chrysopa* sp. and *Nabis* sp.. Results indicating a high variability in mortality rates of these beneficials led the authors to speculate that some pesticides could be used in conjunction with natural enemies in an integrated approach.

Bartlett (1958, 1963, 1964b) and colleagues (Bartlett and Lagace 1960) were among the first to conduct controlled laboratory tests specifically designed to evaluate pesticides on beneficial predators and parasites. Initial work with scale insects demonstrated that malathion drift resulted in cottony-cushion scale resurgences due to mortality of the Vedalia beetle, a predaceous coccinellid (Bartlett 1964a). Other laboratory projects evaluated 60 commercial pesticides against *Chrysopa carnea* Stephens (Bartlett 1964b), and the selectivity of aphicides on beneficials associated with the spotted alfalfa aphid, *Therioaphis maculata* (Buckton) (Bartlett 1958).

The majority of research of pesticides on beneficial arthropods emphasizes the effects of topical contact on arthropods. Test conditions predominantly involve placing a droplet of pesticide formulation on the insect's dorsum (Bartlett 1963, Lingren and Ridgway 1967, Lingren et al. 1972, Wilkinson et al. 1975, Wilkinson et al. 1979) or emersing the insect in a formulation (Coulburn and Asquith 1970). Lack of standardization in evaluation techniques and repetitiveness of tests was criticized (Croft and Brown

1975) and an international coordination of evaluation techniques was proposed (Wilkinson and Biever 1977).

CONTROL OF THE MEXICAN BEAN BEETLE

E. varivestis is an oligophagus legume feeder, considered important as a pest on soybean and snapbean in the southeastern United States (Kogan 1981).

Turnipseed (1972) and Shepard et al. (1977) report larval and adult resurgences in soybean fields immediately after applications of monocrotophos and methomyl. Pesticide-treated fields had significantly higher populations of *E. varivestis* larvae and adults than untreated checks. These findings corroborate other researcher's reports of similar pest resurgences, so the authors concluded that natural enemies, destroyed by the use of these two compounds, exert considerable control over beetle populations. Dobrin and Hammond (1983) report similar problems with pest resurgences in field tests where carbaryl and acephate were evaluated for control of *E. varivestis*. Results from the summer of 1981 indicated that acephate provided control 14 days post-treatment, while carbaryl's effectiveness diminished significantly after only 7 days. Results from 1982, revealed much different control levels - where both carbaryl and acephate proved to be equally effective through 21 days post-treatment (Dobrin and Hammond 1983). McClanahan (1981) reports that using the manufacturer's recommended rates of carbaryl and acephate, carbaryl more effectively controlled populations of _E_. _varivestis_. Turnipseed et al. (1974) reports 83% control of adults and 95% control of larvae with carbaryl at 1/5 the manufacturer's recommended rate; a formulation rate which proved significantly less destructive to natural enemies. Zungoli et al. (1983) also reports good control of _E_. _varivestis_ with carbaryl used at the manufacturer's recommended rate of 1 lb (AI)/a. She compared carbaryl with diflubenzuron, a chitin inhibitor reported to have minimal effects on hymenopterous and dipterous parasitoids, in treatments involving inundative releases of _Pediobius faveolatus_ (Crawford), an imported parasitoid of _E_. _varivestis_. Results indicate that neither pesticide interfere appreciably with development of the parasitoid while in the host, but carbaryl proves highly toxic to the adult.

TOXICITY OF CARBARYL AND ACEPHATE

There has been little research done on the effects of acephate on beneficials, due to its relatively recent appearance as a pesticide. Carbaryl on the other hand has been used in a variety of control programs since the late 1950's (Ware 1983) Wilkinson and et al. (1979) are the only researchers who have tested _P_. _maculiventris_ for selectivity to pesticides. It is necessary, therefore, to consider the effects of pesticides on other beneficial arthropods.

Turnipseed (1972) achieved 70-80% control of several major pests of soybeans, including E. varivestis, when applying carbaryl at rates of 0.063-0.38 lb (AI)/a. At these reduced rates, the survival of several important parasitoids and predators such as Brachymeria intermedia (Nees), Campoletis sonorensis (Cameron) , Meteorus leviventris (Wesmael), Voria ruralis (Fallen) and Chrysopa carnea (Stephens) was between 20-100%. Hippodamia convergens Guerin-Meneville prove to be an exception to the rule as even low concentrations of carbaryl causes high mortality. In tests using two organophosphates (sulprofos and profenfos) and two pyrethroids (permethrin and fenvalerate), Wilkinson et al. (1979) determine that the two organophosphates are extremely toxic to P. maculiventris and H. convergens. Elsey and Cheatam (1976) report that both carbaryl and acephate are relatively non-toxic to the predator Jalysus spinosus; however, only acephate is less toxic to two parasitoids tested. A review of laboratory screening programs by Grafton-Cardwell and Hoy (1985) to determine the response of acephate and carbaryl on C. carnea shows a high variability of reported results. For carbaryl, two groups of results indicate an extremely high detrimental effect of the pesticide as reflected in larval mortality (Bartlett 1964, Sukhoruchenko et al. 1977) while two other laboratory tests report a low detrimental effect on larvae (Plapp and Bull 1978, Wilkinson et al. 1975). When tested for larval mortality, acephate indicated only a high detrimental effect (Plapp and Bull 1978). Grafton-Caldwell and Hoy (1986) report that carbaryl had a highly detrimental effect on adults, but found that effects on C. carnea larvae varied depending on geographical location of collected larvae. This lead the authors to suggest that some strains had become partially resistant to carbaryl. Recent investigations (Hoy 1986, Hoy 1985, Hoy 1982, Croft and Morse 1979) succeeded in obtaining strains of phytoseiid mites resistant to carbamate and organophosphorous insecticides in laboratory and field crosses. These strains were established, survived spraying of relevant organophosphorus pesticides in the field, multiplied, and over-wintered to have an impact on spider mite populations in orchards in the western United States (Hoy 1986) and greenhouses (Field and Hoy 1986).

The paucity of comparable data in the literature regarding the toxicity of commonly used pesticides on beneficial arthropods was previously noted (Croft and Morse 1979, Wilkinson and Biever 1977). A review of available results provides only a cursory view of the impact of pesticides on beneficials, particularly predators. The following experiment was conducted in the laboratory to determine the effects of acephate and carbaryl on components of fitness of P. maculiventris.

III. MATERIALS AND METHODS

P. maculiventris nymphs were collected from a population maintained for an undetermined number of generations at the University of Tennessee in Knoxville . Adults and nymphs of the resevoir population were reared on *Galleria mellonella* larvae at 27 ± 2 ^{o} C and 40-70% RH and a 16:8 (L:D) photoperiod.

EXPERIMENTAL DESIGN

Second, third, fourth and fifth instar *P. maculiventris* nymphs were evaluated in four separate tests, each using a completely randomized design consisting of five treatments of twenty replicates each. Data taken were used to determine the effects of carbaryl and acephate on mortality, developmental time per stadia, survival time of treatment groups and morphology of eclosed adults. Each predator was maintained in a single 5.5 cm plastic petri dish at ca. 27 ± 2^{o} C and 60-70% RH on a 16:8 (L:D) photoperiod. Petri dishes were lined with a single 5.5 cm Fisher filter paper (coarse 9-795 A) and a cotton plugged shell vial (12 x 35 mm) filled with distilled water was provided. Prey were provided at 24 h intervals and filter paper and water vials were changed daily to eliminate the possibility of predator mortality caused by tarsal contact with toxins brought in by the prey.

Snapbeans used in treatments were planted at a rate of 6 seeds per 12.7 cm pot and maintained in a greenhouse. Mature pre-bloom foliage was sprayed to the point of run-off using a 710 ml handheld Mayo all purpose sprayer and dried for 24 h before Mexican bean beetles were placed on the leaves for feeding. At the end of each 7 day period fresh plants were treated and previously treated plants discarded.

Acephate (Orthene 75S) and carbaryl (Sevin 50 WP) were applied at the manufacturer's recommended rate as well as at a rate determined to be 1/5 the recommended rate (Acephate 2.996 g (AI)/l max. rec. rate and .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).

Data on mortality and duration of stadia between molts were taken at 12h intervals until eclosion of the adult and duration of stadia between molts and mortality were recorded for each individual. Twenty-four to 48 h after eclosion, adults were measured for lengths (from tip of membranous wings to anterior tip of head) and widths (across the humeral spines of the pronotum) using an ocular micrometer. Mexican bean beetles were obtained from a resevoir population maintained on snapbean in a greenhouse at the University of Tennessee, Knoxville at $28 \pm 5^{\circ}$ C and 60-90% RH with a 16:8 (L:D) photoperiod. Third and fourth instars were removed from the population and starved for ca. 12 h before being placed on snapbean plants treated with carbaryl or acephate. Larvae were allowed to feed until they could be observed suspending themselves by the base of the abdomen from the basal leaf surface. This time was determined to be enough to injest the toxin without inducing immediate mortality.

The General Linear Models procedure (SAS 1985) was conducted on all data sets because of unequal sample size. Waller-Duncan K-ratio t-test was used to test for significance in mean separation among total developmental time means. Where applicable and necessary, sums of squares among treatments were decomposed into a set of orthogonal, single degree of freedom, comparisons so that sums of squares and degrees of freedom were independent of each other and additive among different groups. In some cases, orthogonal comparisons were non-estimable because of sample size.

IV. RESULTS AND DISCUSSION

TEST 1 : SECOND INSTARS

Second instar P. maculiventris nymphs exhibited a higher degree of overall mortality than did nymphs in tests involving third, fourth and fifth instar nymphs. Mortality in all treatment groups of test 1 can be attributed in part to initial handling in the experiments where youngest immature stages are vulnerable to injury.

In Test 1 (Table 1) as in tests of third, fourth and fifth instars, numbers in columns for developmental stage reflect mean preimaginal development time for nymphs surviving through that instar. If a specimen died between molts, it was excluded from consideration in the stadia during which it died. Numbers in the total column 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 and the control treatments, total means reflect the developmental time of that group before eclosion of the adult as well as the expected survivability of the treatment group as a whole.

In test one, a significant difference was found between all treatments in development of nymphs through the second instar ($P < 0.0003$), and third instars ($P < 0.0143$). There were no significant differences indicated in development of nymphs surviving through the fourth and fifth instars in

Table 1. Development, mortality and survival of second instar *P. maculiventris* nymphs injesting carbaryl and acephate treated *E. varivestis* larvae.

Treatment (g AI/l)	$\bar{x}$ Nymphal developmental time (h) 2nd instar	3rd instar	4th instar	5th instar	Survival time
Acephate (.59)	96.1 (17)*	115.6 (1)	192.0 (1)	--	228.8 (20)c**
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

* Numbers of surviving nymphs in each stage.
** Means within columns followed by the same letter are not significantly different ($P < 0.05$ Waller-Duncan k-ratio t-test).

the two carbaryl and control treatment groups. The greatest difference in mortality and development was found among the treatments of acephate and all other treatments as reflected in mortality of individuals and total mean survival time (Table 1). Within the two treatments of acephate an expected higher mortality was observed for the corresponding higher dosage of pesticide. There was little difference among treatments of carbaryl and the control treatment in overall mortality. Orthogonal contrasts (Table 2) indicate significant differences between the control treatment and both carbaryl treatments in development time for nymphs as second and third instars. For development as second instars, nymphs in carbaryl treatments molted sooner than the control group. In later preimaginal stages of nymphs in this test and tests of third, fourth and fifth instars, the control group exhibited a significantly faster rate of development.

Table 2. Orthogonal contrasts of developmental times of second instar P. maculiventris nymphs.

Treatments	Developmental stage			
	2nd instar	3rd instar	4th instar	5th instar
Trt 1 vs. Trt 2	0.9707*	0.7814	0.0855	--
Trt 3 vs. Trt 4	0.1101	0.2087	0.5190	--
Trt 4 vs. Trt 5	0.0001	0.0259	non-est	--
Trt 3 vs. Trt 5	0.0017	0.0009	non-est	--

* Probability of F values.
Trt 1 = Acephate (.59 g (AI)/l), Trt 2 = Acephate (3.0 g (AI)/l), Trt 3 = Carbaryl (1.5 g (AI)/l), Trt 4 = Carbaryl (7.5 g (AI)/l), Trt 5 = Control.

TEST 2 : THIRD INSTARS

In test two, where third instar P. maculiventris nymphs were provided chemically-treated E. varivestis, immatures survived initial handling as well as consumption of E. varivestis larvae which had injested toxins (Table 3). Significant differences existed among all treatments for development and mortality of nymphs in the third ($P < 0.0001$) and fourth ($P < 0.001$) instars. Initial mortality from acephate treatments was reduced during the first stadia (third instar) in which treated prey were injested and more nymphs survived into successive developmental stages. Eleven nymphs injesting prey on the high acephate

Table 3. Development, mortality and survival of third instar _P. maculiventris_ nymphs injesting carbaryl and acephate treated _E. varivestis_ larvae.

Treatment (g AI/l)	$\bar{x}$ nymphal development time (h)			
	3rd instar	4th instar	5th instar	Survival time
Acephate (.59)	102.2 (20)*	119.7 (10)	--	246.8 (20)b**
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

* Number of nymphs surviving in each stage.
** Means within column followed by the same letter are not significantly different ($P < 0.05$ Waller-Duncan k-ratio test).

dosage survived to become fourth instars but died during that stadia. Nymphs injesting the low acephate-treated prey which survived through the fourth instar treatment died before molting into fifth instars. There was little difference in mortality, developmental time and total survival times among nymphs in the carbaryl and control treatments (Table 3). While there was some mortality in both carbaryl groups, it is reflected only in survival time of the group.

Orthogonal comparisons between acephate treatments (Table 4) indicated a significant difference in development of third instars. Those in the reduced formulation treatment survived injestion of treated prey and developed more rapidly as third instars than nymphs provided E. varivestis larvae injesting a higher concentration of acephate. Also, the expected survival time of the nymphs injesting a more concentrated formulation of acephate is significantly reduced. Orthogonal contrasts of development rates (Table 4) show no significant differences between development times except during the fourth instar. Nymphs fed on E. varivestis larvae treated with the concentrated carbaryl formulation developed faster than those in the control group and lower rate of carbaryl treatment.

Mean total survival time were not significantly different among the carbaryl and control treatment groups.

Table 4. Orthogonal contrasts of developmental times of third instar P maculiventris nymphs.

Treatment	Developmental stage		
	3rd instar	4th instar	5th instar
Trt 1 vs. Trt 2	0.0001	0.0658	--
Trt 3 vs. Trt 4	0.8875	0.0003	--
Trt 3 vs. Trt 5	0.3844	--	--
Trt 4 vs. Trt 5	0.4765	--	--

* Probability of F values.
Trt 1 = Acephate (.59 g (AI)/l), Trt 2 = Acephate (3.0 g (AI)/l), Trt 3 = Carbaryl (1.5 g (AI)/l), Trt 4 = Carbaryl (7.5 g (AI)/l), Trt 5 = Control.

TEST 3 : FOURTH INSTARS

Mortality among all treatment groups was further reduced (Table 5) in this test. Increased survival rate of nymphs in the two treatments of acephate was indicated by number of individuals surviving each development stage and reduced disparity between total survival times among all treatment groups. A high degree of significance between treatment groups as fourth ($P < 0.0025$) and fifth ($P < 0.0001$) instars was indicated.

Orthogonal comparisons between the two acephate treatments indicated no difference between development rates (Table 6). Contrasts of developmental times in the two carbaryl treatments show no significant difference

Table 5. Development, mortality and survival of fourth instar P. maculiventris nymphs injesting carbaryl and acephate treated E. varivestis larvae.

	$\bar{x}$ Nymphal developmental time (h)		
Treatment (g AI/l)	4th instar	5th instar	Survival time
Acephate (.59)	114.7 (13)*	168.7 (3)	153.2 (20)c**
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

* Numbers of surviving nymphs in each stage.
** Means within columns are not significantly different (P < 0.05; Waller-Duncan k-ratio test).

Table 6. Orthogonal contrasts of developmental times of fourth instar P. maculiventris nymphs.

	Developmental stage	
Treatment	4th instar	5th instar
Trt 1 vs. Trt 2	0.2786	0.8801
Trt 3 vs. Trt 4	0.3574	0.1007
Trt 3 vs. Trt 5	0.0002	0.0001
Trt 4 vs. Trt 5	0.0038	0.0001

* Probability of F values.
Trt 1 = Acephate (.59 g (AI)/l), Trt 2 = Acephate (3.0 g (AI)/l), Trt 3 = Carbaryl (1.5 g (AI)/l), Trt 4 = Carbaryl (7.5 g (AI)/l), Trt 5 = Control.

between fourth and fifth instars. Comparisons of the control treatment with the carbaryl treatments indicated that nymphs in the control treatment developed significantly faster than those in the pesticide treatments.

TEST 4 : FIFTH INSTARS

Nymphs administered acephate treated *E. varivestis* exhibited a significantly higher rate of mortality than the nymphs in other treatments (Table 7). The high dosage of acephate caused the highest mortality rate compared to all other treatments. Significant differences in development and mortality of fifth instars ($P < 0.0002$) and total survival of treatment groups ($P < 0.0001$) were indicated. Orthogonal contrasts of development of fifth instars show little difference in development times among chemical treatments (Table 8). However, orthogonal comparisons of nymphs in the control treatment with nymphs in both carbaryl treatments indicate significant differences in development times.

Table 7. Development, mortality and survival of fifth *P. maculiventris* nymphs injesting carbaryl and acephate treated *E. varivestis* larvae.

	$\bar{x}$ Nymphal developmental time (h)	
Treatment (g AI/L)	5th instar	Survival time
Acephate (.59)	172.1 (17)*	170.2 (20)a**
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

* Numbers of surviving nymphs in each stage.
** Means within columns followed by the same letter are not significantly different ($P < 0.05$; Waller-Duncan k-ratio test).

Table 8. Orthogonal contrasts of developmental times of fifth instar *P. maculiventris* nymphs.

Treatment	Developmental stage 5th instar
Trt 1 vs. Trt 2	0.1764*
Trt 3 vs. Trt 4	0.7427
Trt 3 vs. Trt 5	0.0004
Trt 4 vs. Trt 5	0.0001

* Probability of F values.
Trt 1 = Acephate (.59 g (AI)/l), Trt 2 = Acephate (3.0 g (AI)/l), Trt 3 = Carbaryl (1.5 g (AI)/l), Trt 4 = Carbaryl (7.5 g (AI)/l), Trt 5 = Control.

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. Unquantified data indicated substantial mortality due to unsuccessful molting in pesticide treatment groups. Physiological impairments were manifested in distended abdomens observed among nymphs treated with acephate.

Orthogonal contrasts did not ascribe significant length and width differences in adults among treatment groups. Nevertheless, it is important to note that with the exception of the fifth instars were tested, adults in the control group were numerically larger or equal in size to nymphs in the other treatment groups (Tables 9 and 10).

Table 9. Lengths of insecticide-treated _P._ _maculiventris_ surviving to adult. [a]

Treatment (g AI/l)	Treatment groups			
	2nd instars	3rd instars	4th instars	5th instars
Acephate (.59)	--	--	10.2 (3)[b]	10.8 (17)
Acephate (3.0)	--	--	10.6 (1)	10.3 (4)
Carbaryl (1.5)	11.2 (17)	10.9 (19)	11.1 (20)	11.1 (20)
Carbaryl (7.5)	10.6 (14)	10.6 (18)	10.7 (20)	11.0 (20)
Control	11.4 (15)	11.4 (20)	11.3 (19)	10.9 (19)

[a] Length, in millimeters, from anterior tip of rostrum to tip of membranous wings.

[b] Numbers in parentheses represent number of individuals measured.

Table 10. Widths of insecticide-treated P. maculiventris surviving to adult.[a]

Treatment (g AI/l)	2nd instars	3rd instars	4th instars	5th instars
	Treatment groups			
Acephate (.59)	--	--	6.2 (3)[b]	6.5 (17)
Acephate (3.0)	--	--	6.1 (1)	5.9 (4)
Carbaryl (1.5)	6.7 (17)	6.5 (19)	6.7 (20)	6.6 (20)
Carbaryl (7.5)	6.5 (14)	6.4 (18)	6.5 (20)	6.6 (20)
Control	6.7 (15)	6.7 (20)	6.9 (19)	6.6 (19)

[a] Widths, in millimeters, from tip to tip of humeral spines.

[b] Numbers in parentheses represent number of individuals measured.

V. SUMMARY AND CONCLUSIONS

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 eclosed as smaller adults than those which developed on a diet determined to be adequate. Landis (1937) reported marked differences in development and survival of P. maculiventris nymphs preying on Colorado potato beetle, Leptinotarsa decemlineata (Say), larvae reared on different host plants. Drummond and co-workers (1984) noticed a similar phenomenon among P. maculiventris nymphs reared on different prey. Nymphal developmental rate was fastest on Galleria mellonella (Say) and slowest on L. decemlineata, and E. varivestis. They also observed that the diet of L. decemlineata caused a significant degree of mortality among nymphs, whereas the E. varivestis diet produced a high survival rate. The authors hypothesized that the low quality of L. decemlineata as prey could be attributable to toxins injested from its host plants in the family Solenaceae.

The effects of acephate on P. maculiventris would preclude its consideration for use in integrated pest management strategies designed to control pests of snapbean through chemical applications and inundative releases of the predator. Even at a greatly reduced concentration acephate causes significant mortality as well as slower development of preimaginal nymphs. Detrimental effects do not significantly differ among second, third, fourth, or fifth instars, although mortality rates were decreased slightly in the later instars. Further, size of adults in the acephate treatment groups were smaller than adults in the other groups. It is anticipated that other negative effects accrued through injestion of toxins would be manifested in other components of fitness in the adult, such as preoviposition period, fecundity, longevity as well as overall fitness of successive generations.

Since one of the tools of integrated pest management is the use of chemicals that do not effectively impair biological control agents (Mullin and Croft 1986), carbaryl is a candidate for use on snapbean. It is as effective or better (McLanahan 1981) 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 injestion is minimal. Wilkinson et al. (1979) noted that the organophosphates sulprofos and profenfos were extremely toxic to _P_. _maculiventris_ when administered through topical or tarsal contact. The results presented in this study corroborate the results of Wilkinson et al. (1979) which demonstrate the detrimental effect of organophosphates on the predator. The relative non-toxicity of carbaryl was not expected but could be attibuted at least in part to the reversible nature of its bonding with cholinesterase in the insect's nervous system (Ware 1983).

Manifestation of detrimental effects were noted in preimaginal developmental time, which for third, fourth, and fifth instars was longer for nymphs in the carbaryl treatments than those in the control group. It was not determined what effects injestion 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 apt to remain in areas of releases whereas adults are able to migrate to other areas. An increased developmental time associated with injestion of toxins through prey, as long as there were no other detrimental effects due to diminished predaceous behavior, would assure an extended control period.

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