Effects of Insecticides on *Pediobius foveolatus* (Hymenoptera: Eulophidae), a Parasitoid of the Mexican Bean Beetle (Coleoptera: Coccinellidae)

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ABSTRACT We studied the effects of insecticides on *Pediobius foveolatus* (Crawford), a parasitoid of the Mexican bean beetle, *Epilachna varivestis* Mulsant. Acephate, carbaryl, carbophenothion, dimethoate, encapsulated methyl parathion, and methomyl (two formulations) were applied by helicopter to a soybean field at normally recommended rates. The effects on immature parasitoids were assessed by exposing parasitized hosts at the time of application. Adult parasitoid mortality was assessed by exposing females to field residue samples. Insecticide applications had no effect on the survival of mature pupae of *P. foveolatus*. However, prepupae and young pupae were vulnerable, especially to methyl parathion and acephate. The residues of parathion and carbaryl caused high adult mortalities for 6 to 9 days following application. The remaining insecticide residues dissipated to nontoxic levels after 1 to 3 days. It was concluded that acephate, dimethoate, and methomyl were most promising for developing a Mexican bean beetle management program involving *P. foveolatus*.

IT IS GENERALLY RECOGNIZED that natural enemies exert significant influence on most pest populations, and that the application of insecticides frequently disrupts this influence (Ripper 1956, Bartlett 1964, Croft and Brown 1975). In the development of integrated pest management (IPM) programs, the effects of insecticides on natural enemies should be evaluated. Few studies, however, have dealt with such effects, especially on parasitoids (Croft and Brown 1975).

To integrate chemical and biological control, physiologically selective insecticides or selective application techniques are used to favor survival of natural enemies over pests (Ripper 1956, Bartlett 1964). Since there generally is a more severe dichotomy in the life cycles of parasitoids (i.e., free-living, mobile adults and parasitic, immobile immatures) than of predators, selective application techniques appear to have a greater immediate potential in the development of IPM programs involving parasitoids. Adult parasitoids are affected by both the application and the residue of the insecticide, whereas the immatures are primarily affected at application (Bartlett 1958, 1964). The amount of contact with residues by the adult depends on its mobility. To develop IPM programs involving parasitoids, data on the effects of insecticides on adult and immature parasitoids are required, in addition to basic information on parasitoid biology (Ripper 1956). The studies reported here are a first step in the development of such an IPM program.

The Mexican bean beetle (MBB), *Epilachna varivestis* Mulsant, is the most serious pest of soybeans in the eastern Midwest and in certain eastern states. It possesses few indigenous natural enemies, and insecticides have been heavily relied upon for control. In 1966, the gregarious larval endoparasitoid, *Pediobius foveolatus* (Crawford) (Pf), was introduced into the United States from India. Releases indicated that it had a substantial effect on MBB in soybeans, but that it could not overwinter (Angalet et al. 1968). An inoculative release program was developed for the eastern states (Stevens et al. 1975) and is being investigated in the midwest. Midwestern investigations have shown that Pf releases can be effective in certain soybean fields, depending on weather, distance from release point, planting date, and soybean cultivar (Flanders, unpublished data). Because these various factors may affect Pf efficiency in controlling MBB, it is reasonable to assume that economic control may require the supplemental application of an insecticide. McWhorter and Shepard (1977) and Zungoli et al. (1983) reported on the impact of diflubenzuron (an insect growth regulator) and carbaryl on Pf, but the impact of other insecticides has not been studied. The purpose of this study was to ascertain the potential for integrating applications of other insecticides for MBB control with biological control by Pf.

Methods and Materials

Pf and MBB were cultured in the Department of Entomology at Purdue University. Rearing techniques were similar to those described by Stevens et al. (1975) and Flanders (1984).

Seven insecticides were selected for study based on their present or future use to control Mexican bean beetle (MBB) in soybeans. The insecticides and their application rates were acephate (Orthene) at 0.2577 kg(AI)/ha, carbaryl (Sevin XLR) at 0.8407 kg(AI)/ha, carbophenothion (Trithion) at 0.8407 kg(AI)/ha, dimethoate (Cygon) at 0.2577 kg(AI)/ha, encapsulated methyl parathion (Penncap-M) at 0.8407 kg(AI)/ha, methomyl (Lannate) at 0.2577 kg(AI)/ha, and methomyl (Nudrin) at 0.2577 kg(AI)/ha.

A field at the Southeastern Purdue Agricultural Center, near Butlerville, Ind., was planted with 'Williams' soybeans 24 June 1981. We planted 56 kg/ha in 76.2-cm rows. A randomized complete block design, with eight treatments replicated three times, was used. Each plot measured 15.2 by 61.0 m, and adjacent plots were separated by 45.7-m soybean borders.

The treatments were applied on 5 September by a helicopter using TeeJet disc-core D7-45 nozzles mounted on a 12-m spray boom. All insecticides were applied in water at 18.7 liters/ha. Each plot was treated by a single pass of the helicopter. The soybeans were in the R6 growth stage (Fehr et al. 1971). On the day of treatment, the air temperature was ca. 25°C and the wind was from the southwest at ca. 5 mph.

Just before treating the field, mummies (parasitized MBB larvae that had ceased feeding) were placed in each plot to determine the effect of the insecticides on immature Pf. Two age classes of mummies were used; young mummies with Pf larvae and young pupae enclosed (9 days after parasitoid eggs laid); and mature mummies with mature pupae enclosed (14 days after parasitoid eggs laid) (Bledsoe et al. 1983). Three mummies of a single age class were placed on the adhesive side of a 5 by 8 cm piece of duct tape. The tape was then stapled to a 5.5 by 10.5 cm manila tag so that the mummies were exposed. Before applying insecticides, each tag with mummies was attached to an upper leaf of a randomly selected soybean plant. Three tags were placed in each plot for each mummy age class.

Within 24 h following insecticide applications, the tags were removed and each mummy was placed in an individual 000 gelatin capsule. The capsules were held at 25°C, 14L:10D photocycle, and 50% RH to await emergence of adults. Data recorded included: number of live Pf adults emerging, sex, and age at time of insecticide application. Mummies that fell from the tags or were damaged in handling were not included in the analyses.

To determine the effect of the insecticide residues on Pf adults, three trifoliates were randomly removed from each plot at intervals of 1, 3, 6, and 9 days following application. Leaves from the upper third of the plant canopy were placed individually in plastic bags. Samplers wore latex gloves that were replaced after sampling each plot. In the laboratory, three leaflet tissue samples 17 mm in diameter (1,361.9 mm^2, total area) were removed from each trifoliate with a no. 10 cork borer. These discs were placed in a 1-oz clear plastic cup (36 mm diam by 40 mm). Cotton organdy was put over the top of the cup, and held in place by a plastic snap-on lid with a central, 30 mm hole. Ten Pf females (1–2 days old) were placed in each cup. Clover honey was streaked on and pressed through the organdy for food. The cups were then placed in a temperature cabinet at 25°C, 50% RH, and 14L:10D photocycle, with the tops exposed to a constant fresh air flow. The number of dead Pf females in each cup was recorded at 12, 24, and 36 h following initial exposure to insecticide. All statistical analyses were performed using an arc sine transformation to stabilize variances, but only nontransformed means are reported.

During the period that residue samples were taken, rainfall occurred only on 8 September and totaled 0.28 cm. During this period, daily maximum temperatures ranged from 18 to 27°C.

Results and Discussion

The data from the study on mummy exposure at application indicated that there was relatively little effect on mummy viability with any of the insecticides. Chi-square tests of two way contingency tables indicated that there were no significant differences ($P < 0.05$) between observed and expected values for mature mummy viability between the treatments. However, there were significant deviations between treatments for young mummies (Table 1). This was a result of the higher-than-expected mortalities of young mummies exposed to applications of acephate and parathion.

The mean number of Pf adults emerging from mature mummies was not significantly different ($P < 0.05$, ANOVA) among treatments (mean = 15.04), but was significantly different from young mummies. The mean number of Pf adults emerging from young mummies was highest for carbaryl, followed by methomyl (Nudrin) and dimethoate. The lowest mean number of parasitoids emerging occurred in young mummies exposed to methomyl (Lannate), followed by acephate and parathion. The high mean number of adults emerging after exposure to carbaryl and methomyl (Nudrin) could be a result of hormoligosis, or insecticide-induced increase in pupal parasitoid viability (Luckey 1968, Croft and Brown 1975). If this was the case, this effect may depend on the age of the mummy at the time of exposure, because no such effect could be discerned in the mature mummies.

Number of female progeny emerging from young or mature mummies was not significantly different ($P < 0.05$, ANOVA) between treatments. There were 82.1% females emerging from young,

Table 1. Effects of insecticides on young pupae of Pf within host mummies exposed to direct applications

Treatment (kg [AI]/ha)	% Viable mummies (n)	Pf per viable mummy (n)	% Females emerging (n)
Control	100.0 (19)	16.28 (14)bcd	76.3 (14)
Dimethoate (0.2577)	100.0 (24)	19.61 (23)abc	84.0 (23)
Methomyl (0.2577, Lannate)	95.6 (23)	12.32 (22)d	77.1 (21)
Methomyl (0.2577, Nudrin)	100.0 (23)	21.87 (23)ab	84.3 (23)
Acephate (0.2577)	82.4 (17)	12.94 (16)cd	81.6 (13)
Methyl parathion (0.8407)	83.3 (24)	15.39 (23)bcd	83.3 (20)
Carbaryl (0.8407)	100.0 (18)	25.59 (17)a	84.6 (17)
Carbophenothion (0.8407)	95.8 (24)	18.64 (22)abcd	80.0 (21)
Total	94.8 (172)	17.87 (160)	82.1 (152)

Means followed by the same letter are not significantly different ($P < 0.05$; Duncan's multiple range test).

and 82.5% females emerging from mature mummies.

The results indicated that Pf pupae protected within the intact integument of the host were relatively unaffected by the insecticides at the time of application. However, it does appear that younger Pf pupae were more vulnerable, especially to methomyl (Lannate) and acephate. Even with chemicals that caused some reduction in adults emerging, there was no differential mortality between the sexes. It was observed that adults emerging from mummies exposed to applications of parathion and carbaryl as compared to other treatments rapidly died within the gelatin capsules. This probably was a result of toxic residues remaining on the exteriors of the mummies.

Analyses of data on adults for each sampling date indicated that mortality, due to leaf residues, stabilized at or near 24 h exposure, and that 36 h exposure resulted in relatively high control mortality. Consequently, only 24 h exposure results will be discussed (Table 2).

Residue samples taken 1 day following application resulted in statistically significant differences ($P < 0.01$, ANOVA) among treatments. Parathion caused 100% mortality, which was significantly higher ($P < 0.05$, Duncan's multiple range test) than any other treatment. Carbaryl (88.9%) and acephate (70.0%) also resulted in average percentages of dead Pf that were significantly different from all other treatments and each other. The remaining insecticide treatments were not significantly different from each other or from the control. The relatively high mortality (25.6%) of control parasitoids on this sample date indicated that drifting of insecticide between plots may have occurred. However, there were no significant differences ($P < 0.05$, ANOVA) between blocks. Had differences been detected, this would have indicated a severe drift problem.

Table 2. Effects of insecticide residues on the survival of Pf adults over time

Treatment (kg [AI]/ha)	Residue effect after application (% mortality)			
	1 day	3 days	6 days	9 days
Control	25.6d	3.3c	0.0b	1.1b
Dimethoate (0.2577)	34.4d	2.2c	1.1b	1.1b
Methomyl (0.2577, Lannate)	35.6d	5.6c	1.1b	0.0b
Methomyl (0.2577, Nudrin)	18.9d	1.1c	6.7b	11.1a
Acephate (0.2577)	70.0c	2.2c	1.1b	0.0b
Methyl parathion (0.8407)	100.0a	52.2b	33.3a	0.0b
Carbaryl (0.8407)	88.9b	74.4a	30.0ab	2.2b
Carbophenothion (0.8407)	27.8d	1.1c	2.2b	0.0b

Means, within a column, followed by the same letter are not significantly different ($P < 0.05$; Duncan's multiple range test). Mortality was determined after 24 h exposure to residues on each sampling day.

Three days after application, treatments were still significantly different ($P < 0.01$, ANOVA). However, the mean percentage of mortality caused by acephate had decreased to a level where it was no longer significantly different from the control. Also, mortality caused by parathion decreased to 52.2%, which was significantly less than that caused by carbaryl (74.4%).

Adult mortality 6 days following application indicated that significant differences ($P < 0.01$, ANOVA) still existed among treatments. Mortality due to parathion residues (33.3%) was the highest, but was not significantly different from that caused by carbaryl (30.3%). Nor was carbaryl mortality significantly different from mortality caused by the remaining pesticides.

Nine days after application, methomyl (Nudrin) residues caused 11.1% mortality, which was significantly different ($P < 0.05$, Duncan's multiple range test) from other treatments. Parathion and carbaryl were not significantly different from the group of lowest treatment means. The rise in mortality on days 6 and 9 due to methomyl (Nudrin) residues could not be explained, especially with respect to those exhibited by methomyl (Lannate), which was applied at the same dosage.

The results indicated that commonly used insecticides mainly affected adult Pf, the prepupae and pupae being relatively unaffected. These results are similar to those reported by Bartlett (1958) for parasitoids of the spotted alfalfa aphid, and by Zungoli et al. (1983) for Pf responses to diflubenzuron and carbaryl. Parathion and carbaryl residues caused the greatest Pf adult mortality. However, under the environmental conditions of the study, the residues of these insecticides dissipated to low or nontoxic levels in 6 to 9 days. The remaining insecticides dissipated to nontoxic levels in 1 to 3 days.

The successful integration of chemical and biological control, therefore, must take into account the persistence of insecticide residues that are toxic to Pf adults. It is assumed that survival of Pf eggs and larvae within MBB larvae that are still feeding is primarily dependent on the survival of the host. It is also assumed that most Pf adults in the field at the time of application will be killed. Because most Pf larvae and pupae within mummies will survive insecticide applications, the shorter the residual activity of an insecticide the greater the probability that emerging adults will survive. The prepupal and pupal stages of Pf require between 7 and 10 days at 25°C. Therefore, only those insecticides whose residues are active for a shorter time will be of value in an integrated control program. Within this critical period, the shorter the residual activity of an insecticide, the greater will be the population of new Pf adults. Based on these considerations, only acephate, carbophenothion, dimethoate, and methomyl appear to be appropriate.

Following insecticide application and residue deterioration, there must be a sufficient number of MBB remaining in the field to maintain the emerging Pf adults. To evaluate the feasibility of integrating acephate, carbophenothion, dimethoate, or methomyl with Pf, the effects of each on MBB populations must be considered. The effects of the same insecticides on MBB were investigated at the same time and in the same plots as this study (C. R. Edwards, unpublished data). In that study, the residues of carbaryl and carbophenothion caused high MBB larval mortality for up to 21 days following application. Parathion caused very high mortality for 1 day following application, but dissipated rapidly by day 6. Dimethoate and acephate caused moderate mortalities for 1 day following application and also dissipated by day 6. Methomyl (Nudrin and Lannate) exhibited low toxicity 1 day following application and dissipated by day 3. Because the purpose of insecticide application in an integrated control program is only to lower the density of the pest to a level where the surviving parasitoids can exert their influence, carbaryl, carbophenothion, and parathion do not appear to possess desirable attributes for inclusion in an integrated control program with *P. foveolatus*.

Based on our results, it appears that dimethoate, acephate, and methomyl are the most promising insecticides for integrated control of MBB at the doses used. This conclusion is based on the assumption that a MBB larval population sufficient to support the remaining Pf population will survive initial treatment and contact with residues.

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