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THE RELATIONSHIP BETWEEN FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) INSTAR AND SUSCEPTIBILITY TO INSECTICIDES APPLIED TO SWEET CORN

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ABSTRACT

Toxicities of 2 concentrations of fenvalerate and methomyl to second, fourth and sixth instar fall armyworms, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), were determined in laboratory and field tests. In laboratory tests, the LC_{50} for both methomyl and fenvalerate increased as larval age increased from second to fourth to sixth instar. Fenvalerate was more toxic than methomyl to second instars but less toxic than methomyl to sixth instars. In the 1986 field tests with whorl stage sweet corn, all treatments effectively reduced whorl damage caused by second, fourth and sixth instars compared with the untreated. Both rates of methomyl were significantly more effective than either rate of fenvalerate in reducing whorl damage caused by fourth or sixth instar fall armyworm. In 1987, both rates of methomyl and the 0.224 kg AI/ha rate of fenvalerate significantly reduced second and fourth instar fall armyworm whorl damage compared with the untreated, but only the 1.0 kg AI/ha rate of methomyl significantly reduced sixth instar whorl damage. All insecticide treatments resulted in significantly fewer second instars recovered from the whorls, but only the methomyl treatments resulted in significantly fewer fourth instars compared with the untreated. Greater whorl damage was caused by fourth and sixth instars compared with second instars. Results indicate that timing of application is as important as selection of pesticide for management of fall armyworm on whorl stage sweet corn.

Key Words: *Spodoptera frugiperda*, corn, whorl damage, fenvalerate, methomyl.

RESUMEN

Se determínaron on pruebas de laboratorío y de campo la toxicidád de dos concentraciones de fenvalerato y metomilo a los segundos, cuartos y sextos instares del qusano

cogollero del maíz, *Spodoptera frugiperda* (J. E. Smith) Lepidoptera: Noctuidae). En las pruebas de laboratorio, el LC_{50} para metomilo y fenvalerato se aumentó a medida que se aumentó la edad de las larvas desde el segundo al cuarto y al sexto instar. Fenvalerato fué mas tóxico que metomilo a los segundos instares pero menos tóxico que metomilo a los sextos instares. En las pruebas de campo de 1986 con maíz dulce en la etapa del verticilo, todos los tratamientos efectivamente redujeron los daños a los verticilos causodos por segundos, cuartos y sextos instares al compararse con el testigo. Ambas concentraciones de metomilo fueron significativamente más efectivos que cualquiera de las dos concentraciones de fenvalerato en reducir daños al verticilo causado por gusanos cogolleros del maíz de cuarto o sexto instar. En 1987, ambas concentraciones de metomilo y la concentración de 0.224 kg AI/ha do fenvalerato significativament redujeron daños de segundo y cuarto instar al verticilo comparado con el testigo, pero solamente la concentracíon de 1.0 kg AI/ha de metomilo significativamente redujo daños causados por el sexto instar. Todos tratamientos resultaron en significativemente menos segundos instares recuperados de los verticilos, pero solamente los tratamientos de metomilo resultaron en significativamente menos cuartos instares comparado con el testigo. El daño mas grande al verticilo fué causado por cuartos y sextos instares comparado con segundo instares. Los resultados indican que escoger la ocasión precisa de alicación de plaguecidas es tan importante como la selección de la plaguecida en el control del gusano cogollero de maíz sobre maíz dulce en la etapa del verticilo.

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) is a serious pest of sweet corn (*Zea mays* L.) in the mid-Atlantic region. Adult moths migrate into the region from southern states during early to mid-August, and can infest sweet corn at nearly all crop stages. Control of this insect pest thoughout Central and North America is obtained primarily with insecticides, including fenvalerate and methomyl.

With many insects, susceptibility to insecticides generally decreases with increasing larval age. Ahmad & Forgash (1975) reported that susceptibility of gypsy moth larvae to carbaryl and diazinon decreased with older instars, and Kuhr & Hessney (1977) demonstrated that fifth instar European corn borers were less susceptible to methomyl than third or fourth instars. Yu (1983) reported that, in laboratory tests, the LD_{50} values for methomyl, diazinon and permethrin increased with older instars.

Laboratory and field data are often difficult to compare (Bagent 1964), and reports of the efficacy of insecticides against fall armyworm in laboratory tests have not been consistent with field trials. Bass (1978) reported poor control of fall armyworm with permethrin and fenvalerate in field trials, but Wood et al. (1981) found permethrin to be more toxic to fall armyworm in laboratory tests than several other insecticides.

The objective of our study was to conduct laboratory and field tests to determine the susceptibility of different FAW instars to two commercially available insecticides, fenvalerate and methomyl. Results of insecticide bioassays with laboratory-reared fall armyworm were compared with field experiments to evaluate the effect of insecticides on fall armyworm mortality and feeding damage to sweet corn.

Materials and Methods

Laboratory Study.

In 1988, FAW were reared from eggs on a wheat germ-agar artificial diet (Bio-Serv Corn Earworm Rearing Media, Bio-Mix #9394, Bio-Serv, Frenchtown, NJ) in the laboratory at the E. I. du Pont de Nemours' Stine-Haskell Research Farm, Newark, Delaware (USA). Larvae were maintained on diet in rearing chambers at 60% R.H. and 26.7° C before testing.

Fall armyworm larvae (5 second, fourth or sixth instars) were placed in flat, plastic 237-ml cups (11.4 cm diam) containing an artificial wheat germ-agar diet for each treatment replicate. Cups were placed on a moving belt sprayer that passed beneath a single stationary nozzle (8001E) calibrated to deliver 935.4 liters/ha at 1.2 kPa. Concentrations of technical methomyl and fenvalerate in ppm were respectively: 12.5, 25, 50, 100, 200, 400 and 6.25, 12.5, 25, 50, 100, 200. An acetone control treatment was included. Treatments were replicated 4 times. All larvae were maintained in temperature-controlled rearing chambers for 48 h after application. Data from laboratory tests were corrected for control mortality with Abbott's (1925) formula. Log dosage-probit lines were determined using probit analysis (SAS Institute 1985).

Field Study.

'Silver Chief' cultivar sweet corn was planted on 1 July 1986 and 15 June 1987 in a Sassafras sandy loam field at the Rutgers Research & Development Center, Bridgeton, New Jersey (USA). In southern New Jersey, sweet corn planted in mid- to late June would be in the mid-whorl stage of development before infestation by fall armyworm. Treatment rows were 7.62 m long and 0.8 m wide. Treatments were replicated 4 times in a split-plot experimental design. The main plots received the following rates of insect icide: fenvalerate (Pydrin 2.4EC) at 0, 0.112 or 0.224 kg AI/ha and methomyl (Lannate 1.8L) at 0, 0.50 or 1.00 kg AI/ha. Subplots were infested with different fall armyworm instars (second, fourth or sixth). Each subplot consisted of 4 rows: the middle 2 rows were treatment rows and the outer 2 rows were nontreated buffer rows. Twenty plants from the center 2 rows of each subplot were infested on 14 August 1986 and 17 July 1987 with either first, third or fifth instars, and marked with a 0.3 m garden stake placed in the soil at the base of the plant. First instars were applied with a Bio-Serv #9040 "bazooka" dry grit applicator (approximately 25 larvae per whorl), and third and fifth instars were applied with soft forceps (4 larvae per plant whorl, or 80 larvae per subplot). Foliar sprays were applied 48 h after infestation using a self-propelled, high-clearance sprayer (John Deere 6000 Hi-Cycle) with a single nozzle (TeeJet 8010) centered over each of the middle 2 rows. Sprayer application volume was 224.4 liter/ha at 275.8 kPa pressure and a sprayer ground speed of 3.2 km/h. Dissection of infested, untreated plants each year showed that at the time of application of the foliar sprays, or shortly thereafter, larvae had aged by one instar. Infested plants were evaluated on 22 August 1986 and 21 July 1987 for FAW whorl damage according to a modified method from Carvalho (1970): (0) no damage; (1) slight damage, 0-10% whorl feeding; (2) moderate damage, 10-25% whorl feeding; (3) heavy damage, 25-50% whorl feeding; (4) severe damage, 50-75% whorl feeding, emerging tassel damaged and (5) whorl destroyed. Ten whorls from each subplot were dissected in the field and the numbers of live FAW larvae were recorded. The remaining plants were harvested on 7 September 1986 and 18 August 1987. The ears were husked and weighed and FAW damage evaluated as "marketable" (clean or less than 3.6 cm of tip damage) or "cull" (tip damage beyond 3.6 cm and/or side or bottom damage).

The data from individual plots were averaged to obtain a plot mean for each insecticide and FAW instar treatment. Data for each year and parameter were subjected to analyses of variance (ANOVA) (SAS 1985). Means were separated by Duncan's (1955) new multiple range test.

Results

Laboratory Study.

Fenvalerate was significantly more toxic to second instar larvae than methomyl, but methomyl was significantly more toxic to sixth instars than fenvalerate (Table 1). LC_{50}'s

TABLE 1. LABORATORY TOXICITY DATA FOR METHOMYL AND FENVALERATE APPLIED TO 2ND, 4TH AND 6TH INSTAR FALL ARMYWORM, NEWARK, DE, 1988.

Insecticide	Instar	LC_{50}[1]	95% Fiducial Limits
Methomyl	2nd	103.9	79.9- 147.1
Methomyl	4th	157.7	105.0- 265.5
Methomyl	6th	189.4	134.4- 299.9
Fenvalerate	2nd	35.8	31.6- 40.3
Fenvalerate	4th	136.6	112.7- 174.4
Fenvalerate	6th	823.0	341.9-7130.0

[1]μg/fall armyworm larva.

increased as instar increased from second to fourth to sixth for both methomyl and fenvalerate. In addition, sixth instars were 1.7- and 10.8-fold more tolerant of methomyl and fenvalerate, respectively, than were 2nd instars. These results are in agreement with those of Yu (1983) who reported that LD_{50}'s for methomyl, diazinon and permethrin increased with increasing FAW larval age.

Field Study.

In each year, ANOVA demonstrated significant ($P \leq 0.05$) insecticide (whole plots), instar (sub-plots) and insecticide X instar interactions for both whorl damage ratings and recovered larvae (Table 2). When the data from 1986 and 1987 were combined, both rates of methomyl were significantly more effective than the 0.112 kg AI/ha rate of fenvalerate in reducing whorl damage caused by FAW (Table 3); no significant differences between either rate of fenvalerate were observed. Methomyl (1.0 kg AI/ha) resulted in significantly fewer larvae recovered from whorls than all other treatments (Table 3).

Yields. No significant treatment differences were observed for mean ear weight, total number of ears per 20 stalks, or ear damage caused by FAW in 1986 or 1987 (yield data not shown). Ghidiu & Drake (1989) reported that no significant loss in marketable sweet corn ears occurred when plants were infested by FAW larvae during the pre-whorl to mid-whorl stages of plant development.

Field Trials 1986.

Whorl Damage Ratings. The whorl damage caused by fall armyworm significantly increased as larvae aged from second to fourth instar in untreated plots (Table 4). All

TABLE 2. ANALYSIS OF VARIANCE STATISTICS FROM FIELD EXPERIMENTS.

Year	Variable	df	Whorl Damage[1] *F*	No. Larvae Recovered[1] *F*
1986	Insecticide	5	21.84	35.31
	Instar	2	93.39	295.41
	Insecticide × Instar	10	5.08	9.61
1987	Insecticide	5	5.04	13.03
	Instar	2	122.80	100.83
	Insecticide × Instar	10	2.99	4.51

[1]$P \geq 0.05$ for analysis of all variables in both years.

TABLE 3. EFFECT OF INSECTICIDES ON FALL ARMYWORM IN WHORL STAGE SWEET CORN, BRIDGETON, NEW JERSEY[1].

Treatment	Rate (kg AI/ha)	Whorl Damage[2,3]	Mean No. Live Larvae Per 20 Corn Whorls[3]
Untreated	0.0	2.3 c	19.6 b
Fenvalerate	0.112	1.7 b	10.5 a
Fenvalerate	0.224	1.4 ab	8.8 a
Methomyl	0.5	1.0 a	6.3 a
Methomyl	1.0	0.9 a	6.5 a

[1]1986 and 1987 data combined.
[2]Rated 0-5 (0 = no damage, 5 = whorl destroyed).
[3]Numbers in a column with a letter in common are not significantly different (Duncan's multiple range test; $P \geq 0.05$).

treatments significantly reduced whorl damage by all 3 instars compared with the untreated. Both rates of methomyl resulted in significantly less whorl damage by fourth and sixth instar FAW than did either rate of fenvalerate.

Recovery of FAW. All treatments resulted in lower recovery of second instars compared with the untreated control (Table 4). Both rates of methomyl resulted in significantly fewer fourth instars recovered than did either rate of fenvalerate. Although fewer sixth instars were recovered in corn plots treated with both rates of methomyl and the 0.224 kg AI/ha rate of fenvalerate, the differences were not significant compared with untreated corn.

Field Trials 1987.

Whorl Damage Ratings. Both rates of methomyl and the 0.2 kg AI/ha rate of fenvalerate significantly reduced whorl damage caused by second or fourth instars (Table 5) compared with the untreated. However, there were no significant differences among insecticide treatments in whorl damage caused by second or fourth instars. Only the 1.0 kg AI/ha rate of methomyl resulted in significantly less whorl damage caused by sixth instar FAW.

Recovery of FAW. The 1.0 kg AI/ha rate of methomyl resulted in significantly fewer second instars recovered compared with all other treatments, although all treatments resulted in significantly ($P \geq 0.05$) fewer second instars than did the untreated control

TABLE 4. EFFECT OF INSECTICIDES ON VARIOUS FALL ARMYWORM INSTARS IN THE WHORL OF SWEET CORN, BRIDGETON, NJ, 1986.

Treatment	Rate (kg AI/ha)	Whorl Damage[1] Instar			Mean No. Larvae Recovered[1] Instar		
		2nd	4th	6th	2nd	4th	6th
Untreated	—	1.1 b	2.6 d	3.6 c	26 c	43 b	12 ab
Fenvalerate	0.112	0.3 a	1.8 c	2.5 b	9 ab	32 b	14 ab
Fenvalerate	0.224	0.3 a	1.7 c	1.8 b	6 a	39 b	5 a
Methomyl	0.5	0.3 a	1.1 b	1.0 a	10 ab	17 a	4 a
Methomyl	1.0	0.3 a	0.9 ab	1.0 a	9 ab	21 a	5 a

[1]Numbers in a column with a letter in common are not significantly different. (Duncan's multiple range test; $P \geq 0.05$).

TABLE 5. EFFECT OF INSECTICIDES ON VARIOUS FALL ARMYWORM INSTARS IN THE WHORL OF SWEET CORN, BRIDGETON, NJ, 1986.

Treatment	Rate (kg AI/ha)	Whorl Damage[1] Instar 2nd	Whorl Damage[1] Instar 4th	Whorl Damage[1] Instar 6th	Mean No. Larvae Recovered[1] Instar 2nd	Mean No. Larvae Recovered[1] Instar 4th	Mean No. Larvae Recovered[1] Instar 6th
Untreated	—	1.4 bc	1.4 bc	2.7 b	105 b	35 bc	23 ab
Fenvalerate	0.112	1.1 ab	1.1 ab	3.3 b	70 c	22 ab	14 a
Fenvalerate	0.224	0.9 a	1.0 a	2.7 b	67 c	25 ab	11 a
Methomyl	0.5	0.8 a	0.9 a	2.6 b	53 bc	19 a	14 a
Methomyl	1.0	0.5 a	0.6 a	1.8 a	33 a	15 a	8 a

[1]Numbers in a column with a letter in common are not significantly different (Duncan's multiple range test; $P \geq 0.05$).

(Table 5). Both rates of methomyl resulted in significantly fewer fourth instars compared with the untreated control, although there were no significant differences in recovered fourth instars among the insecticide treatments. Further, there were no significant differences among any treatments in the numbers of sixth instars recovered from the whorls.

DISCUSSION

Laboratory studies indicated that fenvalerate was more toxic to second instars than methomyl (based on LC_{50} values). However, field studies demonstrated that fenvalerate and methomyl were equally toxic to second instars. In the laboratory, fenvalerate and methomyl were equally toxic to fourth instars, but methomyl was more toxic to fourth instars than fenvalerate in the field experiments (1986). Methomyl was more toxic to sixth instars than fenvalerate in the laboratory, but in field studies this trend was observed only in whorl damage and not with numbers of larvae recovered. These findings agree with previous research demonstrating the difficulty in making meaningful comparisons between laboratory and field results (Bagent 1964).

Laboratory studies also showed that LC_{50} values increased for both fenvalerate and methomyl as test fall armyworm aged from second to sixth instars. This agrees with Yu (1983) who reported that the LD_{50} values of permethrin and methomyl increased as the fall armyworm larvae aged.

In each year of the field study, the whorl damage caused by fall armyworm increased as larval age (size) increased. Mulder & Showers (1986) showed that in field corn, defoliation increased as armyworms (*Pseudaletia unipuncta* Haworth) aged from fourth through sixth instars.

Our field study results showed that methomyl and fenvalerate were equally effective in reducing whorl damage by second instars during each year, but methomyl was more effective than fenvalerate in reducing whorl damage by fourth and sixth instars in 1986. In 1986, both rates of fenvalerate and methomyl significantly reduced whorl damage caused by sixth instars compared with untreated corn, but only the high rate of methomyl significantly reduced sixth instar whorl damage in 1987. Guillebeau & All (1991) reported that fenvalerate gave more variable control of fall armyworm on sweet corn than did methomyl.

Both rates of fenvalerate and methomyl significantly ($P \leq 0.05$) reduced the numbers of live second instars recovered in the whorls each year, and both rates of methomyl significantly reduced the numbers of fourth instars recovered each year, compared with untreated corn. However, none of the fenvalerate or methomyl treatments significantly

reduced the numbers of sixth instar FAW recovered in the whorls in either year compared with untreated corn.

Greater numbers of second instar FAW were recovered from the whorls in 1987 than in 1986. This may have been due to rainfall [0.51 cm (0.21 inches)] on 17 August 1986, the day after the spray application. The rain may have helped carry the spray residue deeper into the whorl, and thus increased the amount of toxicant at the larval feeding site. No rainfall occurred within 1 wk of the 1987 spray application.

Control of fall armyworm may depend not only on selection of an effective insecticide, but also on timing of application. An application of fenvalerate or methomyl would be less effective against older larvae (sixth instar) compared with younger larvae. A delay in application, either due to poor weather conditions or inaccurate timing, may result in reduced effectiveness of the insecticide, rectified only by additional pesticide applications or increasing dosage. Such a delay would be counterproductive to a sound fall armyworm management program. Pesticide applications should be directed against the younger instars to obtain best results. A pest management program should, therefore, utilize larval instar data, as well as percentage infestation (number of plants infested during the whorl stage of plant development) to make more precise spray decisions and maximize crop protection.

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