EVALUATION OF SELECTED INSECTICIDES FOR CONTROL OF DIAMONDBACK MOTH AND CABBAGE LOOPER IN CABBAGE IN CENTRAL FLORIDA WITH OBSERVATIONS ON INSECTICIDE RESISTANCE IN THE DIAMONDBACK MOTH

GARY L. LEIBEE AND KENNETH E. SAVAGE
Central Florida Research and Education Center,
University of Florida, IFAS,
2700 East Celery Avenue, Sanford, FL 32771

ABSTRACT

A field study was conducted to evaluate selected insecticides for the control of *P. xylostella* and cabbage looper, *Trichoplusia ni* (Hübner), in cabbage, *Brassica oleracea* L. (Capitata group). Chlorpyrifos, endosulfan, mevinphos, and *Bacillus thuringiensis* subsp. *kurstaki* were considerably more effective at controlling *P. xylostella* than cypermethrin, permethrin, methomyl, and thiodicarb. Cypermethrin, permethrin, thiodicarb, and endosulfan were the most effective at controlling *T. ni*. Mixtures of two insecticides improved efficacy apparently due to one component controlling *T. ni*. and not *P. xylostella* and the other component controlling *P. xylostella* and not *T. ni*. Laboratory examination of selected populations from the field study indicated that poor efficacy of the pyrethroids and carbamates on *P. xylostella* was probably due to insecticide resistance.

RESUMEN

Se realizo un estudio para evaluar insecticidas selectivos para el control de *P. xylostella* y del medidor del repollo, *Trichoplusia ni* (Hubner) en repollo, *Brassica oleracea* L. (grupo capitata). Chlorpyrifos, endosulfan, mevinphos y *Bacillus thuringiensis* sbesp. *kurstaki* fueron considerados mas efectivos al controlar *P. xylostella* que cypermethrin, permethrin, methomyl y thio-dicarb. Cypermethrin, permethrin, thiodicarb y endosulfan fueron los mas efectivos en controlar *T. ni*. Las mezclas de 2 insecticidas fueron aparentemente mas eficaces dado que un solo compuesto controla *T. ni* pero no *P. xylostella* y el otro compuesto controla *P. xylostella* y no *T. ni*. Pruebas de laboratorio indicaron que los bajos resultados obtenidos con los pirethroides y carbamatos en poblaciones de *P. xylostella* seleccionadas del campo, se debieron probablemente a su resistencia a los insecticidas.

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), a worldwide pest of cruciferous crops (Talekar 1986), was easily managed in Florida until about the mid-1980s, when growers observed that fenvalerate and permethrin were failing to control *P. xylostella* in crucifers in transplant production facilities and in the field. Magaro and Edelson (1990) noted that failures to control *P. xylostella* in south Texas were first reported by cabbage producers in the spring of 1987. Weekly applications of fenvalerate failed to reduce damage from caterpillars in cabbage in the spring of 1985 at the Central Florida Research and Education Center (CFREC) in Sanford, FL (Leibee 1986). Pyrethroid insecticides provided poor control of *P. xylostella* at the CFREC from the winter of 1986-87 to the present, (Author, unpublished data). Other researchers indicated that *P. xylostella* had become increasingly more difficult to control in the southern and eastern United States during the late 1980s. Since insecticide resistance in *P. xylostella* had been reported in Taiwan (Liu et al. 1982), Japan (Hama

1987), and in other areas of southeast Asia (Cheng 1988), it was suspected that a similar problem was developing in Florida.

We evaluated selected insecticides alone and in combination for control of diamondback moth and cabbage looper, *Trichoplusia ni* (Hübner), in cabbage. In addition, we determined the susceptibility to fenvalerate in diamondback moth populations from selected treatments to document the presence of pyrethroid resistance.

Materials and Methods

Insecticides

Formulated materials used in the field trials were chlorpyrifos (50% wettable powder [WP], Dow Chemical Co.), methomyl (215.7 g/liter soluble liquid [L], E. I. duPont deNemours & Co.), thiodicarb (383.5 g/liter flowable liquid [F], Rhone-Poulenc), endosulfan (359.5 g/liter EC, FMC), cypermethrin (359.5 g/liter EC, ICI Americas), permethrin (383.5 g/liter EC, FMC), mevinphos (479.4 g/liter EC, E. I. duPont deNemours & Co.), Dipel 2X (*Bacillus thuringiensis* subsp. *kurstaki*, 32.0 BIU/kg wettable powder [WP], Abbott), and Javelin (*B. thuringiensis* subsp. *kurstaki*, 16 billion Spodoptera Units/liter, Sandoz). Fenvalerate (287.6 g/liter EC, E. I. duPont deNemours & Co.) was used in the leaf residue bioassays.

Field Study

'Golden Acre Yellows Resistant' cabbage was transplanted from seedbeds on 20 and 21 April 1989 into Myakka fine sand at CFREC-Sanford. Plots consisted of four 15.2-m rows with a 0.76-m spacing between rows and a 0.28 m plant spacing within rows. A 3.8-m unplanted buffer separated plots within each replicate. Treatments were arranged in a randomized complete block design with four replications; replicates were separated by 7.6-m alleyways. All treatments, except for endosulfan, were assigned to the plots in a randomized complete block design with four replications. The endosulfan treatment was observational and was assigned to a plot at the same end of each block originally not to be used because of excessive soil moisture. Standard cultural practices for the area were used for fertilization and weed control. Sprays were applied with a tractor-mounted, 4-row, compressed-air sprayer. Three hollow-cone nozzles (D2-25) were used per row; one overhead and one drop on each side. The sprayer delivered 467.4 liter/ha at 3163.6 g/cm^2 (45 psi) and 3.2 km/h. Applications were made on 11, 16, and 23 May, 1, 8, and 16 June 1989. Insecticide treatments included: chlorpyrifos (1.12 kg AI/ha), cypermethrin (0.067 kg AI/ha), Javelin (1.17 liter/ha), methomyl (1.01 kg AI/ha), permethrin (0.22 kg AI/ha), thiodicarb (0.84 and 1.12 kg AI/ha), mevinphos (1.12 kg AI/ha), and endosulfan (1.12 kg AI/ha). Additional treatments consisting of mixtures of two of the insecticides and rates listed above included: cypermethrin with chlorpyrifos, cypermethrin with Javelin, chlorpyrifos with Javelin, and thiodicarb with mevinphos. An additional treatment of chlorpyrifos mixed with Dipel 2X (0.56 kg/ha) was also included. These treatments were compared to nontreated plants. A wetting agent (X-77, Chevron Chemical Co.) was used (0.62 ml/liter) in all treatments.

Plots were sampled on 22 and 31 May and 7 and 14 June 1989. The sample consisted of the bud or head and the next four youngest leaves (wrapper leaves in the head stage) from four randomly selected plants per plot (two from the middle of each center row). The whole plant was taken only if four leaves were present. Cut plants from each plot were placed in a plastic bag and transported to the laboratory. All plant material was placed into Berlese funnels and heated for 24 h. When heads were present, the infested head leaves were pulled away from the head and the uninfested portion of the head was cut out to reduce the amount of plant material that went into the funnel. Larvae that

moved down the funnel were collected in jars of 70% ethyl alcohol attached to the bottom of the funnels. All insect species, except *P. xylostella*, were categorized according to size (small, medium, and large). *Plutella xylostella* was categorized according to instar by head capsule size. The numbers of larvae in each size category for each species were recorded. Ten mature plants were rated for damage on 16 June 1989 using a scale of 1-6 (Greene et al. 1969). Percent marketability for normal market conditions (no head damage) was based on the proportion of plants having a damage rating of 3.0 or less. Percent marketability for exceptional market conditions (slight amount of head damage) was based on the proportion of plants having a damage rating of 4.0 or less. Damage ratings were taken from only one plot of the endosulfan treatment because of severe stunting in three of the replicates due to excessive soil moisture.

Fenvalerate Susceptibility Study

Colonies of *P. xylostella* were established from the nontreated check, chlorpyrifos, cypermethrin, and thiodicarb plots of the field trial. Larvae and pupae were collected from each replicate of a treatment and combined to provide at least 100 individuals to start each colony. Collections were made from the nontreated check plots on 22 June, the cypermethrin-treated plots on 23 June, and the chlorpyrifos- and thiodicarb-treated plots on 26 June 1989. Colonies were maintained on rape seedlings into the F-2 generation until there were enough larvae to determine the toxicity of fenvalerate to individuals of each colony using a leaf residue bioassay.

Leaf residue bioassays were conducted by placing 6-10 early fourth instar larvae (3-4 mg) in glass Petri dishes containing pieces of rape seedlings coated with dried residues of fenvalerate and recording the number of dead or moribund larvae after 24 h. The rape seedlings were dipped as whole plants for 5 sec in water dilutions of formulated fenvalerate (0.24, 0.48, 0.96, 1.92, and 3.84 g AI/liter) and allowed to dry. The check was dipped in water only. A wetting agent (X-77, Chevron Chemical Co.) was used (0.62 ml/liter) in all treatments, including the check. Each concentration was replicated three times within the bioassay. Each bioassay was repeated four times for each strain. The range of dilutions was designed to include concentrations that would be used in the field (0.48 g AI/liter represents the recommended field rate of 224 g AI/ha in 467.4 liter/ha). Enough plants were dipped for each dose to provide extra for replenishing the food supply, if necessary, during the bioassay. Each Petri dish contained three seedlings (generally two cotyledon leaves and one completely expanded true leaf) excised well into the dipped part of the stem. The Petri dish bottoms were lined with filter paper.

Statistical Analysis

Data from the field trial were subjected to analysis of variance and means were separated by Duncan's (1955) multiple range test ($P = 0.05$ level). Damage ratings were not transformed. Data from all bioassays were corrected for control mortality using Abbott's (1925) formula. Percentage data were transformed to the Arc Sine $\sqrt{\%}$, and larval count data were transformed to log(X + 1.5) for *P. xylostella* and to sq. rt.(X + 0.5) for *T. ni* to stabilize error variance. Nontransformed means are presented in tables. The endosulfan data were considered observational and not included in analyses.

Results and Discussion

Field Study

Infestations of *P. xylostella* and *T. ni* were present throughout the field study. On individual sample dates, numbers of *T. ni* were much lower than numbers of *P. xylos-*

TABLE 1. EFFECTS OF SELECTED INSECTICIDAL TREATMENTS ON LARVAL NUMBERS FOR *P. XYLOSTELLA* AND *T. NI* ON CABBAGE.

Insecticide & rate (kg/AI or liter formulation/ha)	No. 2-4 instar *P. xylostella*/4 plants[1]			No. *T. ni* larvae/4 plants totaled over all sample dates[1]
	31 May	7 June	14 June	
Untreated check	7.3 ab	5.0 cde	11.0 cde	6.3 a
Chlorpyrifos 1.12	0.8 fgh	2.3 e-h	3.3 efg	6.0 a
Cypermethrin 0.067	7.8 a	18.0 a	31.8 b	0.8 def
Javelin 1.17 liter	3.5 bcd	3.7 c-f	5.5 def	4.5 abc
Cypermethrin 0.067 + Chlorpyrifos 1.12	0.3 gh	1.7 e-h	2.8 a	1.8 b-f
Cypermethrin 0.067 + Javelin 1.17 liter	1.3 e-h	6.7 bcd	14.3 bcd	1.8 c-f
Chlorpyrifos 1.12 + Dipel 2X 0.56	1.8 d-g	1.7 e-h	3.5 efg	5.5 ab
Chlorpyrifos 1.12 + Javelin 1.17 liter	0.8 fgh	1.0 fgh	2.0 fg	4.8 abc
Methomyl 1.01	6.5 ab	2.3 d-g	17.5 bcd	3.8 a-d
Permethrin 0.22	6.8 ab	9.3 abc	24.8 bc	0.5 ef
Thiodicarb 1.12	2.8 def	13.0 ab	21.8 bc	0.5 ef
Thiodicarb 0.84	6.0 abc	7.7 bc	33.0 b	2.0 b-f
Thiodicarb 0.84 + Mevinphos 1.12	1.0 fgh	1.3 fgh	8.5 c-f	1.5 c-f
Mevinphos 1.12	3.0 cde	1.0 fgh	6.3 efg	6.3 a
Endosulfan 1.12	0.8 (0.5)[2]	1.0 (1.0)[2]	3.5 (1.3)[2]	2.9 (1.7)[2]

[1]Means in the same column followed by the same letter are not significantly different (P = 0.05; Duncan's [1955] multiple range test).

[2]Endosulfan results not included in ANOVA (see text). Mean (SEM) presented.

tella. *Trichoplusia ni* numbers did not differ ($P > 0.05$) among treatments on the last three sample dates. However, when *T. ni* numbers were totaled over these dates, significant differences ($P < 0.05$) were detected among treatments (Table 1). Even though *T. ni* numbers appear low relative to *P. xylostella* numbers, a considerable amount of damage could be attributed to *T. ni* because the cabbage consumption ratio of *T. ni* to *P. xylostella* can be 18.4 to 1.0 (East et al. 1989).

Even though the observational endosulfan treatment was assigned to marginal plots (plants were stunted in three plots due to excessive soil moisture), the data are included in the discussion due to the obvious effectiveness of endosulfan. In the treatments consisting of one insecticide, chlorpyrifos, mevinphos, endosulfan, and Javelin were considerably more effective at controlling *P. xylostella* than cypermethrin, permethrin, methomyl, and thiodicarb. Cypermethrin, permethrin, thiodicarb, and endosulfan were most effective at controlling *T. ni*. Endosulfan was the only insecticide that was effective against both species and produced the most marketable cabbage heads among all treatments consisting of a single insecticide. All other single insecticide treatments produced very little marketable cabbage under normal market conditions.

With the exception of the cypermethrin-Javelin combination treatment, the treatments consisting of a mixture of two insecticides resulted in significantly ($P < 0.05$) less damage than the treatments consisting of either of the insecticides in the mixture applied alone. Based on the frequency of damage ratings of 3 or less, a significant ($P < 0.05$) increase in marketability over the nontreated plants was found in the treatments consisting of the following mixtures listed in order of decreasing marketability: cypermethrin with chlorpyrifos, thiodicarb with mevinphos, and chlorpyrifos with Dipel 2X.

TABLE 2. EFFECTS OF SELECTED INSECTICIDAL TREATMENTS FOR THE CONTROL OF *P. XYLOSTELLA* AND *T. NI* ON DAMAGE RATINGS (DR) AND TWO LEVELS OF MARKETABILITY IN CABBAGE.

Insecticide & rate (kg/AI or liter formulation/ha)	Damage rating[1]	Percent marketable[1] (DR≤3)	Percent marketable[1] (DR≤4)
Untreated check	6.0 a	0.0 f	0.0 d
Chlorpyrifos 1.12	5.2 cd	2.5 ef	10.0 cd
Cypermethrin 0.067	6.0 a	0.0 f	0.0 d
Javelin 1.17 liter	5.1 d	0.0 f	20.0 bc
Cypermethrin 0.067 + Chlorpyrifos 1.12	3.5 ef	40.0 d	95.0 a
Cypermethrin 0.067 + Javelin 1.17 liter	4.9 d	0.0 f	40.0 b
Chlorpyrifos 1.12 + Dipel 2X 0.56	4.0 e	17.5 e	82.5 a
Chlorpyrifos 1.12 + Javelin 1.17 liter	3.9 e	12.5 ef	95.0 a
Methomyl 1.01	5.9 ab	0.0 f	0.0 d
Permethrin 0.22	6.0 a	0.0 f	0.0 d
Thiodicarb 1.12	5.7 abc	0.0 f	0.0 d
Thiodicarb 0.84	5.7 abc	0.0 f	0.0 d
Thiodicarb 0.84 + Mevinphos 1.12	3.7 ef	22.5 e	87.5 a
Mevinphos 1.12	5.4 bcd	0.0 f	5.0 cd
Endosulfan 1.12	3.4 -	50.0 -	100.0 -

[1]Means in a column followed by the same letter are not significantly different (P = 0.05; Duncan's [1955] multiple range test). "-" indicates unreplicated. See text.

Cypermethrin with chlorpyrifos was significantly ($P < 0.05$) more effective than all other mixtures. Based on the frequency of damage ratings of 4 or less, which represents a relatively high level of insect control, all mixtures resulted in a significant increase in marketability over the untreated check. In general, based on larval numbers, the increase in efficacy from the mixtures was probably due to one component controlling *P. xylostella* (and not *T. ni*) and the other component controlling *T. ni* (and not *P. xylostella*). The cypermethrin-chlorpyrifos mixture resulted in the greatest reduction in damage probably because the cypermethrin alone provided the best *T. ni* control and the chlorpyrifos alone provided the best *P. xylostella* control.

Fenvalerate Susceptibility Study

The highest mortality among all strains was 37% in the nontreated strain at an 8.0-fold increase over a typical field concentration of fenvalerate (Table 3). These data, along with the low efficacy of cypermethrin and permethrin occurring in the field, support the contention that a pyrethroid-resistant *P. xylostella* population was present in the field study. The cypermethrin strain was less ($P < 0.05$) susceptible than the nontreated strain to both a 2.0- and 4.0-fold increase over the field concentration of fenvalerate and less ($P < 0.05$) susceptible than the chlorpyrifos strain to a 4.0-fold increase. The thiodicarb strain was less ($P < 0.05$) susceptible than the nontreated strain to a 2.0-fold concentration of fenvalerate. These results suggest that cypermethrin and thiodicarb selected for a resistance mechanism that increased resistance to fenvalerate. The susceptibility to fenvalerate of the chlorpyrifos strain was similar (P

TABLE 3. MORTALITY (%) OF FOUR STRAINS OF *P. XYLOSTELLA* EXPOSED TO FENVALERATE LEAF RESIDUES. THE STRAINS WERE ESTABLISHED FROM MATURE CABBAGE FIELD PLOTS THAT WERE NONTREATED AND TREATED WITH CHLORPYRIFOS, CYPERMETHRIN, AND THIODICARB.

	Concentration of fenvalerate[1]				
Strain	0.5X	1.0X	2.0X	4.0X	8.0X
Nontreated	10.0(3.8)NS	22.9(7.2)NS	31.3(2.4)a	32.1(6.1)a	36.9(2.2)NS
Chlorpyrifos	10.8(3.5)	18.5(6.5)	19.6(2.0)ab	31.1(2.9)a	32.6(1.8)
Cypermethrin	0.0(0.0)	9.8(0.7)	9.8(1.4)b	14.5(4.8)b	23.6(3.3)
Thiodicarb	10.7(9.3)	11.4(3.1)	14.2(4.4)b	20.8(2.4)ab	35.7(6.4)

[1]Means in the same column followed by the same letter are not significantly different (P = 0.05; Duncan's [1955] multiple range test). NS indicates no significant differences (P > 0.05) among strains. 1.0X = 0.48 g AI/liter, or equivalent to the concentration necessary to deliver 224.4 g of fenvalerate in 467.4 liter of spray to 1 ha (0.2 lb AI/acre).

> 0.05) to the nontreated strain, suggesting that chlorpyrifos did not alter the resistance level of the population.

In summary, the field study indicated that chlorpyrifos, endosulfan, mevinphos, and *B. thuringiensis* were considerably more effective at controlling *P. xylostella* populations than cypermethrin, permethrin, methomyl, and thiodicarb. Cypermethrin, permethrin, thiodicarb, and endosulfan were most effective at controlling *T. ni*. Mixtures of two insecticides were shown to improve efficacy; apparently one component controlled *T. ni* (and not *P. xylostella*) and the other component controlled *P. xylostella* (and not *T. ni*). Laboratory examination of populations from the field study indicated that poor efficacy of the pyrethroids and carbamates on *P. xylostella* was probably due to insecticide resistance.

These results demonstrate how insecticide resistance can increase the complexity of insect control, especially when a pest complex is involved. Knowing what species are present, their resistance characteristics, and the efficacy of available insecticides on each species becomes a necessity for making sound control recommendations.

Acknowledgments

We thank A. Ali and R. K. Jansson for their critical review of an earlier version of this manuscript. This manuscript was approved for publication as Florida Agricultural Experiment Station Journal Series No. R-01542.

References Cited

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Cheng, E. Y. 1988. Problems of control of insecticide-resistant *Plutella xylostella*. Pesti. Sci. 23: 177-188.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

East, D. A., J. V. Edelson, and B. Cartwright. 1989. Relative cabbage consumption by the cabbage looper (Lepidoptera: Noctuidae), beet armyworm (Lepidoptera: Noctuidae), and diamondback moth (Lepidoptera: Plutellidae). J. Econ. Entomol. 82: 1367-1369.

Greene, G. L., W. G. Genung, R. B. Workman, and E. G. Kelsheimer. 1969. Cabbage looper control in Florida-a cooperative program. J. Econ. Entomol. 62: 798-800.

Hama, Y. 1987. Development of pyrethroid resistance in the diamondback moth, *Plutella xylostella* Linne' (Lepidoptera: Yponomeutidae). Appl. Ent. Zool. 22: 166-175.

Leibee, G. L. 1986. Caterpillar control on cabbage, spring 1985. CFREC-Sanford Research Report SAN 86-10. Univ. Fla. IFAS. 2 p.

Liu, M. Y., Y. J. Tzeng, and C. N. Sun. 1981. Diamondback moth resistance to several synthetic pyrethroids. J. Econ. Entomol. 74: 393-396.

Magaro, J. J., and J. V. Edelson. 1990. Diamondback moth (Lepidoptera: Plutellidae) in south Texas: a technique for resistance monitoring in the field. J. Econ. Entomol. 83: 1201-1206.

Talekar, N. S. [ed.]. 1986. Diamondback moth management: Proceedings of the first international workshop, March 11-15, 1985. Asian Vegetable Research and Development Center, Shanhua, Taiwan.