EFFICACY OF EMAMECTIN BENZOATE AND *BACILLUS THURINGIENSIS* AT CONTROLLING DIAMONDBACK MOTH (LEPIDOPTERA: PLUTELLIDAE) POPULATIONS ON CABBAGE IN FLORIDA

GARY L. LEIBEE[1], RICHARD K. JANSSON[2], GREGG NUESSLY[3] AND JAMES L. TAYLOR[4]

[1]University of Florida Central Florida Research and Education Center
Institute of Food and Agricultural Sciences 2700 East Celery Avenue
Sanford, FL 32771

[2]Merck Research Laboratories P. O. Box 450 Hillsborough Road
Three Bridges, NJ 08887

[3]University of Florida Everglades Research and Education Center
Institute of Food and Agricultural Sciences P. O. Box 8003
Belle Glade, FL 33430

[4]Merck Research Laboratories P. O. Box 1893
Sanford, FL 32772

ABSTRACT

Emamectin benzoate (MK-244; Merck & Co., Rahway, NJ), used alone and alternated with *Bacillus thuringiensis* (Berliner) ssp. *aizawai* (*Bta*), *Bta* alone, and *B. thuringiensis* ssp. *kurstaki* (*Btk*) alone, were evaluated for control of diamondback moth, *Plutella xylostella* (L.), in head cabbage at three locations in Florida. Additional treatments unique to each location were also evaluated. Emamectin benzoate alone, *Bta* alone, emamectin benzoate alternated with *Bta*, and mevinphos were shown to be effective. *Btk* was less efficacious than *Bta* at two locations.

Key Words: *Plutella xylostella*, emamectin benzoate, *Bacillus thuringiensis*, field efficacy

RESUMEN

El benzoato de emamectina (MK-244; Merck & Co., Rahway, NJ) usado solo y alternado con *Bacillus thuringiensis* (Berliner) ssp. *aizawai* (Bta), Bta solo, y *B. thuringiensis* ssp *kurstaki* (Btk) solo, fueron evaluados para el control de la polilla de diamante, *Plutella xylostella* (L.), en col de repollo en tres localidaes de la Florida. También fueron evaluados tratamientos adicionales únicos en cada localidad. El benzoato de emamectina solo, Bta solo, el benzoato de emamectina alternado con Bta, y el mevinfós mostraron ser efectivos. Btk fue menos eficaz que Bta en las dos localidades.

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), a worldwide pest of cruciferous crops (Talekar 1986), was easily managed in Florida until the onset of insecticide resistance in the 1980s (Leibee & Savage 1992a,b). Loss of efficacy with pyrethroids and methomyl caused growers to switch to intensive use of other insecticides, especially *Bacillus thuringiensis* (Berliner) ssp. *kurstaki* (*Btk*). Shelton et al. (1993) documented resistance to *Btk* and control failures with *Btk* products in several populations of diamondback moth in Florida in 1992. At present, the diamondback moth has become very difficult to control with any of the currently registered synthetic insecticides and *Btk*-based products. The recently introduced products based on *B. thuringiensis* (Berliner) ssp. *aizawai* (*Bta*) appear to be providing effective control of diamondback moth in Florida. This is consistent with reports describing resistance to *Btk,* but not to *Bta,* in Florida (Leibee & Savage 1992c, Shelton et al. 1993).

The development of new insecticides that circumvent the mechanisms of resistance that have developed in the diamondback moth has become extremely important, not only for control, but also for management of insecticide resistance. The availability of several new insecticides with different chemistry and mode of action would allow the implementation of management schemes designed to slow down the selection for resistance to any one insecticide. Emamectin benzoate (MK-244) is a new avermectin insecticide in development at Merck Research Laboratories targeted for control of lepidopterous pests on a variety of crops.

This study was conducted to compare the efficacy of emamectin benzoate used alone and alternated with *Bta*, *Bta* alone, and *Btk* alone for control of diamondback moth on cabbage at three locations in Florida. Additional treatments unique to each location were also evaluated.

Materials and Methods

Studies were conducted in Florida during 1992 at the Central Florida Research and Education Center (CFREC) in Sanford, Everglades Research and Education Center (EREC) in Belle Glade, and the Tropical Research and Education Center (TREC) in Homestead. Additional studies were conducted during 1993 at the EREC.

Insecticidal Treatments

The insecticides common to all three locations were emamectin benzoate [MK-244 0.16 EC (emulsifiable concentrate), Merck Research Laboratories, Merck & Co., Rahway, NJ] at 0.0084 kg (AI)/ha, *B. thuringiensis* ssp. *aizawai* (*Bta*) (XenTari, Abbott Laboratories, North Chicago, IL) at 1.12 kg/ha, and *B. thuringiensis* ssp. *kurstaki* (*Btk*) (DiPel 2X, Abbott Laboratories, North Chicago, IL) at 1.12 kg/ha. Additional insecticides, adjuvants, and combinations tested at TREC were: *Btk* [AC 513,696 2X WP (wettable powder), American Cyanamid Co., Princeton, NJ] at 1.12 kg/ha; *Btk* [AC 513,696 48 LC (liquid concentrate), American Cyanamid Co.] at 2.8 liter/ha; *Btk* [Larvo-Bt LC (liquid concentrate), Knoll Bioproducts Co., Inc., Santa Fe, NM] at 0.3 liter/ha alone and at 0.3 liter/ha in combination with a feeding stimulant (Konsume, Fermone, Phoenix, AZ) at 7.0 liter/ha; AC 513,696 48 LC at 2.8 liter/ha in combination with Konsume at 7.0 liter/ha; *Btk* transconjugate [Cutlass WP (wettable powder), Ecogen, Inc., Langhorne, PA] at 2.24 kg/ha; and mevinphos [Phosdrin 4 EC (emulsifiable concentrate), E. I. duPont de Nemours & Co., Wilmington, DE] at 0.56 kg (AI)/ha in combination with Cutlass WP at 2.24 kg/ha. Additional insecticides and combinations tested at EREC were: *Btk*/*Bta* transconjugate [Condor OF (oil flowable), Ecogen, Inc., Langhorne, PA] at 2.34 liter/ha; *Btk* recombinant (MVP, Mycogen Corp., San Diego, CA) at 4.67 liter/ha; Cutlass WP at 2.24 kg/ha; *Btk* [Javelin WG (wettable powder), Sandoz Agro, Inc., Des Plaines, IL] at 1.12 kg/ha; *Btk* [Biobit FC (flowable concentrate), E. I. duPont de Nemours & Co., Wilmington, DE] at 3.5 liter/ha; thiodicarb [Larvin 3.2 AF (aqueous flowable)], Rhone-Poulenc Ag Co., Research Triangle Park, NC] at 0.9 kg (AI)/ha; methamidophos [Monitor 4 EC (emulsifiable concentrate), Miles, Inc., Kansas City, MO] at 1.12 kg (AI)/ha; Larvin 3.2 AF at 0.9 kg (AI)/ha in combination with DiPel 2X at 1.12 kg/ha; esfenvalerate [Asana XL 0.66 EC (emulsifiable concentrate), E. I. duPont de Nemours & Co., Wilmington, DE] at 0.055 kg (AI)/ha; Asana XL at 0.055 kg (AI)/ha in combination with DiPel 2X at 1.12 kg/ha; mevinphos (Phosdrin 4EC) at 1.12 kg (AI)/ha; and mevinphos at 1.12 kg (AI)/ha in combination with DiPel 2X at 1.12 kg/ha.

Two alternating application patterns were used for emamectin benzoate and *Bta* at CFREC. One pattern started with two applications of emamectin benzoate and then rotated every two applications with *Bta*; the other alternation started with *Bta* and rotated every two applications with emamectin benzoate. Also at CFREC, an additional *Bta* treatment was tested in which applications were skipped if the infestation level was ≤ 5%. At TREC, one alternation pattern starting with *Bta* was used as described above. At EREC, the pattern tested was three applications of emamectin benzoate followed by three applications of *Bta*.

CFREC-Sanford

'Golden Acre' cabbage was transplanted on 4 Mar. 1992 into Myakka fine sand. Plots consisted of four 9.0-m rows with a 0.76-m row spacing and about a 0.28-m plant spacing. Four rows were left unplanted between each plot to provide a separation of 3.8 m. Plots were arranged in five blocks and the blocks were separated by 7.6-m alleyways. All the treatments were assigned to plots in a randomized complete block design with five replications. Conventional cultural practices were used for fertilization and weed control.

Sprays were applied with a tractor-mounted, compressed-air sprayer. Three hollow-cone nozzles (D2-25) were used per row; one overhead and one drop on each side. The delivery rate of spray was 467.4 liter/ha with a boom pressure of about 3.2 kg/cm^2 (45 psi) and a speed of 3.2 km/h. Application dates were 26 March, 1, 8, 15, 22, and 29 April, and 6 and 13 May 1992. A buffer (Helena Buffer PS, Helena Chemical Co., Memphis, TN) was used to maintain the pH of the spray water at 6.9. A spreader-sticker (Triton B-1956, Rohm and Haas Co., Philadelphia, PA) was used in all treatments at the rate of 5.0 ml per 7.6 liter of spray. The nontreated check received water and spreader-sticker at each application.

Ten plants per plot (5 randomly selected plants in the center of each of the two middle rows) were examined weekly to determine the presence or absence of larvae and pupae of each species on the bud (or head if formed) and next 4 youngest leaves. At harvest (14 May), 10 mature plants (5 randomly selected plants in the center of each of the two middle rows) were each placed into one of six damage categories. The head and first four wrapper leaves were cut as a unit from the plant. Each wrapper leaf was removed and inspected and then the head was inspected. A scale of 1 to 6, similar to that of Greene et al. (1969), was used, in which 1 = no damage; 2 = no head damage with minor feeding damage on wrapper leaves, found only by close inspection; 3 = no head damage with obvious damage to wrapper leaves, generally obvious before removal of wrapper leaves; 4 = very minor feeding damage on head, not completely through outer head leaves, evident only by close inspection; 5 = feeding completely through outer head leaf or further into head; 6 = similar to 5 but more extensive, damage radiates further towards or past equator of head from top or bottom and laterally around head. A damage rating of ≤ 3 is marketable under normal market conditions, wrapper leaves might be removed to market. A damage rating of ≤ 4 is marketable under exceptional market conditions.

TREC-Homestead

'Rio Verde' cabbage seeds were incorporated into a germination mix (Pro-Mix) and direct-seeded into a Krome, very gravelly loam soil on 8 January 1992. The soil was fumigated with Terr-O-Gas (75% methyl bromide, 25% chloropicrin; 246 kg/ha) and covered with white on black plastic mulch on 27 December 1991. Plants were spaced 0.3-m apart within rows and 0.76-m apart between rows on 1.8 m-center beds. Conventional cultural practices were used for fertilization and weed control. All treatments except the emamectin benzoate (MK-244)/XenTari rotation treatment were applied on 7 dates between 14 February and 27 March. Plants receiving the emamectin benzoate/XenTari rotation treatment were sprayed with XenTari on 4 dates (14 and 21 February, and 13 and 20 March) and with emamectin benzoate on the three remaining dates (28 February, and 6 and 27 March). Treatments were replicated 4 times in a randomized complete block design. Treatment plots were 4 rows (2 beds) by 9.1-m long. A 1.5-m long section of nontreated plants separated replicates. Applications were made using a tractor-mounted, single bed boom sprayer that operated at 6.9 kg/cm^2 (100 psi) and delivered 935 liters/ha through 6 D-4 Albuz red disc type ceramic cone nozzles at 4.8 km/h. All treatments were applied in water. The pH of the water was maintained between 6.5 and 7.5 using sulfuric acid buffer. All treatments were applied with a surfactant, Triton B-1956, (0.49 liters/ha). The nontreated check was not sprayed. Eight plants per plot (4 randomly selected plants in the center of each of the two middle rows) were examined on 6 dates between 4 February and 19 March to determine numbers of larvae and pupae per plant. Foliage injury was rated on 24 plants per plot (12 randomly selected plants in the center of each of the two middle rows) at harvest (6 April), using a scale of 1-6 as previously described. Percentages of marketable heads were based on ratings ≤ 3.

EREC-Belle Glade

Both the 1992 and 1993 trials were conducted on Lauderhill soil. The following methods and materials were common to both trials. 'Bravo' cabbage was direct-seeded to raised beds on 0.91-m centers. Seeds were planted to two rows spaced 0.3-m apart on each bed and later thinned to 0.3-m spacing between plants within each row. Treatments were replicated four times in a randomized complete block design. The nontreated check plots received no treatments. The pH of the spray water ranged from 6.4 to 6.6 and was not adjusted. A CO_2 pressurized hand sprayer boom was used to spray two beds simultaneously. Except for the Condor OF treatment in 1992, wetting agents were used. Leaf Act 80 [PureGro Co., West Sacramento, CA (0.58 liter/ha)] was used with the emamectin benzoate treatments, and X-77 [Chevron Chemical Co., San Francisco, CA (0.29 liter/ha)] was used for the rest of the treatments. Conventional cultural practices were used for fertilization and weed control. Ten plants per plot (5 randomly selected plants in the center of each of the two middle rows) were examined on each sampling date to determine numbers of larvae and pupae. Marketability was determined at harvest for heads with wrapper leaves and for heads with no more than three wrapper leaves removed. Percentages of marketable heads were based on ratings ≤ 2 (Greene et al. 1969).

In 1992, seeds were planted on 24 January. Treatment plots were two beds wide (4 rows) and 7.62-m long with a 1.52-m nonplanted buffer zone between plots. Applications were initiated when diamondback moth populations averaged < 1 larva per plant. Treatments were applied eight times: 5, 17, and 27 March, 9, 16, and 30 April, and 7 and 22 May. The spray boom had three nozzles over each bed: one centered over each bed and one on each side of the row directed inward. Volume of water applied was 374 liter/ha for the first two sprays. Water volume was increased to 607 liter/ha beginning 25 March, and increased again to 748 liter/ha from 16 April until the last spray on 22 May. Plots were sampled on 3, 10, 20, and 25 March, 1, 13, and 20 April, and 5 and 19 May. Plants were harvested on 28 May.

In 1993, Diazinon 14G was applied and incorporated into the soil 15 days before planting for wireworm control. Seeds were planted on 16 March. Applications began when diamondback moth populations averaged slightly more than 1 larva per plant. Treatment plots were four beds wide (8 rows) and 6.1-m long with a 1.52-m nonplanted buffer zone between plots. Treatments were applied 7 times: 23 and 30 April, 6, 13, and 24 May, and 2 and 6 June. The spray boom had four nozzles over each bed: one over each row and one on each side of the bed directed inward. Volume of water applied was 374 liter/ha for the first two sprays. Water volume was increased to 607 liter/ha beginning 6 May, and increased again to 748 liter/ha from 24 May until the last spray. Plots were sampled on 21 and 29 April, 5, 11, 20, and 26 May, and 8 and 16 June. Plants were harvested on 18 June. The majority of the insect pressure in both trials was from diamondback moth. Very few southern armyworm, *Spodoptera eridania* (Cramer); beet armyworm, *S. exigua* (Hübner); cabbage looper, *Trichoplusia ni* (Hübner); and cutworms, probably *Agrotis ipsilon* (Hufnagel)and *Feltia subterranea* (F.), were encountered during the experiment.

Statistical analysis

Data were subjected to analysis of variance [SAS System, Version 6.04 (SAS Institute, Inc., Cary, NC)]. Insect count data from Belle Glade and Homestead were 1n (x + 1)- transformed. All percentage data were transformed [ARCSIN (SQRT X)]. Means were separated by Waller-Duncan K-ratio t-test, (K-ratio = 100).

RESULTS AND DISCUSSION

Sanford

Due to consistently low numbers of diamondback moth and the lack of correlation between larval counts and marketability in past studies at CFREC-Sanford, the percentage of plants with the bud (or head) and next 4 youngest leaves infested was used to measure the activity of diamondback moth. This method was found to work well when abundance was low and results correlated well with levels of damage at harvest (G.L.L., unpublished data). We suggest that this method works because efficacious insecticides prevent development to the adult stage, thus preventing oviposition on the new growth in the sampling zone which eventually becomes the marketable portion of the plant. In addition, we suggest that this method also works because there is very little immigration from adjacent plots which may be producing adults.

Infestation levels increased steadily from 16% on 24 March to 98% on 12 May in the nontreated check (Table 1). Weekly applications of emamectin benzoate resulted in very low infestation levels (Table 1) and the highest percentage of marketable cabbage (Table 2). Starting with emamectin benzoate and alternating every two applications with two applications of XenTari also resulted in very low infestation levels (Table 1) and a comparable percentage of marketable cabbage (Table 2). Starting with XenTari and alternating every two applications with two applications of emamectin benzoate resulted in significantly higher infestation levels and significantly ($P < 0.05$) less marketable cabbage than the opposite alternation pattern. This difference in ef-

TABLE 1. EFFECTS OF INSECTICIDES ON MEAN PERCENTAGE OF CABBAGE PLANTS INFESTED WITH LARVAE AND/OR PUPAE OF THE DIAMONDBACK MOTH AT CFREC-SANFORD, FL, 1992.

		Sample Date							
		24 Mar	31 Mar	7 Apr	14 Apr	22 Apr	28 Apr	5 May	12 May
Treatment	Rate per Hectare[1]	% Plants Infested with Diamondback Moth Larvae and/or Pupae (SEM)[2]							
Nontreated	—	16(5.6) NS	20(7.1) a	41(8.0) a	34(13.2) a	60(6.1) a	71(7.0) a	89(3.3) a	98(1.2) a
DiPel 2X	1.12 kg	17(4.1)	8(5.1) ab	14(5.3) bc	21(8.7) bc	26(6.0) b	32(9.3) b	71(7.6) b	71(5.1) b
XenTari	1.12 kg	12(3.0)	5(2.2) ab	14(5.1) bc	32(14.9) bc	17(4.9) bc	5(1.6) cd	18(3.0) c	27(4.6) cd
MK-244 0.16 EC	0.0084 kg (AI)	16(5.3)	3(2.0) b	11(2.9) bcd	20(8.4) c	3(1.2) d	1(1.0) d	6(1.9) de	8(4.1) f
XenTari R/ MK-244 0.16 EC[3]	1.12 kg / 0.0084 kg (AI)	17(5.1)	10(3.5) ab	19(8.3) b	12(8.5) c	6(2.9) d	5(1.6) cd	16(5.8) cd	19(5.1) de
MK-244 0.16 EC R/ XenTari[4]	0.0084 kg (AI) / 1.12 kg	18(2.5)	2(1.2) b	2(1.2) d	19(3.7) c	11(3.7) cd	2(1.2) d	5(2.2) e	10(4.5) ef
XenTari[5]	1.12 kg	11(1.9)	8(3.7) ab	5(2.7) cd	11(3.7) b	26(1.9) b	12(2.5) c	19(3.3) c	42(7.5) c

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on transformed (ARCSIN[SQRT %]) data. Nontransformed means presented. Means within the same column followed by the same letter are not significantly different ($P > 0.05$, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

[3]Insecticides rotated (R/) every two applications starting with XenTari.

[4]Insecticides rotated (R/) every two applications starting with MK-244 (emamectin benzoate).

[5]Third application skipped. Applied water +X-77 only.

TABLE 2. EFFECTS OF INSECTICIDES ON MEAN PERCENT OF PLANTS WITH DAMAGE RATINGS ≤ 3 AND ≤ 4 IN MATURE HEAD CABBAGE AT CFREC-SANFORD, FL, 1992. DAMAGE RATED ON A SCALE OF 1-6.

		% Plants at Two Levels of Damage (SEM)[2]	
Treatment	Rate per Hectare[1]	DR ≤ 3	DR ≤ 4
Nontreated	—	0 (0.0) d	2 (2.0) e
DiPel 2X	1.12 kg	2 (2.0) d	16 (8.1) e
XenTari	1.12 kg	32 (6.6) b	72 (6.6) bc
MK-244 0.16 EC	0.0084 kg (AI)	62 (11.1) a	92 (5.8) a
XenTari R/ MK-244 0.16 EC[3]	1.12 kg 0.0084 kg (AI)	20 (8.9) bc	44 (14.7) d
MK-244 0.16 EC R/ XenTari[4]	0.0084 kg (AI) 1.12 kg	60 (7.1) a	86 (2.4) ab
XenTari[5]	1.12 kg	12 (4.9) c	56 (12.9) cd

[1]Rates expressed as formulated product unless otherwise indicated (AI).
[2]ANOVA performed on transformed (ARCSIN [SQRT %]) data. Nontransformed means presented. Means followed by the same letter within each column are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).
[3]Alternated every two applications starting with XenTari.
[4]Alternated every two applications starting with MK-244 (emamectin benzoate).
[5]Third application skipped. Applied only water and X-77.

ficacy between the two alternation patterns may have been the result of the significantly (P <0.05) higher reduction in the level of infestation early (7 April) and late (5 May) in the treatment that started with emamectin benzoate. This was supported further by the fact that the last two treatments in the alternation pattern that started with emamectin benzoate was XenTari, which was the weaker of the two insecticides when used alone. XenTari alone was the third most efficacious treatment based on marketability and resulted in consistently low infestation levels. Using XenTari when the infestation level exceeded 5% resulted in the elimination of only the third application. The percent infestation of diamondback moth did not differ significantly (P >0.05) on any date between the XenTari treatments. However, the percentage of harvested plants that were rated ≤ 3 was significantly lower in the treatment where the third application was skipped, suggesting that the third application was important in maintaining control. Disappointing results with DiPel 2X strongly suggested that this diamondback moth population was resistant to *Btk*, especially because *Btk*-resistance in diamondback moth has been documented in central Florida (Leibee & Savage 1992c, Shelton et al. 1993) and suspected in southern Florida (Jansson 1992).

Homestead

The numbers of diamondback moth were unusually high and peaked at 213.7 larvae and pupae per plant in the nontreated check on 16 March (Table 3). All treatments prevented the high numbers that occurred in the nontreated check. Weekly applications of emamectin benzoate and XenTari and the rotational treatment of these two insecticides were most efficacious at reducing populations. All remaining treatments

TABLE 3. EFFECTS OF INSECTICIDES ON NUMBER OF DIAMONDBACK MOTH LARVAE AND PUPAE PER PLANT AT TREC, HOMESTEAD, FL, 1992.

		Sample Date					
		27 Feb	2 Mar	9 Mar	16 Mar	23 Mar	30 Mar
Treatment	Rate per Hectare[1]	Total Diamondback Moth Larvae and Pupae per Plant (SEM)[2]					
Nontreatment	—	43.5(6.1) a	122.3(9.1) a	135.9(12.4) a	213.7(19.6) a	188.3(19.5) a	65.4(7.2) ab
AC 513,696 2X WP	1.12 kg	15.5(1.8) c-e	24.5(2.6) d	25.8(2.2) de	43.5(6.8) cd	59.6(7.9) b-d	45.3(6.2) bc
AC 513,696 48 LC	2.8 liters	20.2(3.3) cd	39.5(4.4) c	37.6(2.8) cd	56.3(6.1) bc	93.8(11.9) b	75.6(7.4) a
Larvo-Bt LC	0.3 liters	38.1(5.4) ab	61.1(5.0) b	54.2(5.0) bc	80.2(6.4) b	81.4(11.8) bc	51.1(8.9) a-c
Larvo-Bt LC +	0.3 liters						
Konsume	7.0 liters	23.9(3.9) bc	64.0(6.0) b	72.5(5.9) b	82.6(7.6) b	70.7(8.4) b-d	52.6(6.4) a-c
AC 513,696 48 LC +	2.8 liters						
Konsume	7.0 liters	12.9(2.9) c-e	21.8(1.8) d	20.8(2.0) d-g	36.2(5.3) c-e	54.3(6.7) cd	56.4(8.1) a-c
DiPel 2X	1.12 kg	8.5(1.3) c-e	19.3(2.2) d	12.9(1.7) e-g	24.3(2.7) c-e	44.3(5.0) d	38.6(5.2) c
MK-244 0.16 EC	0.0084 kg (AI)	0.6(0.3) e	0.1(0.0) e	0.1(0.1) g	0.9(0.3) e	0.8(0.3) e	1.0(0.2) d
XenTari	1.12 kg	2.5(0.5) e	1.3(0.3) e	0.7(0.2) fg	1.1(0.3) e	2.7(0.6) e	2.9(0.5) d
MK-244 0.16 EC R/	0.0084 kg (AI)						
XenTari	1.12 kg	7.3(1.3) de	0.6(0.2) e	0.2(0.1) fg	0.1(0.1) e	0.9(0.3) e	2.1(0.5) d
Mevinphos 4 EC +	0.56 kg (AI)						
Cutlass WP	2.24 kg	14.3(2.0) c-e	16.3(2.0) d	10.8(0.8) e-g	19.4(1.6) de	43.6(4.9) d	57.4(6.1) a-c
Cutlass WP	2.24 kg	19.3(3.8) cd	15.9(1.5) d	21.0(2.6) d-f	28.6(3.2) c-e	51.8(6.4) cd	38.0(4.4) c

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on 1n-transformed data. Nontransformed means presented. Means within the same column followed by the same letter are not significantly different ($P > 0.05$, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

were not very efficacious at reducing larval abundance on plants. Emamectin benzoate, XenTari, and their alternation were also the most efficacious at reducing damage to cabbage plants and produced significantly higher (P <0.05) percentages of marketable heads (Table 4). It is interesting to note that maintaining larvae and pupae to 1.0 or less per plant (emamectin benzoate used alone) resulted in only 74% marketability. The diamondback moth population at Homestead was probably *Btk*-resistant because *Bta* (XenTari) was much more effective at reducing numbers and damage than the *Btk*-based insecticides. The addition of mevinphos to Cutlass WP provided no significant (P >0.05) benefit over Cutlass WP alone. The addition of a feeding stimulant (Konsume) to AC 513,696 produced a significant (P<0.05) reduction in larval and pupal numbers over AC 513,696 alone on two dates (2 and 23 March). No significant (P >0.05) reduction of larval and pupal numbers occurred when a feeding stimulant (Konsume) was added to Larvo-Bt. No benefit was observed from the addition of the feeding stimulant to either insecticide based on damage rating and marketability.

Belle Glade

1992 Trial. The numbers of diamondback moth were low (Table 5). Feeding damage on the frame leaves was evident early in the trial. Feeding damage to the wrapper leaves was not evident until the last three weeks of the trial. Diamondback moth den-

TABLE 4. EFFECTS OF INSECTICIDES ON DAMAGE RATING (1-6) AND PERCENT MARKETABILITY OF CABBAGE AT TREC, HOMESTEAD, FL, 1992.

Treatment	Rate per Hectare[1]	Damage Index per Plant (SEM)[2]	% Marketable Heads (SEM)[2]
Nontreated	—	5.1(0.1) a	3(1.8) c
AC 513,696 2X WP	1.12 kg	4.6(0.1) ab	17(3.8) bc
AC 513,696 48 LC	2.8 liters	4.6(0.1) ab	16(3.7) bc
Larvo-Bt LC	0.3 liter	4.6(0.1) ab	17(3.8) bc
Larvo-Bt LC + Konsume	0.3 liter 7.0 liters	4.3(0.1) ab	21(4.2) bc
AC 513,696 48 LC + Konsume	2.8 liters 7.0 liters	4.5(0.1) b	23(4.3) b
DiPel 2X	1.12 kg	4.0(0.1) b	32(4.8) b
MK-244 0.16 EC	0.0084 kg (AI)	2.7(0.1) c	74(4.5) a
XenTari	1.12 kg	2.8(0.1) c	75(4.4) a
MK-244 0.16 EC R/ XenTari	0.0084 kg (AI) 1.12 kg	2.6(0.1) c	75(4.4) a
Mevinphos 4 EC + Cutlass WP	0.56 kg (AI) 2.24 kg	4.3(0.1) b	21(4.2) bc
Cutlass WP	2.24 kg	4.6(0.1) ab	22(4.2) b

[1]Rates expressed as formulated product unless otherwise indicated (AI).
[2]Data subjected to ANOVA. Percentage marketable data were transformed (ARCSIN [SQRT %]). Nontransformed means presented. Means within the same column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

TABLE 5. EFFECTS OF INSECTICIDES ON NUMBER OF DIAMONDBACK MOTH LARVAE AND PUPAE PER PLANT AT EREC, BELLE GLADE, FL, 1992.

		Sample Date				
		10 Mar	20 Mar	25 Mar	1 Apr	13 Apr
Treatment	Rate per Hectare[1]	Diamondback Moth Larvae and Pupae per Plant (SEM)[2]				
Nontreated	—	0.5(0.1) bc	0.3(0.1) bcd	0.9(0.2) a	2.4(0.4) a	2.1(0.6) a
Condor OF	2.34 liter	0.2(0.1) ef	0.2(0.1) cf	0.1(0.1) ef	0.3(0.1) hi	0.6(0.2) c-g
MVP	4.67 liter	0.8(0.1) a	0.3(0.1) cde	0.2(0.1) def	0.3(0.1) ghi	0.2(0.1) g
MK-244 0.16 EC R/	0.0084 kg (AI)					
XenTari	1.12 kg	0.2(0.1) fg	0.2(0.1) c-f	0.3(0.1) bcd	0.1(0.1) i	0.3(0.1) d-g
MK-244 0.16 EC	0.0084 kg (AI)	0.0(0.0) g	0.0(0.0) f	0.1(0.1) ef	0.2(0.1) i	0.3(0.1) efg
Cutlass WP	2.24 kg	0.6(0.1) ab	0.4(0.1) bc	0.5(0.1) bc	1.4(0.3) bc	0.8(0.2) bcd
XenTari	1.12 kg	0.1(0.1) fg	0.3(0.1) c-f	0.1(0.1) ef	0.3(0.1) ghi	0.5(0.2) d-g
Javelin WG	1.12 kg	0.2(0.1) def	0.3(0.1) b-e	0.3(0.1) cde	0.6(0.1) efg	0.4(0.1) d-g
DiPel 2X	1.12 kg	0.4(0.1) cde	0.6(0.1) ab	0.3(0.1) cde	1.0(0.2) cde	0.6(0.1) c-f
Biobit FC	3.5 liter	0.4(0.1) bcd	0.3(0.1) cde	0.3(0.1) cd	1.0(0.2) cd	0.6(0.2) c-f
Thiodicarb 3.2 AF	0.90 kg (AI)	0.2(0.1) efg	0.9(0.2) a	0.5(0.1) b	1.7(0.3) b	1.2(0.3) ab
Thiodicarb 3.2 AF +	0.90 kg (AI)					
DiPel 2X	1.12 kg	0.4(0.1) cde	0.2(0.1) c-f	0.3(0.1) cde	0.8(0.2) def	0.9(0.3) bcd
Esfenvalerate XL	0.055 kg (AI)	0.2(0.1) efg	0.1(0.1) ef	0.2(0.1) def	1.0(0.3) def	1.1(0.3) bc
Esfenvalerate XL +	0.055 kg (AI)					
DiPel 2X	1.12 kg	0.1(0.1) fg	0.2(0.1) c-f	0.1(0.0) f	0.6(0.1) fgh	0.2(0.1) fg
Mevinphos 4 EC	1.12 kg (AI)	0.1(0.1) fg	0.2(0.1) c-f	0.1(0.1) ef	0.1(0.1) i	0.7(0.2) b-e
Mevinphos 4 EC +	1.12 kg (AI)					
DiPel 2X	1.12 kg	0.2(0.1) efg	0.1(0.0) def	0.1(0.0) f	0.1(0.1) i	0.2(0.1) g

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on 1n (x + 1)-transformed data. Nontransformed means presented. Means within each column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100). NS = nonsignificant (P >0.05) data.

TABLE 5. CONT'D.

Treatment	Rate per Hectare[1]	Sample Date: 20 Apr	5 May	18 May	29 May
		Diamondback Moth Larvae and Pupae per Plant (SEM)[2]			
Nontreated	—	2.5(0.3) a	7.4(1.1) ab	3.2(0.5) c	0.7(0.2) ef
Condor OF	2.34 liter	1.1(0.2) d-h	2.1(0.8) ghi	3.0(0.9) de	1.9(0.6) cd
MVP	4.67 liter	1.3(0.2) b-f	6.7(2.0) cde	5.0(1.6) c	4.0(1.3) b
MK-244 0.16 EC R/	0.0084 kg (AI)				
XenTari	1.12 kg	0.9(0.2) h	1.7(0.5) hi	0.7(0.3) g	0.1(0.1) fg
MK-244 0.16 EC	0.0084 kg (AI)	0.8(0.2) h	1.2(0.5) i	0.5(0.2) g	0.4(0.2) g
Cutlass WP	2.24 kg	1.2(0.2) c-g	5.1(1.2) cde	4.9(1.5) c	1.0(0.3) de
XenTari	1.12 kg	1.0(0.2) gh	4.1(0.8) cde	2.2(0.7) de	1.1(0.3) de
Javelin WG	1.12 kg	1.2(0.3) e-h	3.1(0.5) def	2.2(0.5) de	0.7(0.3) ef
DiPel 2X	1.12 kg	1.0(0.2) e-h	3.8(0.8) de	3.8(1.0) cd	1.9(0.6) cd
Biobit FC	3.5 liter	1.6(0.3) b-e	8.2(2.2) bc	6.2(2.8) c	2.6(0.6) bc
Thiodicarb 3.2 AF	0.90 kg (AI)	1.8(0.3) bcd	11.1(2.2) a	9.2(2.2) b	1.0(0.3) de
Thiodicarb 3.2 AF +	0.90 kg (AI)				
DiPel 2X	1.12 kg	1.0(0.2) fgh	3.0(0.6) efg	1.8(0.5) ef	0.2(0.1) fg
Esfenvalerate XL	0.055 kg (AI)	1.8(0.2) ab	20.2(6.3) a	31.0(8.7) a	6.0(2.2) b
Esfenvalerate XL +	0.055 kg (AI)				
DiPel 2X	1.12 kg	1.2(0.2) d-h	5.3(1.0) cd	10.0(2.9) b	8.5(3.0) a
Mevinphos 4 EC	1.12 kg (AI)	0.9(0.2) gh	1.7(0.4) hi	0.8(0.3) fg	0.6(0.2) efg
Mevinphos 4 EC +	1.12 kg (AI)				
DiPel 2X	1.12 kg	1.8(0.3) bc	2.2(0.5) fgh	0.2(0.1) g	0.6(0.3) efg

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on 1n (x + 1)-transformed data. Nontransformed means presented. Means within each column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100). NS = nonsignificant (P >0.05) data.

sity did not average above one per plant until after 20 April. Therefore, data from the last three sampling dates provide the best indicator of efficacy.

Emamectin benzoate, emamectin benzoate alternated with XenTari, XenTari, mevinphos, and mevinphos in combination with DiPel 2X treatments produced the lowest numbers of diamondback moth (Table 5) and the highest marketability (Table 6). The addition of DiPel 2X to esfenvalerate and thiodicarb produced cleaner plants when compared with applications of the chemical insecticides alone. Mevinphos, alone or in combination with DiPel 2X, was as efficacious as the emamectin benzoate treatments at reducing numbers and increasing marketability. Thiodicarb alone and esfenvalerate, alone and in combination with DiPel 2X, did not provide significant control. Numbers of diamondback moth produced in these treatments were higher than in the nontreated check in late season, and also the highest numbers produced in the trial. Counts in the nontreated plots declined at the end of the trial, possibly be-

TABLE 6. EFFECTS OF INSECTICIDES ON PERCENT MARKETABILITY OF GREEN CABBAGE AT EREC, BELLE GLADE, FL, 1992.

		% Marketability (SEM)[2]	
Treatment	Rate per Hectare[1]	Wrapper Leaves Attached	Wrapper Leaves[3] Removed
Nontreated	—	8(4.8) d	20(4.1) de
Condor OF	2.34 liters	28(9.5) cd	40(13.5) de
MVP	4.67 liters	13(6.3) d	20(11.5) e
MK-244 0.16 EC	0.0084 kg (AI)		
R/ XenTari	1.12 kg	80(4.1) a	80(0.0) abc
MK-244 0.16 EC	0.0084 kg (AI)	75(5.0) a	85(11.9) a
Cutlass WP	2.24 kg	25(11.9) cd	35(6.5) de
XenTari	1.12 kg	33(13.8) cd	60(17.8) a-d
Javelin WG	1.12 kg	38(16.5) bcd	50(13.5) b-e
DiPel 2X	1.12 kg	25(8.7) cd	45(15.0) cde
Biobit FC	3.5 liters	18(6.3) d	33(8.5) de
Thiodicarb 3.2 AF	0.90 kg (AI)	8(4.8) d	15(2.9)e
Thiodicarb 3.2 AF	0.90 kg (AI)		
+ DiPel 2X	1.12 kg	53(14.9) abc	63(10.3) a-d
Esfenvalerate XL	0.055 kg (AI)	15(8.7) d	23(13.1) e
Esfenvalerate XL	0.055 kg (AI)		
+ DiPel 2X	1.12 kg	15(8.7) d	35(17.6) de
Mevinphos 4 EC	1.12 kg (AI)	58(7.5) abc	83(6.3) ab
Mevinphos 4 EC	1.12 kg (AI)		
+ DiPel 2X	1.12 kg	68(7.5) ab	88(6.3) a

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on transformed (ARCSIN [SQRT %]) data. Nontransformed means presented. Means within each column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

[3]Marketability rated again after removing no more than three wrapper leaves.

cause the plants were so badly damaged that they were no longer attractive to ovipositing females. Counts in the esfenvalerate and thiodicarb plots also declined at the end of the trial.

The marketability of the heads before trimming (Table 6) appeared to be the best criterion to separate treatments under these conditions of low insect pressure. Emamectin benzoate and emamectin benzoate alternated with XenTari provided the highest percentage of marketable heads. DiPel 2X in combination with thiodicarb provided slightly better control than did the Bt's alone before trimming. The low marketability ratings for the esfenvalerate plots, even in combination with of DiPel 2X, demonstrated the problems of season-long use of this pyrethroid.

The Bt-based insecticides performed poorly at this location. Few differences were observed among the *Btk*-based insecticides in their efficacy at reducing numbers of diamondback moth and levels of marketability. *Bta* was comparable to the *Btk*-based insecticides in this test. Conditions other than insecticide resistance, such as the lengthy intervals between the applications of the Bts, may have contributed, in part, to the poor performance of the Bt-insecticides.

1993 Trial. Diamondback moth pressure was much higher in this trial. Pesticides were applied more regularly except for a rainy period between 15 and 23 May. Populations increased greatly over this period (Table 7). The greater population pressure was probably responsible for the lack of differences in percent marketability among treatments before or after wrapper leaves were removed. Therefore, only one set of marketability values is presented in Table 8.

Emamectin benzoate provided excellent control and out-yielded all other treatments despite the 11-day break in treatments. Esfenvalerate provided good early season control; however, it allowed numbers to rise to damaging levels in late season, an observation also found in 1992. Surprisingly, methamidophos provided better control than the Bt-based insecticides throughout most of the trial and yielded over 70% marketable heads. Plants treated with DiPel 2X and XenTari supported low numbers of diamondback moth in early season, but were severely damaged in late season and had low marketability. XenTari provided better control than DiPel 2X in early season when applied at regular weekly intervals.

In conclusion, emamectin benzoate alone and rotated with *Bta* was very efficacious at controlling diamondback moth. A rotation strategy that started with emamectin benzoate was more efficacious than one that started with *Bta*. The lower efficacy of *Btk*-based insecticides compared with that of *Bta* suggested that these populations were developing resistance to *Btk*, but not to *Bta*, which concurs with Shelton et al. (1993).

Given the history of resistance development in the diamondback moth and the documentation of apparent low levels of resistance to *Bta* in Florida (Shelton et al. 1993), complete reliance on *Bta* for control could result in the rapid development of resistance to *Bta*. For these reasons, resistance management programs for *Bta* and other effective insecticides are needed to delay the onset of resistance. The use of rotation strategies, as demonstrated in this study, should help to delay the development of resistance to all insecticides used in a management program.

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TABLE 7. EFFECTS OF INSECTICIDES ON NUMBER OF DIAMONDBACK MOTH LARVAE AND PUPAE PER PLANT AT EREC, BELLE GLADE, FL, 1993.

Treatment	Rate per Hectare[1]	Sample Date: Apr 21	Apr 29	May 5	May 11
		Mean (SEM)[2] Diamondback Moth Larvae and Pupae per Plant			
Nontreated	—	1.7(0.2) ns	0.9(0.2) bc	0.8(0.2) ab	5.2(0.3) a
XenTari	0.56 kg	2.1(0.2)	1.5(0.3) a	1.1(0.2) a	1.6(0.2) c
DiPel 2X	1.12 kg	1.5(0.2)	1.0(0.2) ab	1.1(0.2) a	4.7(0.8) b
MK 244 0.16 EC	0.0084 kg (AI)	1.4(0.2)	0.4(0.1) d	0.5(0.1) c	0.1(0.1) e
Methamidophos 4 E	1.2 kg (AI)	1.6(0.2)	0.6(0.1) cd	0.6(0.1) bc	0.5(0.1) d
Esfenvalerate XL	0.055 kg (AI)	1.6(0.2)	0.5(0.1) d	0.4(0.1) c	1.6(0.2) c
		May 20	May 26	Jun 8	Jun 16
Nontreated	—	15.9(1.5) a	41.2(6.0) a	6.3(1.0) b	0.8(0.3) d
XenTari	0.56 kg	13.5(1.6) b	24.0(2.4) b	3.4(0.6) c	2.0(0.4) b
DiPel 2X	1.12 kg	15.6(2.3) b	29.1(3.7) ab	3.1(0.7) c	1.5(0.3) bc
MK 244 0.16 EC	0.0084 kg (AI)	1.2(0.3) d	3.7(1.1) d	0.8(0.3) d	0.7(0.2) d
Methamidophos 4 E	1.12 kg (AI)	7.1(0.9) c	8.8(1.3) c	0.5(0.2) d	1.1(0.3) cd
Esfenvalerate XL	0.055 kg (AI)	11.3(1.3) b	21.2(2.1) b	32.8(7.0) a	11.8(3.2) a

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on 1n (x + 1)-transformed data. Nontransformed means presented. Means within each column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

TABLE 8. EFFECTS OF INSECTICIDES ON PERCENT MARKETABILITY OF GREEN CABBAGE AT EREC, BELLE GLADE, FL, 1993.

Treatment	Rate per Hectare[1]	% Marketability (SEM)[2]
Nontreated	—	11(0.7) e
XenTari	0.56 kg	45(0.5) c
DiPel 2X	1.12 kg	23(0.9) d
MK 244 0.16 EC	0.0084 kg (AI)	98(0.2) a
Methamidophos 4 E	1.12 kg (AI)	73(0.5) b
Esfenvalerate XL	0.055 kg (AI)	15(0.4) de

[1]Rates expressed as formulated product unless otherwise indicated (AI).

[2]ANOVA performed on transformed (ARCSIN [SQRT %]) data. Nontransformed means presented. Means within each column followed by the same letter are not significantly different (P >0.05, Waller-Duncan *K*-ratio *t*-test, *K*-ratio = 100).

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