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Evaluating Biological Based Insecticides for Managing Diamondback Moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)

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Abstract: This study evaluated multiple applications of spinosad at three application rates, emamectin benzoate, *Beauveria bassiana*, azadirachtin and different *Bacillus thuringiensis* delta endotoxins for controlling diamondback moth populations, *Plutella xylostella* (L.), on three commercial collard (*Brassica oleracea* var. *acephala* de Condolle) farms in South Carolina. Spinosad and emamectin benzoate were the most efficacious at consistently providing excellent control of diamondback moth populations. Azadirachtin, *B. bassiana* and *B. thuringiensis* delta endotoxins may be useful early in collard growth to control low populations of diamondback moth, but were not consistently effective at maintaining diamondback moth populations below the economic threshold in the later stages of field trials, especially when diamondback moth larvae averaged more than three per plant.

Key words: *Bacillus thuringiensis*, collard, diamondback moth, insecticides, *Plutella xylostella*

INTRODUCTION

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is the most destructive insect pest of crucifers, particularly of the genus Brassica. The diamondback moth, first reported in the United States in 1854 (Fitch, 1855), is the most important pest of collard (*Brassica oleracea* var. *acephala* de Condolle) in Lexington County, South Carolina. Collard is the most economically important crucifer grown in South Carolina. In 1995, Lexington County contributed $2.1 million of South Carolina collard crop valued at $3.3 million (South Carolina Agricultural Statistics Service, 1996). Collard is produced for the fresh market in South Carolina, North Carolina, Virginia, Tennessee and Pennsylvania. Fresh-market collards have a high cosmetic standard and provide for one grade -U.S No. 1 (Adams, 1991). The standard requires that fresh-market collard must be insect-free. In the early 1990s, growers used *Bacillus thuringiensis* Berliner products, such as *B. thuringiensis* varieties *kurstaki* and *B. thuringiensis* subspecies *aizawai* to successfully control diamondback moth. However, since 1994, growers reported reduced efficacy of *B. thuringiensis* products used to control diamondback moth larvae, particularly in July through September, despite increasing the rate and frequency of applications.

The diamondback moth, because of selection pressure resulting from intense and prolonged pesticide exposure, has developed resistance to most synthetic chemical classes registered in the United States (Lasota *et al*., 1996). The diamondback moth has also developed resistance to

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B. thuringiensis (Tabashnik *et al*., 1990; Van Rie and Ferré, 2000). Because of insecticide resistance, it is necessary to develop chemicals with different modes of action, which do not select for cross-resistance to conventional insecticides. Insecticides that circumvent the mechanisms of resistance in diamondback moth are important for insect control and for managing insecticide resistance. The availability of insecticides with different modes of action for use in an insecticide rotation program should reduce selection pressure for resistance and prolong the usefulness of all products. In addition, the availability of a biological based insecticide that effectively controls diamondback moth and can be used just prior to harvest because of a short or no pre-harvest interval will be a useful tool for the grower. The objective of this research therefore was to evaluate the efficacy of biological based insecticides with different modes of action for controlling diamondback moth on collard in Lexington County, South Carolina (SC).

MATERIALS AND METHODS

Field trials were conducted at three collard farms in Lexington County, SC during 1997 and 1998. In all field trials, except Trial 2, four to six week old collard cultivar 'Top Bunch' seedlings were transplanted on plots 1.8 m in width and 4.5 m in length with spacing of 30 cm between plants in the row. Insecticide applications commenced when diamondback moth larvae were observed in the plots. In Trial 2, insecticides were evaluated for controlling a high population of diamondback moth in test plots set up within a seven week old collard field where the diamondback moth population was not controlled by repeated applications of *B. thuringiensis* products. The collard around the test plot was plowed under at the beginning of the experiment. Treatments were applied with a CO_2 pressurized backpack sprayer operating at 4.2 kg cm^{-2} and delivering 893 L ha^{-1} through a 3-nozzle boom equipped with TX 10 hollow cone tips.

In 1997, treatments evaluated were spinosad (Spintor® 2SC, Dow AgroSciences, Indianapolis, Indiana) at three application rates -0.028, 0.062 and 0.095 kg (AI)/ha and *B. thuringiensis* (Mattch® [A blend of Cry1A(c) and Cry1C derived delta endotoxins of *B. thuringiensis* encapsulated in killed *Pseudomonas fluorescens*] Mycogen Corporation, San Diego, California) at 0.588 kg (AI)/ha. Treatments were applied with a surfactant, Chem-Surf® (Chemorse Ltd., Des Moines, Iowa) at 0.5 ml L^{-1} of spray solution. There were also untreated check plots. Standard cultural practices were used for fertilization, weed control and irrigation (Adams, 1991; Zimet *et al*., 2000).

In 1998, the treatments were spinosad at three application rates -0.028, 0.062 and 0.095 kg (AI)/ha; emamectin benzoate (Proclaim, Novartis Crop Protection, Inc.; Greensboro, North Carolina) at 0.0084 kg (AI)/ha; azadirachtin (Neemix® 4.5, Thermo Trilogy Corporation, Columbia, Maryland) at 0.188 kg (AI)/ha; *Beauveria bassiana* (Mycotrol® ES, Mycotech Corp., Butte, Montana) at 0.317 kg (AI)/ha; *B. thuringiensis* subspecies *aizawai* (XenTari® WDG, Abbott Laboratories, North Chicago, Illinois) at 0.112 kg (AI)/ha; *B. thuringiensis* (Mattch®) at 0.588 kg (AI)/ha; *B. thuringiensis* variety *kurstaki* (MVP®II, Mycogen Corp., San Diego, California) at 1.001 kg (AI)/ha; *B. thuringiensis* [chimeric Cry1F delta endotoxin of *B. thuringiensis* encapsulated in killed *P. fluorescens*] (M-Press™, Mycogen Corp., San Diego, California) at 1.001 kg (AI)/ha; *B. thuringiensis* [Cry1C delta endotoxin of *B. thuringiensis* encapsulated in killed *P. fluorescens*] Mycogen Corp., San Diego, California) at 0.751 kg (AI)/ha; *B. thuringiensis* [Cry1A(c) delta endotoxin of *B. thuringiensis* encapsulated in killed *P. fluorescens*] Mycogen Corp., San Diego, California) at 1.001 kg (AI)/ha. Treatments were applied with a surfactant, Chem-Surf® (Chemorse Ltd., Des Moines, IA) at 0.5 ml L^{-1} of spray solution. There were also untreated check plots. Diamondback moth larvae and pupae were counted on five randomly selected plants per plot just before the first spray application and about five to seven days after application of treatments.

In 1997, five trials were conducted. Trial 1 was done at the Clinton Sease Farm where treatments were applied on 20, 25 June, 2, 12, 17, 28 July. Insect counts were taken on 20 (pretreatment), 25 June, 2, 12, 17, 28 July and 5 August. Trial 2 was done at the Walter Rawl and Sons Farm where treatments were applied on 9, 14, 22 August and insect counts were taken on 9 (pretreatment), 14, 22, 29 August. Trial 3 was done at the Clayton Rawl Farm. Treatments were applied on 29 August, 5, 12, 19 September and insect counts were taken on 29 August (pretreatment), 5, 12, 19, 26 September. Trials 4 and 5 were done at the Clinton Sease and the Walter Rawl and Sons Farms, respectively. On both farms, treatments were applied on 5, 12, 19, 26 September and 3 October and insect counts were done on 5 (pretreatment), 12, 19, 26 September and 3, 10 October.

In 1998, three trials were conducted. In Trial 6, done at the Clayton Rawl Farm, treatments were applied on 16, 23, 29 July and 5, 12 August. Insect counts were taken on 16 (pretreatment), 23, 29 July and 5, 12, 19 August. Trial 7 was done at the Clinton Sease Farm where treatments were applied on 29 July, 5, 12, 19, 26 August. Insect counts were taken on 29 July (pretreatment), 5, 12, 19, 26 August and 2 September. Trial 8 was conducted at the Walter Rawl and Sons Farm. Treatments were applied on 12, 19, 26 August and 2, 7 September. Insect counts were taken on 12 (pretreatment), 19, 26 August, 2, 7, 14 September.

All trials were arranged in a randomized complete block design with four replicates. Treatments were considered fixed effects and replicates random effects for the analysis of variance. Data analysis was performed with the ANOVA procedure of the Agriculture Research Manager, version 6.0 software package (Gylling Data Management Inc., Brookings, South Dakota, 1999). Tukeys' Honestly Significant Difference (HSD) procedure was used to compare treatments when the F-test for treatments was significant (p = 0.05).

RESULTS

1997

Trial 1

The diamondback moth population increased as the season progressed, from 0.2 larva to 2.1 larvae and pupae per plant in the untreated check plots (Table 1). The economic threshold of one larva per plant was reached in the untreated check just over three weeks after the first use of insecticides. Spinosad, at all application rates and a blend of Cry1A(c) and Cry1C derived delta endotoxins effectively kept the diamondback moth population below the economic threshold and resulted in significantly better control than the untreated check at harvest.

Trial 2

At the commencement of the trial, there was an average of 7.6 diamondback moth larvae and pupae per plant across all plots (pretreatment). In the untreated check plots, the diamondback moth population increased from 6 to 35.4 larvae and pupae per plant (Table 2). Five days after the first treatment, all the spinosad treatments resulted in significantly lower diamondback moth population

Table 1: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Clinton Sease Farm, Lexington County, South Carolina, 1997

	Rate ha^{-1}							
Insecticide	ai (kg)	20 Jun	25 Jun	2 Jul	12 Jul	17 Jul	28 Jul	5 Aug
Spintor® 2SC	0.028	0.2a	0.0a	0.0a	0.0b	0.0b	0.4b	0.0b
Spintor® 2SC	0.062	0.0a	0.0a	0.0a	0.0b	0.0b	0.1b	0.0b
Spintor® 2SC	0.095	0.1a	0.0a	0.0a	0.0b	0.0b	0.1b	0.0b
Mattch®	0.588	0.2a	0.1a	0.2a	0.3ab	0.7ab	0.8b	0.4b
Untreated check		0.2a	0.4a	0.7a	1.0a	1.2a	2.1a	1.8a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Table 2: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Walter Rawl and Sons Farm, Lexington County, South Carolina, 1997

Insecticide	Rate ha^{-1} ai (kg)	9 Aug	14 Aug	22 Aug	29 Aug
Spintor® 2SC	0.028	6.7a	3.9c	5.0b	0.0a
Spintor® 2SC	0.062	8.4a	1.0c	0.2b	0.0a
Spintor® 2SC	0.095	6.3a	0.3c	0.0b	0.0a
Mattch®	0.588	10.9a	19.5a	21.2a	0.0a
Untreated check		6.0a	16.9ab	35.4a	0.0a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Table 3: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Clayton Rawl Farm, Lexington County, South Carolina, 1997

Insecticide	Rate ha^{-1} ai (kg)	29 Aug	5 Sept	12 Sept	19 Sept	26 Sept
Spintor® 2SC	0.028	0.0a	0.2b	0.0b	0.1b	0.2b
Spintor® 2SC	0.062	0.1a	0.0b	0.1b	0.0b	0.0b
Spintor® 2SC	0.095	0.0a	0.0b	0.1b	0.0b	0.0b
Mattch®	0.588	0.0a	1.0a	1.3a	0.7ab	2.0a
Untreated check		0.2a	1.0a	1.5a	1.1a	2.1a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

compared to the untreated check. The highest application rate of spinosad, after one application, effectively reduced the diamondback moth population below the economic threshold. The second highest application rate of spinosad required two applications to reduce the diamondback moth population below the economic threshold. The lowest application rate of spinosad, after two applications, was ineffective at reducing the diamondback moth population below the economic threshold. The blend of Cry1A(c) and Cry1C derived delta endotoxins was ineffective at controlling the diamondback moth population. One week after the third insecticide treatment, there was no larva or pupa in the spinosad treated plots where the plants were in a healthy condition, nor in the untreated check and the blend of Cry1A(c) and Cry1C treated plots where all the plants were defoliated.

Trial 3

The diamondback moth population increased from 0.2 larva per plant, at pretreatment, to 2.1 larvae and pupae per plant in the last week of the trial in the untreated check (Table 3). The economic threshold was reached in the untreated check one week after the first treatment. Spinosad treatments provided effective control and resulted in significantly lower diamondback moth population than the untreated check throughout the trial. The blend of Cry1A(c) and Cry1C derived delta endotoxins treatment resulted in diamondback moth larvae and pupae that were not significantly lower in number than the untreated check and, except for the third week of the experiment, was not effective in consistently keeping the diamondback moth population below the economic threshold.

Trial 4

The diamondback moth population in the untreated check was relatively low during this trial. There was no significant difference in the number of diamondback moth larvae and pupae between treated and untreated plots until the final week of the experiment when the economic threshold was reached in the untreated check plots (Table 4). At the conclusion of the trial, spinosad and the blend of Cry1A(c) and Cry1C derived delta endotoxins treatments resulted in significantly lower numbers of diamondback moth larvae and pupae compared to the untreated check and kept the pest numbers below the economic threshold.

Table 4: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Clinton Sease Farm, Lexington County, South Carolina, 1997

	Rate ha^{-1}						
Insecticide	ai (kg)	5 Sept	12 Sept	19 Sept	26 Sept	3 Oct	10 Oct
Spintor® 2SC	0.028	0.0a	0.0a	0.2a	0.1a	0.7a	0.1b
Spintor® 2SC	0.062	0.0a	0.0a	0.2a	0.1a	0.5a	0.1b
Spintor® 2SC	0.095	0.0a	0.0a	0.2a	0.0a	0.7a	0.0b
Mattch®	0.588	0.0a	0.0a	0.5a	0.2a	0.8a	0.4b
Untreated check		0.0a	0.0a	0.4a	0.5a	0.7a	1.1a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Table 5: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Walter Rawl and Sons Farm, Lexington County, South Carolina, 1997

	Rate ha^{-1}						
Insecticide	ai (kg)	5 Sept	12 Sept	19 Sept	26 Sept	3 Oct	10 Oct
Spintor® 2SC	0.028	0.4a	0.1b	0.2a	0.0b	0.7a	0.9c
Spintor® 2SC	0.062	0.5a	0.0b	0.0a	0.0b	0.1a	0.3c
Spintor® 2SC	0.095	1.7a	0.0b	0.1a	0.0b	0.4a	0.1c
Mattch®	0.588	1.1a	0.7ab	0.5a	0.2ab	2.6a	8.6b
Untreated check		0.5a	1.1a	0.3a	0.6a	1.8a	16.3a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Trial 5

The number of diamondback moth larvae and pupae in the untreated check plots increased from 0.5 at the beginning of the trial to 16.3 per plant at the final insect count (Table 5). Spinosad was effective at keeping the diamondback moth population level below the economic threshold. The number of diamondback moth larvae and pupae were significantly lower in the spinosad treatments compared to the untreated check on the final insect count. The blend of Cry1A(c) and Cry1C derived delta endotoxins was not effective at keeping the diamondback moth population below the economic threshold during the last two weeks of the trial. At the final insect count, although the blend of Cry1A(c) and Cry1C derived delta endotoxins treatment resulted in significantly lower number of diamondback moth larvae and pupae than the untreated check, it still resulted in significant defoliation of most plants in the blend of Cry1A(c) and Cry1C treated plots.

1998

Trial 6

The diamondback moth larval and pupal populations in the untreated check plots increased from 0.3 larva and pupa per plant to 14.9 at the end of the trial (Table 6). Spinosad and emamectin benzoate treatments resulted in effective diamondback moth control throughout the trial. Cry1C and *B. bassiana* kept the diamondback moth larval and pupal numbers below the economic threshold until the diamondback moth population in untreated check plots exceeded 4.3 larvae and pupae per plant. None of the other treatments was effective in keeping the diamondback moth population below the economic threshold from the third through the final week of the trial.

Trial 7

Diamondback moth larval and pupal numbers in the untreated check were above the economic threshold two weeks after the experiment began and was over 8 larvae and pupae per plant for the remainder of the experiment (Table 7). By the third week of the trial, all treatments, except spinosad and emamectin benzoate, resulted in diamondback moth populations that were above the economic threshold.

Table 6: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Clayton Rawl Farm, Lexington County, South Carolina, 1998

	Rate ha^{-1}						
Insecticide	ai (kg)	16 Jul	23 Jul	29 Jul	5 Aug	12 Aug	19 Aug
Spintor® 2SC	0.028	0.2ab	0.1c	0.1cd	0.0d	0.0c	0.0c
Spintor® 2SC	0.062	0.2ab	0.1c	0.1cd	0.0d	0.0c	0.0c
Spintor® 2SC	0.095	0.3ab	0.1c	0.0d	0.0d	0.0c	0.4c
Proclaim 5 SG	0.0084	0.5a	0.1c	0.1cd	0.0d	0.0c	0.0c
Neemix® 4.5	0.188	0.2ab	0.8ab	0.8a-d	1.2bcd	3.4bc	3.8bc
Mycotrol® ES	0.317	0.2ab	0.4abc	0.5a-d	0.1bcd	4.7bc	3.8bc
Xentari® WDG	0.112	0.3ab	0.8ab	0.9abc	1.2bcd	4.0bc	4.5bc
Mattch®	0.588	0.1ab	0.5abc	0.8a-d	1.3bcd	7.5abc	10.0abc
MVP®II	1.001	0.4ab	1.0a	1.2a	2.7ab	10.7ab	9.8abc
M-Press™	1.001	0.5a	0.9ab	1.1ab	2.1bc	14.9a	16.7a
Cry1C	0.751	0.1ab	0.5abc	0.3bcd	0.8cd	6.6abc	6.3abc
Cry1A(c)	1.001	0.1b	0.3bc	1.0ab	1.7bcd	10.3ab	9.5abc
Untreated check		0.3ab	1.0a	1.2a	4.3a	14.4a	14.9ab

Means within a column followed by the same letter do no significantly differ (p = 0.05, Tukey's HSD)

Table 7: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Clinton Sease Farm, Lexington County, South Carolina, 1998

	Rate ha^{-1}						
Insecticide	ai (kg)	29 Jul	5 Aug	12 Aug	19 Aug	26 Aug	2 Sept
Spintor® 2SC	0.028	0.9a	0.0b	0.2cd	0.0c	0.0d	0.0d
Spintor® 2SC	0.062	1.5a	0.0b	0.2cd	0.0c	0.0d	0.1d
Spintor® 2SC	0.095	1.0a	0.0b	0.0d	0.0c	0.0d	0.0d
Proclaim 5 SG	0.0084	0.9a	0.0b	0.1cd	0.0c	0.0d	0.0d
Neemix® 4.5	0.118	0.6a	0.3ab	0.9bcd	2.9bc	5.3abc	5.7abc
Mycotrol® ES	0.317	0.9a	0.5ab	1.2a-d	1.5bc	2.8cd	2.7cd
Xentari® WDG	0.112	0.9a	0.4ab	1.6a-d	6.2ab	5.4abc	6.0abc
Mattch®	0.588	1.0a	0.4ab	1.2a-d	3.7abc	3.6bc	3.2bcd
MVP®II	1.001	0.8a	0.3ab	1.4a-d	6.3ab	8.0ab	8.2ab
M-Press™	1.001	0.6a	0.2ab	3.0ab	5.4abc	6.9abc	7.4abc
Cry1C	0.751	0.6a	0.3ab	1.3a-d	3.0bc	5.2abc	4.8a-d
Cry1A(c)	1.001	1.0a	0.6a	2.2abc	6.7ab	4.7a-d	5.0a-d
Untreated check		0.8a	0.4ab	3.1a	8.6a	9.0a	8.8a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Table 8: The mean number of diamondback moth larvae and pupae per plant treated with insecticides (shaded area indicates where the economic threshold was reached or exceeded), Walter Rawl and Sons Farm, Lexington County, South Carolina, 1998

	Rate ha^{-1}						
Insecticide	ai (kg)	12 Aug	19 Aug	26 Aug	2 Sept	7 Sept	14 Sept
Spintor® 2SC	0.028	0.2ab	0.1c	0.0c	0.1c	0.0e	0.0e
Spintor® 2SC	0.062	0.5ab	0.0c	0.0c	0.1c	0.0e	0.1e
Spintor® 2SC	0.095	0.3ab	0.0c	0.0c	0.0c	0.0e	0.1e
Proclaim 5 SG	0.0084	0.4ab	0.0c	0.0c	0.1c	0.0e	0.0e
Neemix® 4.5	0.188	0.5ab	0.7ab	1.3ab	2.1d	3.4cd	5.3cd
Mycotrol® ES	0.317	0.3ab	0.2bc	1.0b	1.6b	2.3d	4.2d
Xentari® WDG	0.112	0.4ab	0.7ab	1.2ab	1.4b	3.2cd	4.4d
Mattch®	0.588	0.1b	0.3bc	0.9bc	1.3b	2.5d	4.2d
MVP®II	1.001	0.2ab	0.7 ab	1.6ab	2.2b	4.9bc	8.0bc
M-Press™	1.001	0.3ab	0.7ab	1.2ab	2.2b	5.7b	10.3ab
Cry1C	0.751	0.3ab	0.4bc	0.8bc	1.3b	3.0d	5.7cd
Cry1A(c)	1.001	0.7a	0.7ab	1.3ab	1.7b	2.9d	6.4cd
Untreated check		0.6ab	1.0a	2.1a	3.4a	7.8a	12.0a

Means within a column followed by the same letter do not significantly differ (p = 0.05, Tukey's HSD)

Trial 8

Diamondback moth larval and pupal numbers increased from 0.6 at the beginning of the trial and peaked at 12 larvae and pupae per plant at the end of the trial (Table 8). Spinosad and emamectin benzoate treatments effectively kept diamondback moth larval and pupal numbers well below the economic threshold during the trial. All other treatments were ineffective at consistently keeping the diamondback moth larval and pupal numbers below the economic threshold, especially during the last three weeks of the trial.

DISCUSSION

Multiple applications of spinosad, at all application rates, except in Trial 2 and emamectin benzoate effectively controlled diamondback moth populations throughout the growing season. An application rate of 0.095 kg (AI) per hectare of spinosad controlled an unusually high population of diamondback moth (Trial 2) in a commercial collard field where *B. thuringiensis* was ineffective. Diamondback moth collected from that field was subsequently determined to be resistant to *B. thuringiensis* (Khan, 1998). Spinosad was effective, especially at the higher rates, most probably because its mode of action was different from other classes of insecticides, including *B. thuringiensis*. Spinosyn A and spinosyn D, the active ingredients of spinosad causes widespread excitation of the nervous system at a novel target site, the nicotinic acetylcholine receptors at the postsynaptic cell (Salgado, 1997). The diamond back moth populations were never previously exposed to spinosad. Emamectin benzoate was as effective as spinosad in controlling diamondback moth populations, probably also because of its unique mode of action. Emamectin benzoate, an avermectin, disrupts the inhibitory glutamate receptors of insects (Salgado, 1997). Field studies done in Florida (Leibee *et al*., 1995; Leibee, 1997) and laboratory studies (Lasota *et al*., 1996) also showed that emamectin benzoate provided excellent control of diamondback moth larvae, including populations resistant to several classes of synthetic insecticides.

Beauveria bassiana and azadirachtin provided effective diamondback moth control early in the trials when the pest population was low, but were inconsistent at keeping populations below the economic threshold later in the trials. *Beauveria bassiana* resulted in the brown discoloration of collard leaves that would render the product unmarketable for the fresh market. This problem, probably caused by the carrier, would have to be corrected before *B. bassiana* could be considered for use in commercial collard production.

Bacillus thuringiensis delta endotoxins provided effective diamondback moth control early in the season, when the diamondback moth population was relatively low-less than one larva and pupa per plant. However, *B. thuringiensis* was not effective in providing acceptable levels of diamondback moth control when the pest population was much higher than the economic threshold. Similar results were obtained with diamondback moth on cabbage in Florida. Leibee (1997) suggested that the frequency of *B. thuringiensis* resistant diamondback moth larvae in early infestation was low; hence effective control was provided with *B. thuringiensis*. However, as the season progressed, the frequency of resistant individuals increased, resulting in a loss of control with *B. thuringiensis*. It is possible that similar susceptible and resistant populations immigrate to Florida and South Carolina and therefore respond similarly to *B. thuringiensis*.

The diamondback moth has become the key pest of crucifers worldwide because of its ability to evolve resistance to classes of insecticides widely used against it over time. As such, management of diamondback moth should optimize the use of all effective methods available for control. Biological and chemical controls are often incompatible because chemical pesticides can drastically reduce natural enemy populations, especially when pests evolve resistance to the pesticides used while natural enemies usually do not (Ticehurst *et al*., 1982; Hassel, 1984). Therefore, insecticides, particularly broad spectrum insecticides, should be the last line of defense and should be used judiciously.

The biological based *B. bassiana*, azadirachtin and *B. thuringiensis* insecticides have the potential to enhance the activities of parasites and predators of the diamondback moth. It may be possible to use these biological based insecticides in a management system that includes scouting to provide effective diamondback moth control early in collard growth when the pest population is relatively low. Spinosad and emamectin benzoate, considered as natural products (Laemmlen, 1998), are fermentation products derived from the soil bacteria *Saccharopolyspora spinosa* and *Streptomyces avermitilis*, respectively. Spinosad, considered safer to humans, beneficials and the environment, has a preharvest interval of 1 day whereas emamectin benzoate has a preharvest interval of 7 days (Webb, 2004). Spinosad and emamectin benzoate should be used just before the economic threshold is reached, probably at about 0.8 larva and pupa per plant. The availability of spinosad and emamectin benzoate with their novel and different modes of action can be a useful tool in an insecticide rotation program for controlling diamondback moth and managing insecticide resistance, particularly since there is no cross-resistance of the products (Thompson *et al*., 1997; Zhao *et al*., 2002). However, continuous use of spinosad and emamectin benzoate should be avoided because of reports that the diamondback moth, which has the propensity to quickly develop resistance to insecticides, quickly developed resistance to spinosad in Hawaii (Zhao *et al*., 2002), Georgia (Sparks, 2002) and California (Shelton *et al*., 2000).

In Hawaii, resistance developed to spinosad after 30 months of commercial use since the DBM populations were exposed year round to the insecticide. Emamectin benzoate and indoxacarb insecticides were made available to growers and spinosad was voluntarily removed as a management tool for DBM (Mau and Gusukuma-Minuto, 2004). Fortunately for Hawaiian growers, the DBM populations, after six to eight months of non-exposure to spinosad, in some areas quickly reverted to near susceptible levels where spinosad was once again effective and was used in rotation with emamectin benzoate and indoxacarb. The populations remained sensitive to emamectin benzoate (Zhao *et al*., 2006). In Georgia, DBM resistance to spinosad was growing because of improper use resulting in Dow AgroSciences voluntarily cancelling the use of spinosad for use on collard greens and other leafy Brassica crops (Virginia Tech Pesticide Programs, 2006). It is expected that the DBM population in Georgia will revert to susceptibility after a period of non-exposure to spinosad.

Effective management for the DBM should include sanitation to destroy and bury crop residue to deprive the insect of a food source, use older effective insecticides on transplants, use transplants that are insect free, scout and use a threshold before applying insecticides, use the more effective *B. thuringiensis* early in the season when DBM populations tend to be lower, alternate the newer classes of effective insecticides for the more damaging populations and employ a host free period to reduce selection pressure especially when conditions are most favorable for DBM development (Riley and Sparks, 2006).

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