Diamondback Moth Resistance to Synthetic Pyrethroids: How to Overcome the Problem with Deltamethrin

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Abstract

To improve the efficacy of one of the synthetic pyrethroids, deltamethrin, against insecticide-resistant strains of diamondback moth, *Plutella xylostella* (L), a series of experiments involving a mixture of deltamethrin and *Bacillus thuringiensis* were conducted in the Philippines and Taiwan. Deltamethrin tank-mixed with *B. thuringiensis* (16,000 IU/mg) and sprayed at the rate of 20 g AI + 1000 g product/ha, respectively, gave satisfactory control of the insect and increased marketable yields of cabbage. In order to achieve best results, it is essential to apply this mixture late in the afternoon. The applicaion should commence as early as possible during the growing season even if the diamondback moth population is low. The *B. thuringiensis* formulation should be as fresh as possible and applications be made only on the upper part of the productive leaves. This mixture also gives satisfactory control of certain other common crucifer pests, such as aphids, cabbage worm, cutworms, and tomato fruitworm.

Introduction

Diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), is a cosmopolitan species of considerable importance as a pest on several cruciferous plants. It occurs in the tropical, subtropical, and temperate regions (CIE 1967).

The damage caused by this pest in cabbage is quite characteristic: the leaves show irregular white windows rarely larger than 0.5 cm diameter which later break down to form holes. The main vein is untouched but the remainder of the leaf has a frayed appearance. The unexpanded leaves of young plants are also eaten; thus good protection at an early stage, especially within one month after transplanting, is quite important, or yield loss will be serious. The newly hatched caterpillars initially mine within the leaves for a few days. The full grown caterpillars can be distinguished by the absence of longitudinal stripes on its body, and by its yellowish head with dark spots. The light green body shows sparsely distributed, black hair bearing tubercles. The larvae grow up to 9 mm long and react violently when disturbed, by looping themselves or suspending themselves with a silken thread to swing down to the ground or into the air from the leaf edge. A few minutes later, they will crawl back to the leaves along the same silken thread or from the basal part of the plant.

The control of this pest has depended primarily and extensively on the use of insecticides for a long time. Excessive use of insecticides has led to the resistance of DBM to most commercial insecticides in most countries in southeast Asia.

Studies of DBM's resistance to insecticides have indicated the presence of three possible mechanisms: (1) reduced chemical penetration (2) enhanced activity of detoxification enzymes, (3) lower sensitivity of the target site.

Deltamethrin is the first industrially synthesized, non-composite pyrethroid with single d-cis isomer. It is extremely toxic to most insect pests, especially those belonging to orders *Lepidoptera*, Diptera, and Coleoptera, while at the same time relatively safe to mammals. It also possesses repellency properties which result in changes in behavioral traits affecting dispersal, and inducing reduced feeding and hyperactivity in larva, nymph, and adult.

At Roussel Uclaf, we have geared our research to overcome DBM resistance to deltamethrin. In this connection we tried different strains of *Bacillus thuringiensis* Berliner (*Bt*) mixed with different rates of deltamethrin to evaluate the effectiveness of the mixtures for the control of DBM and other insect pests which infest cabbage at the same time as DBM and to justify the performance of the mixtures in terms of yield protection in the area of high incidence of DBM resistance. These investigations were carried out in the Philippines (Laguna, Baquio) and Taiwan (Kaohsiung) from 1981 to 1984. The salient features of our results are described below.

Experimental

The *Bt* used in our field experiments were Dipel (Abbott Laboratories) and Thuricide (Sandoz). These products were spores and crystalline endo-and exo-toxin serotype H-3a3b, 16,000 IU/mg. They are effective against lepidopterous larvae. Deltamethrin 2.8EC used was from our stock. Tank mixtures of deltamethrin and *Bt* were used at various times to control DBM on cabbage both in the Philippines and Taiwan.

All insecticide evaluation work was done in the field with either Chinese cabbage or common cabbage. Suitable pre-planting and post-planting cultural practices such as land preparation, basal and top-dressed fertilizer applications, irrigation, weed control, and disease control were adopted to provide high yields. Field plot evaluation was carried out on 15 sq m plots in Taiwan and 5 sq m plots in the Philippines. Each insecticide treatment was applied to four replicated plots in a randomized complete block design. Insecticides were applied with 10-liter air pressure sprayers. Locally manufactured cone-type nozzles were used. For efficacy evaluation 10 to 16 plants, selected at various intervals during the season. The percent control was determined by the following equation:

$$\% \text{ control} = \left(1 - \frac{Ta \times Ub}{Tb \times Ua}\right) \times 100.$$

Where: Ta = number of larvae in the treated plot after treatment, Tb = number of larvae in the treated plot before treatment, Ua = number of larvae in the untreated plot after treatment, Ub = number of larvae in the untreated plot before treatment.

The % control is calculated for every assessment interval.

At harvest the marketable and unmarketable heads were separated and weighed to determine the yield. Insecticide efficacy and yield data were analyzed by Duncan's multiple range test.

Results and Discussion

In order to avoid the development of cross resistance in DBM, in many Asian countries chemical compounds are applied alternately with *Bt*. In our experiments, we found that deltamethrin tank-mixed with *Bt* sprayed at weekly interval was better than

the alternate use, or individual use, for DBM control (Table 1). Similar results were also obtained in Taiwan (Table 2). DBM strains in Taiwan as well as in the Philippines have developed resistance to scores of commonly used insecticides including synthetic pyrethroids. These results clearly demonstrated that mixtures of *Bt* and deltamethrin can control insecticide-resistant DBM populations.

Table 1. Evaluation of deltamethrin (DM) and *Bacillus thuringiensis* (*Bt*) for DBM control on Chinese cabbage

Insecticides (DM 12.5 g AI and *Bt* 500 g Product/ha)	No. of DBM larvae/16 plants at[a]						mean
	2nd application		3rd application		4th application		
	1DAA	6DAA	1DAA	6DAA	1DAA	6DAA	
(*Bt* × 2 + DM × 1) × 2[b]	6.8a	100.6b	20.2a	83.6b	59.2a	85.2a	59.2b
(DM + B) × 5[c]	2.6a	4.4a	5.8a	19.6a	22.0a	52.2a	17.7a
Bt × 5[d]	8.2a	59.2b	66.0b	63.6b	38.8a	77.0a	52.1b
DM × 5[e]	7.6b	8.0a	25.2a	111.4b	109.8b	206.0b	78.0bc
Control	53.0b	115.4b	162.4b	107.2b	95.2b	115.0b	114.6c

[a] Mean of four replicates, means in each vertical column followed by the same latter are not significantly different at 5% level according to Duncan's multiple range test. 1st application started at seven days after transplanting, the interval between two applications was seven days. DAA: days after application. [b] Two times *Bt* + once DM followed by two times *Bt* + once DM. [c] DM + *Bt* five times. [d] Only *Bt* five times. [e] Only DM five times. *Bt* was serotype III 16,000,000 IU/g, DM was 2.5EC. Test location: Calauan, Laguna. Philippines.

Table 2. Evaluation of deltamethrin (DM) and *Bacillus thuringiensis* (*Bt*) for the control of DBM on common cabbage[a-f]

Insecticides	No. DBM larvae + pupae/10 plants on				Yield t/ha
	2 Feb	17 Feb	23 Feb	4 Mar	
Bactospeine	15.5a	13.3abcd	39.3bcd	39.5c	62.7a
Bt SIII	14.0ab	13.8abcd	43.5bc	49.5bc	61.9a
DM + *Bt* SIII	7.8bc	5.5cde	16.8e	19.3c	62.6a
DM	8.0bc	5.0de	20.8de	40.0c	60.8a
Control	16.8a	18.5ab	55.5ab	75.8ab	52.8b

[a] Cultivar: K Y Cross. [b] Transplanting date: 14 January 1983. [c] DM 2.5EC 25 g AI and Bactospeine or *Bt* SIII at 500 g product/ha. Insecticides applied: 28 Jan, 4, 11, 18, 25 Feb, 4, 11, and 18 Mar 1983. [d] Harvest date: 4 April 1983. [e] Data are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [f] Plot size: 15 sq m Test location: AVRDC, Taiwan, ROC.

How does deltamethrin overcome resistance?

The results described above show that deltamethrin can overcome insecticide resistance in DBM. However, the proper technique of applying the mixture of deltamethrin and *Bt* described above needs to be observed rigorously. A correct application of this mixture is the key to securing the necessary protection and maximizing the yield. In the following sections, we put forward what we have found and propose how to use this mixture properly and effectively.

A. Spray the mixture in the late afternoon and use fresh *Bt* Most of the *Bt* products currently sold in the market are live spores and crystalline delta-endotoxin. Therefore, the efficacy of *Bt* is very much influenced by the storage environment of

the product, and the environment after it has been sprayed on to the crop. For instance, *Bt* applied on slide or membrance filter, after 1, 2, 10 minutes loses 12%, 50% and 99.9% activity respectively. Under natural sunlight, after 30 and 60 minutes, it will lose 50% and 80% activity, respectively (Cantwell 1967, Cantwell et al 1966, Cantwell and Franklin 1966). To ensure that *Bt* is as fresh as possible it should be bought only when needed. Also, once opened, the content of the package or container should all be used during one application. It is advisable to apply the deltamethrin + *Bt* mixture during the late afternoon. This reduces the exposure of the spray to sunlight.

B. Start to application as early as possible during the season Besides its lethal action, deltamethrin also acts as a repellent which causes insects to flee from treated plant. Deltamethrin also has anti-feeding or hyperactivity effects which protect the plant from damage even when the insect pest is present. We have found that 50% of the second generation DBM larvae on the deltamethrin-treated crops took 119 to 145 minutes to re-start feeding on the treated plants. However, the feeding inhibition period of the third generation larvae was only 50 minutes. The adaptation of DBM to this compound which possesses such a repellent effect was very rapid; the feeding inhibition period was about two to five times shorter from one generation to the next (Figure 1). We also found that DBM adults were repelled from landing on the deltamethrin-treated (12.5 g AI/ha) plants. On average only five adults landing per 30 plants in the first six hours after the application in the treated plots. However, in the untreated plots, there were 40 to 45 adults continuously landing on 30 plants at any moment. Therefore, it is necessary to apply the mixture of deltamethrin + *Bt* as early as possible during the planting season, even if the population of DBM is lower than the threshold level (Figure 2).

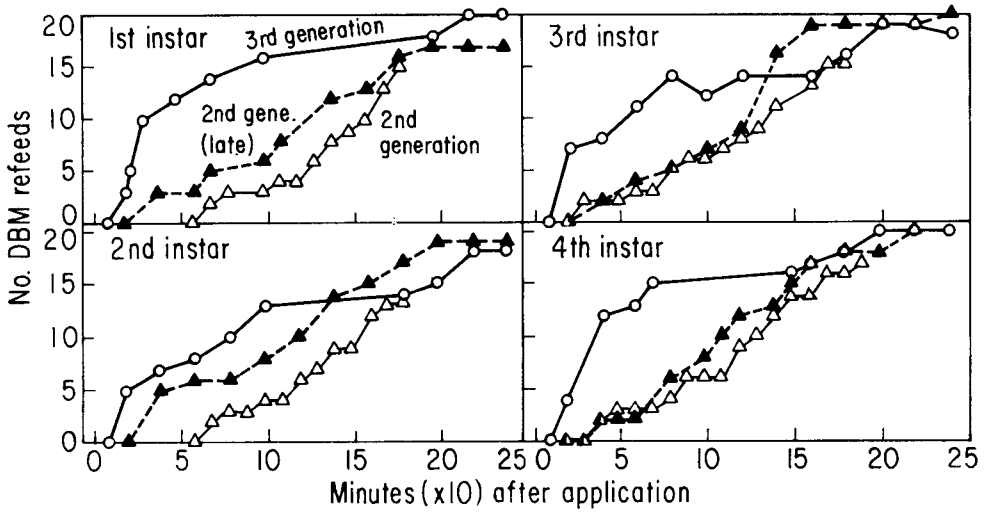

Figure 1. Feeding inhibition period of different larval instars in response to application of deltamethrin at 12.5 g AI/ha

C. Apply the mixture to the upper and productive part of the plant Merely observing the number of DBM larvae in a deltamethrin-treated plot may mislead the observer to conclude that it is not very effective after four or five applications. In several field trials, we observed that deltamethrin treatment restricts DBM larvae to the lower part of the plant and to the underside of the leaves. This was due to the application

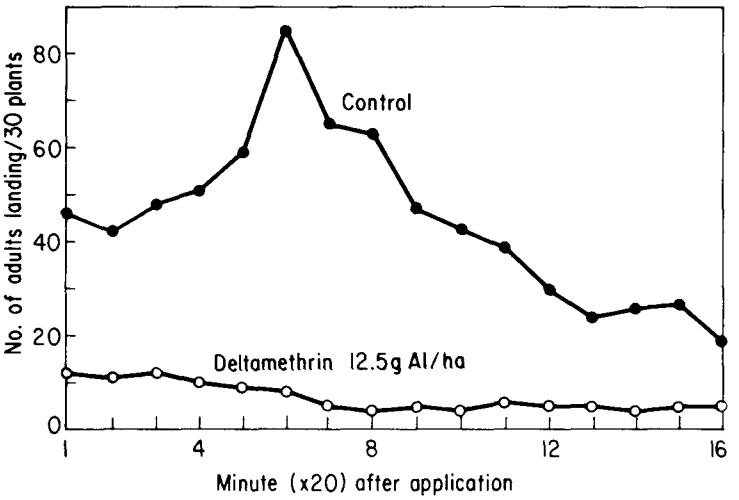

Figure 2. Influence of deltamethrin application on landing of DBM adults on treated and untreated plants

of the active ingredient to the upper part of the plant; it seldom reached the lower parts and underside of the leaves. The lower parts of the plant remained safe enough for the DBM larvae to survive. After four to five weeks, the second generation eggs hatched and the total number of DBM larvae sharply increased, but most of them remained on the lower plant parts until they consumed all these leaves and moved to the next higher leaves. However, damage to the lower leaves of the plant, from five to six weeks after transplanting or emergence, caused minimal yield loss. Another reason for finding most larvae on the lower parts of the plants following the application of deltamethrin + *Bt* is the repellent effect of deltamethrin which causes DBM adults to oviposit only on the foliage which has received no deltamethrin (Figure 3). This indicates that although DBM may not be controlled completely, the application of deltamethrin + *Bt* gives a high level of yield protection (Table 3).

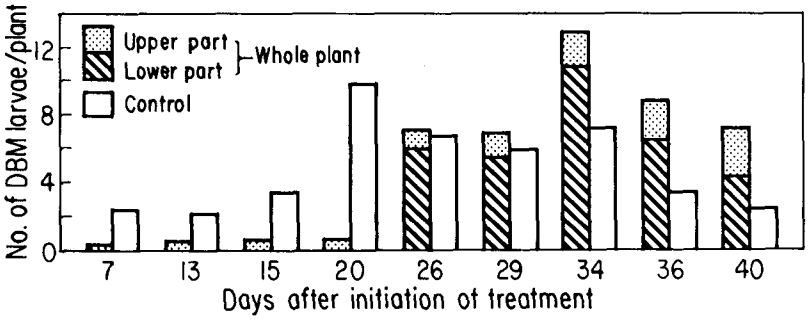

Figure 3. Distribution of DBM larvae in upper and lower parts of deltamethrin treated plants

D. The optimum rate of application Deltamethrin + *Bt* mixture can overcome the problem of DBM resistance on cruciferous crops. However it is necessary to apply on

Table 3. Evaluation of deltamethrin (DM) and *Bacillus thuringiensis* (*Bt*) for the control of lepidopterous pests on Chinese cabbage

Insecticides	Mean No. of larvae/16 plants[a]			Yield, t/ha	
	DBM	TC	TFW	Marketable	Unmarketable
(*Bt* × 2 + DM × 1) × 2[b]	58.23b	5.06a	7.30a	2.80b	8.12a
(DM + *Bt*) × 5[c]	27.95a	1.58a	2.80a	15.16a	3.68b
Bt × 5[d]	53.77b	15.13b	17.33b	0.00b	8.76a
DM × 5[e]	73.55b	7.09a	10.43a	14.44a	3.92b
Control	85.37b	39.73b	45.50b	0.00b	0.00b

[a] Data are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. DBM: diamondback moth, TC: tobacco cutworm, *Spodoptera litura*, TFW: tomato fruitworm, *Heliothis armigera*. [b] Two applications of *Bt* followed by one of DM followed by two of *Bt* and one of DM. [c] DM + *Bt* mixture sprayed five times. [d] Only *Bt* sprayed five times. [e] Only DM sprayed five times. All applications were made at weekly intervals. DM 2.5EC was used at 12.5 g AI and *Bt* 500 g product/ha. Test location: Calauan, Laguna, Philippines.

optimum and economical rate to get a profitable crop. We have tested deltamethrin at a fixed rate of 12.50 g AI/ha by tank-mixing with different rates of *Bt* ranging from 125 to 1500 g product/ha. We found that the minimum rate of *Bt* was at least 500 g product/ha (Table 4). In a second field trial, we fixed the rate of *Bt* at 500 and 1000 g product/ha and varied the rate of deltamethrin from 6.25 to 25.00 g AI/ha (Table 5). We found that the minimum rate of deltamethrin has to be 18.75 g AI/ha and that of *Bt*, 500 g product/ha. In the third field trial, we simultaneously decreased the rate of deltamethrin from 30 to 0 g AI/ha, and increased the rate of *Bt* from 0 to 3 kg product/ha. We found that deltamethrin from 25 to 7.5 g AI/ha, tank-mixed with *Bt* from 0.5 to 2.25 kg product/ha, all gave the same level of control of DBM. Comparing the cost of these different mixing rates in Taiwan and the Philippines (Figure 4), it can be seen that the more deltamethrin and the less *Bt* in the mixture, the less it will cost. The optimum and most economical rate of this mixture we recommend is shown in Table 6.

Table 4. Evaluation of deltamethrin (DM) and *Bacillus thuringiensis* (*Bt*) mixture for the control of DBM on cabbage

Insecticides	Rate g/ha		Control[a] (%) at			Yield
	AI	Product	25DAT	46DAT	68DAT	kg/5 sq m
DM 2.5EC + *Bt*	12.5 +	125	74.7b	78.1bc	8.5c	18.8b
DM 2.5EC + *Bt*	12.5 +	250	74.2b	71.1c	15.5c	18.2b
DM 2.5EC + *Bt*	12.5 +	500	77.6ab	83.3abc	22.4c	19.0ab
DM 2.5EC + *Bt*	12.5 +	750	81.5ab	89.9ab	45.9b	19.5a
DM 2.5EC + *Bt*	12.5 +	1000	81.1ab	91.7a	56.3b	20.2a
DM 2.5EC + *Bt*	12.5 +	1250	85.0ab	92.1a	62.9b	19.6a
DM 2.5EC + *Bt*	12.5 +	1500	91.9a	96.4a	83.6a	22.0a
DM 2.5EC	12.5		76.4ab	70.7c	32.8c	16.7bc
Bt		750	12.2c	40.0d	8.2c	8.6c
Control			0.0	0.0	0.0	0.0d

[a] Data are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. DAT: days after transplanting. *Bt* was serotype III, 16,000 IU/mg. Test site: Calauan, Laguna, Philippines.

Table 5. Evaluation of deltamethrin (DM) and *Bacillus thuringiensis* (*Bt*) mixture for the control of DBM on cabbage

Insecticides	Rate g/ha		Control[a] (%) at			Yield
	AI	Product	25DAT	46DAT	68DAT	kg/5 sq m
DM 2.5EC + *Bt*	6.25 +	500	60.0b	44.4cd	7.0cd	11.2bcd
DM 2.5EC + *Bt*	12.50 +	500	71.7b	64.0c	13.4c	13.3abc
DM 2.5EC + *Bt*	18.75 +	500	84.0a	75.3b	37.3b	13.5abc
DM 2.5EC + *Bt*	25.00 +	500	80.6a	74.4b	31.2b	14.8ab
DM 2.5EC + *Bt*	6.25 +	1000	73.5b	74.4b	31.0b	14.7ab
DM 2.5EC + *Bt*	12.50 +	1000	79.5a	74.4b	36.0b	15.1ab
DM 2.5EC + *Bt*	18.75 +	1000	79.0ab	85.6ab	48.4ab	15.3a
DM 2.5EC + *Bt*	25.00 +	1000	84.3a	91.6a	76.7a	17.1a
DM 2.5EC	12.50		62.4b	38.4d	5.2d	9.4d
Bt		1000	24.2c	34.7d	9.9c	9.9cd
Control			0.0	0.0	0.0	0.0e

[a] Data are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. DAT: days after transplanting. *Bt* was serotype III, 16,000 IU/mg. Test site: Calauan, Laguna, Philippines.

Table 6. Rates of deltamethrin and *Bacillus thuringiensis* (*Bt*) in a mixture for optimum and economical control of DBM

Bt, g product/ha	Deltamethrin g AI/ha		
	22.5	20.0	17.5
750	Yes	No	No
1,000	No	Yes	No
1,250	No	No	Yes

Yes: indicates effective and economical control, No: indicates uneconomical and at times ineffective control.

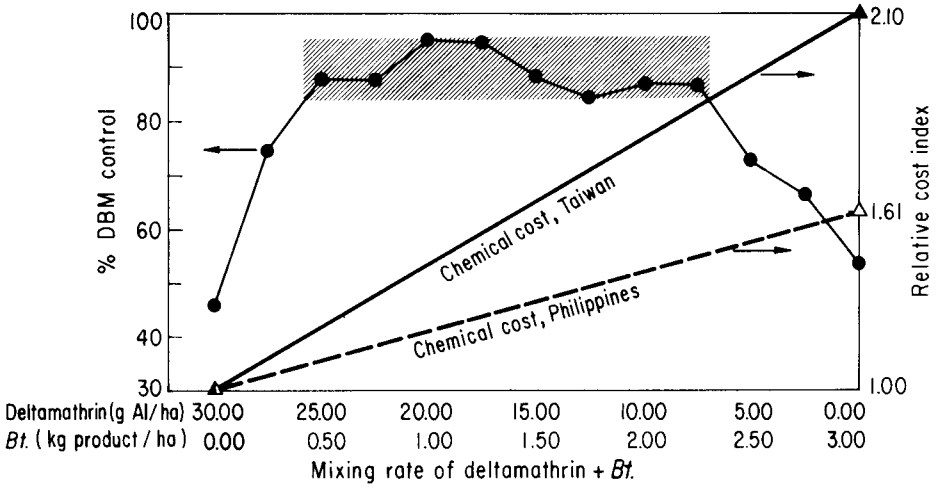

Figure 4. DBM control and relative insecticide cost at various combinations of deltamethrin and *Bt* in Taiwan and the Philippines. The percent DBM control points in shaded area are not significantly different at 5% level according to Duncan's multiple range test

Conclusions

Due to the insecticidal effects of deltamethrin and *Bt* to DBM and other insect pests, as well as the repellent, anti-feeding, and hyperactivity effects of deltamethrin, the mixture of deltamethrin and *Bt* can protect crucifer foliage and secure satisfactory yields. The insecticide mixture minimizes the damage by limiting DBM colonies to the lower plant parts and the unproductive leaves of the plant.

To maximize the effects of deltamethrin + *Bt* mixtures, the following factors need to be implemented: Apply this mixture in the late afternoon, and use fresh *Bt* product. Start to apply this mixture as early as possible during the growing season. Apply this mixture only to the upper parts and to the productive leaves of the plant. The optimum rate of deltamethrin and *Bt* (16,000 IU/mg) is 20 g AI/ha and 1000 g product/ha, respectively.

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