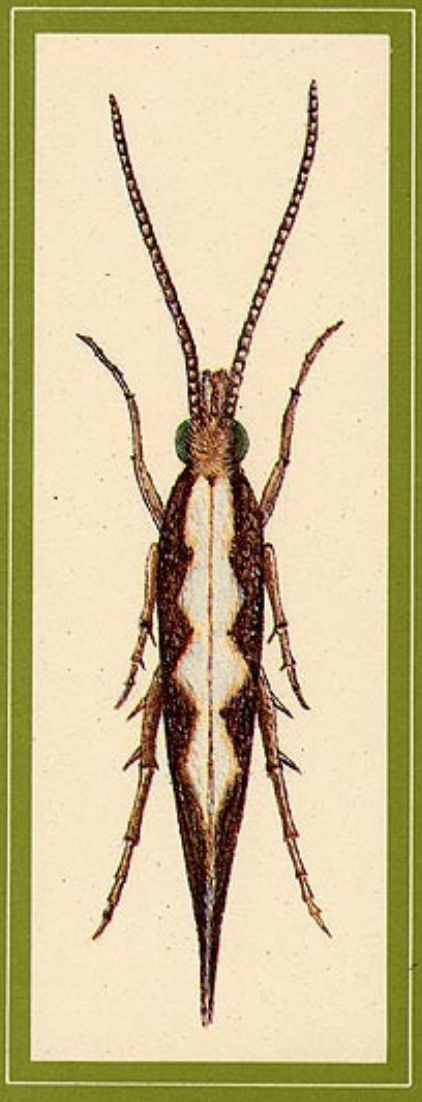
Diamondback Moth Management



Proceedings of the First International Workshop

Asian Vegetable Research and Development Center

Diamondback Moth Management

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Foreword

Cruciferous vegetables are economically important throughout the world. In Asia, they are grown by small landholders around urban centers, in highlands, and in specialized production areas. Often farmers use input-intensive agronomic practices because the sale of these vegetables provide an important source of ready cash income. In recent years, however, crucifer production has been seriously affected by a steady increase in insect pests, especially the diamondback moth, *Plutella xylostella*. The larvae of this insect feed on the foliage of cruciferous plants from the seedling stage to harvest and greatly reduce both yield and quality of the produce. This pest is especially serious in southeast Asia.

To control diamondback moth, farmers in southeast Asia use large quantities of insecticides, often spraying "cocktails" of chemicals. This coupled with rapid turnover of generations in the tropical climate has resulted in the development of resistance to practically all categories of chemical insecticides. At the same time other insects, such as *Spodoptera* spp and *Crocidolomia binotalis* – which were once minor pests of crucifers – have become major problems as a result of destruction of their natural enemies due to indiscriminate insecticide use.

To resolve the diamondback moth problem, researchers are working on alternative control methods such as the use of sex pheromones, juvenile hormones, microbial agents, predators and parasites, and insecticides with novel modes of action. The results of this research, however, are not easily available to others. In some cases, the potential utility is not realized because extension workers are rarely consulted about on-farm problems.

Since Chinese cabbage, *Brassica campestris* ssp *pekinensis* – an important host of diamondback moth – is one of AVRDC's principal crops, we convened an international workshop to discuss the diamondback moth problem. The meeting, which was held from

11 to 15 March 1985 in Tainan, Taiwan, had the following objectives: (1) To facilitate an exchange of information between researchers from universities, government laboratories, and industry; (2) To review all known scientific information from various disciplines pertaining to diamondback moth management; (3) To determine priorties for future research and development; and (4) To establish a communicaion network for the exchange of information, predators, parasites, and insect pathogens.

The proceedings contain 35 papers that were presented and five that were specially commissioned (Nos. 7, 8, 9, 10, and 22). The information printed in this volume thus covers practically all aspects of diamondback moth management and control. For the sake of convenience and clarity, the papers are grouped into the following topics: biology and ecology, sex pheromone, cultural control, biological control, chemical control, insecticide resistance, and integrated control.

The successful holding of the international workshop and publication of the proceedings were brought about through the efforts of many institutions, organizations, and individuals. We are especially grateful to the Council of Agriculture of our host government, for its generous donations which enabled us to cover the expenses of participants from non-profit organizations and the printing of the proceedings. We are also grateful to the following agrochemical corporations for their financial support for organization of the workshop: Sumitomo Chemical Company, American Cyanamid Company, Dow Chemical Pacific Ltd., Duphar B.V., Sandoz Ltd., Teh Hua Chemical and Pharmaceutical Company Ltd., Chung Teh Company Ltd., Ji Kang Company Ltd., Nissan Chemical Company, International Engineers (Taiwan) Corp., Roussel Uclaf, and MSD-AGVET. Without their generous support, the workshop would not have been successful.

Shanhua
26 May 1986

Paul M. H. Sun
Acting Director General

Population Dynamics of the Diamondback Moth in Southern Ontario[1]

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Abstract

In a study of the population dynamics of the diamondback moth, *Plutella xylostella* (L), on cabbage, 74 life tables were compiled from population and mortality data during an 11-year period in southeastern Ontario. Population trends were typically upwards early in the season, peaked in generations three or four, and declined thereafter. Key factor analyses, and analysis of the components of mortality using a variance-covariance matrix of the separate mortalities, expressed as k-values, showed that parasites and reduced fecundity are the most important factors affecting variation in intrageneration survival. The principal parasite is *Diadegma insulare* (Cress), which is density dependent, and whose activity is at times reinforced by that of *Microplitis plutellae* Mues and *Diadromus subtilicornis* (Grav). Fecundity, which is density independent, is related to the crude protein content of the plant and declines throughout the season. When the data were examined in the context of previous studies on intergeneration survival, it was apparent that the population increases early in the season are triggered by high female reproductive capacity, maximal egg deposition under generally benign weather conditions, and minimal activity of *D. insulare* which does not pass the winter in association with its host. Population decreases later in the season are caused by a gradual decline in fecundity, increasing activity of the guild of parasites, and hostile weather which curtails egg deposition.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L), (Lepidoptera: Yponomeutidae) has been known from eastern Canada since 1895. In southern Ontario, it is an occasional pest of cruciferous vegetables and can be a serious problem in some years. Although its outbreaks are sporadic, it is always present during the growing season and the infestation may build from endemic to epidemic levels from one generation to the next. Hence, producers must be constantly on the alert for sudden population eruptions.

In southern Ontario, there are four or five generations a year, depending on seasonal temperatures. The period required for a complete generation varies from 18 to 51 days, averaging 25 in July and August.

The insect does not overwinter in Canada. Annual infestations arise from adults which disperse from winter breeding sites in the southern United States and are carried northward in the spring by favorable winds. In most years, these migrants begin to arrive in southern Ontario during the last half of May.

The female lays in excess of 100 eggs. Fecundity is highest in June and July and declines as the season progresses. Light trap studies have shown that the moths are active

[1] Contribution No. 794. Ottawa Research Station

for an average of 136 days each year and that the heaviest period of flight is from late July to early September (Harcourt 1957). The peak of flight in the night begins 90 minutes after sunset and lasts about one hour. Conditions most favorable to flight and oviposition are high temperatures coupled with low wind velocities. On the other hand, low temperatures, high wind velocities, and rainfall ground the females and greatly curtail egg-laying activity.

The DBM attacks cultivated crops and wild plants of the family Cruciferae as well as a number of cruciferous ornamentals. In our studies, equal numbers of the pest were found on cabbage, cauliflower, brussels sprouts, and broccoli. Wild hosts play an important role in maintaining populations of the insect, particularly in years when adults begin to arrive from the south before the planting of cultivated crops. In southern Ontario, it is commonly found on the weed yellow rocket, *Barbarea vulgaris* R Br, which blooms in the early spring in fields and pastures.

In a four-year (1958-61) study of the population dynamics of the DBM, the author developed life tables for 18 generations of the pest in permanent plots cultivated to cabbage at the Merivale Field Station in southeastern Ontario (Harcourt 1963). Results of this study showed that populations are regimented by factors affecting the adult stage. In particular, mortality of gravid females due to inclement weather was the key factor that determined population trends.

Additional life tables were compiled through 1970. Although the Merivale Field Station was abandoned following the 1966 season, the study was continued at two additional sites within a 16-km radius of the original plots. In an attempt to pinpoint possible key factors in the developmental stages, the focus of the study was on the period from egg to adult flight, viz survival within the generation.

Methods

Experimental plots

Crops of both early and late cabbage were grown each year in adjacent 0.2 ha plots. Populations of the DBM were recorded on the early crop (cv Golden Acre) from May until the end of July, when it was ploughed down, and on the late crop (cv Penn State Ballhead) from July through October. Data were recorded for generations one and two on the early crop, and for generation two and succeeding generations on the late. The data for generation two were combined in final tabulation.

Population and mortality estimates

Sampling techniques for estimating populations of the immature stages were substantially as reported by Harcourt (1961). The sample unit, upon which the life tables were based, is the crown quadrant, and five sampling periods were used to follow the course of a generation from oviposition to moth emergence. A sufficient number of population estimates were taken in each generation at each site to enable us to bracket the various stage peaks. As a rule, samples were taken every three days, although the interval between larval samples was sometimes shortened to two days during periods of hot weather. At each sampling, enough sample units were taken to assure that standard errors of the population estimates approximated 10% of the mean. These estimates were integrated into a single value by the method of Southwood and Jepson (1962).

To enable us to isolate the activity of the various mortality factors, the DBM life stages were partitioned as follows: eggs; small larvae (L_1 to L_3); large larvae (L_4), when the parasite, *Microplitis plutellae* Mues (Hymenoptera: Braconidae) emerges from its host

leaving it to die; prepupae, when the *Diadegma insulare* (Cress) (Hymenoptera: Icheumonidae) emerges after killing its host; pupae, when *Diadromus subtilicornis* (Grav) (Hymenoptera: Ichneumonidae) emerges after killing its host; and moths. Rates of parasitism were derived from extensive rearings of DBM larvae and pupae collected just prior to parasite emergence. Fertility data were based on samples of the eggs collected at peak oviposition. Adult sex ratio was derived from pupal collections. The incidence of mortality of small larvae caused by rainfall was obtained by subtractive methods, and by taking population counts before and after periods of intensive rainfall.

The number of 'normal females' represents the number of females capable of laying a full complement of eggs (Harcourt 1963). To obtain data on fecundity, records of the number of eggs laid per female were obtained under controlled conditions in a flight chamber and compared to the standard of 216, which was the maximum number recorded in any year or generation. In these studies, moths reared from cocoons collected from the plots at the peak of pupation were liberated in groups of 20 (10 male, 10 female) in 61 × 61 × 61 cm screened oviposition cages containing small potted plants of cabbage. The moths were fed on absorbent cotton soaked in a solution of sugar-water. Temperature in the flight chamber was maintained at 25 ± 1°C, and a relative humidity of 70 ± 5%. The fecundity of at least 100 moths was recorded in each generation.

Scope of the life table study

Data for the final two years of the original investigation, comprising eight life tables, were included in the present analysis. This provided a total array of 74 life tables for synthesis and appraisal (Table 1).

Table 1. Scope of the life table study on DBM

Years	Site	No. generations
1960-66	Merivale	30
1965-70	Ottawa	26
1967-70	Twin Elm	18

Results and Discussion

There were four generations per year in seven of the 11 years, and five generations in the remaining four. In our study plots, the infestation ranged from as few as eight eggs per 100 plants to as many as 7700. Population trends were typically upwards early in the season owing to the continued invasion of moths from the south and an influx of populations from cruciferous weeds where three-quarters of the first generation eggs are laid (Figure 1). Populations peaked in generations three or four, and declined thereafter. Economic infestation levels were reached in eight of the 11 years.

The column headings for the life tables are those of the conventional ecological type (Morris 1963, Harcourt 1969) and all *lx* and *dx* values represent the number of specimens per 100 plants in each stage interval. Table 2 presents a mean life table for the 74 sets of data. For simplicity, the values in columns 2 and 4 have been rounded to the nearest whole number and column 5 was calculated directly from them. Table 2 shows that the sequential action of rainfall, parasites, and reduced fecundity limited intrageneration survival (S_{WG}) to just under 12%. Survival was greatest in the first generation (49%), but decreased to 22, 10, 5, and 7% in the next four.

Figure 2 presents a synopsis of the phenology of the more important mortality factors. When viewed on a seasonal basis, it is apparent that mortality from rainfall

was relatively high in all generations. *M. plutellae* was most active early in the season, reaching its peak in generation three. *D. insulare* started slowly but steadily increased its rate of attack, reaching its peak in generation four; it was the most abundant parasite during the last two generations. *D. subtilicornis* was the most abundant parasite during the first two generations and was co-dominant with *D. insulare* in generation three; thereafter its rate of attack fell abruptly. Reductions in fecundity increased steadily throughout the season.

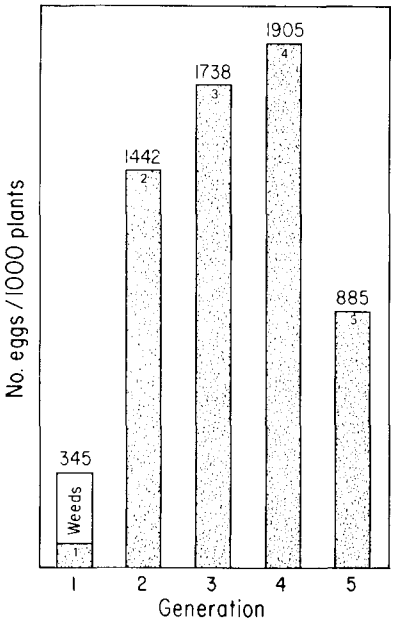

Figure 1.
Seasonal incidence of eggs in the study plots, expressed on a generation to generation basis. Mean values were based on 17 life tables for generations one to four, and six life tables for generation five

Table 2. Life table for DBM based on mean values for 74 generations at three sites in southeastern Ontario, 1960-70

x Stage interval	**lx**[a] No. alive at beginning of **x**	**dxF** Factor responsible for **dx**	**dx**[a] No.dying during **x**	**100 qx** **dx** as percent of **lx**
Eggs	1293	Infertility	12	0.9
Small larvae	1281	Rainfall	600	46.8
Large larvae	681	*M. plutellae*	105	15.4
Prepupae	576	*D. insulare*	218	37.8
Pupae	358	*D. subtilicornis*	67	18.7
Moths	291	Sex (51% female)	-6	-2.0
Females	297	Reduced fecundity	145	48.8
'Normal' females	152			
Generation totals			1141	88.2

[a] lx and dx values are numbers per 100 plants. $S_{WG} = 0.118$

Principal mortality factors

Rainfall The larvae are very susceptible to drowning. During heavy rainfalls, the small larvae are readily disturbed and are washed, or wriggle, into leaf axles containing water or spin threads and drop to the ground where they perish in puddles caused by the rain.

The large larvae are less readily dislodged and usually regain the plant when washed off. In general, high mortalities are associated with thunderstorm activity, and rainfall during periods of cool weather (Harcourt 1963). Figure 3 shows that small larval mortality (SLM) is directly related to the amount of rainfall that occurs during this stage interval. The following equation explains 60% of the variation in SLM:

$$SLM = 0.959x + 13.967 \quad (1)$$

where x is the amounmt of rainfall, in mm.

During the 11 years, rainfall caused an average SLM of 47%, individual 100 qx values ranging from 0 to 79. Large larval mortality was negligible.

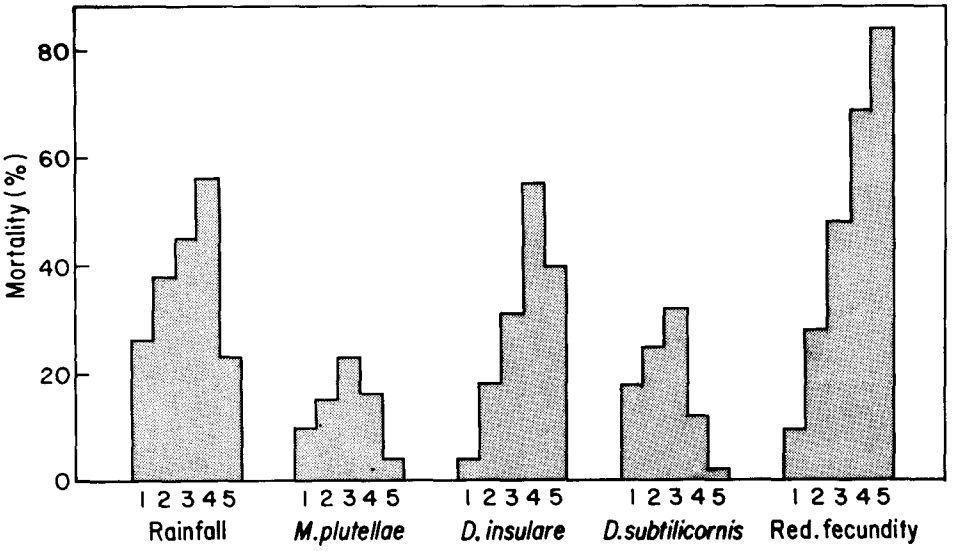

Figure 2. Rates of mortality of the principal mortality factors in five generations of DBM in southeastern Ontario

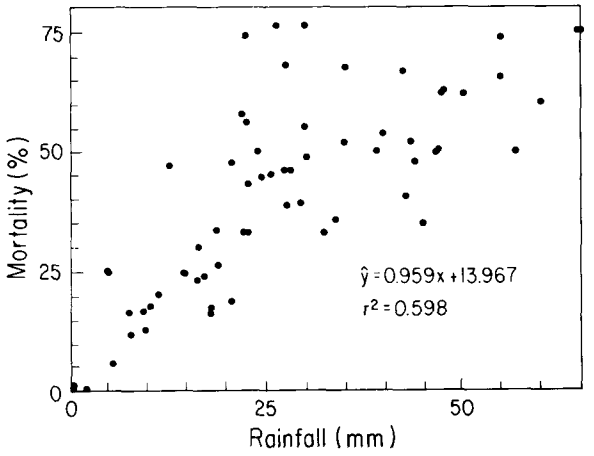

Figure 3.
Mortality of small larvae (L_1 to L_3) in relation to rainfall in southeastern Ontario, 1960-1970

Parasites All of the major parasites are specific to the DBM in southern Ontario. *D. insulare* is the most abundant and important of the three species. It is highly synchronized with development of its host and has four or five generations per year before hibernating as a pupa, within the cocoon of its host, amongst the remnants of the crop (Harcourt 1960). Seasonal populations of the parasite rise with those of the DBM, reaching a peak at the beginning of September. It lays its eggs in the first three larval instars and its presence prevents pupation of the host. The fully-fed parasite emerges from the prepupa shortly after the host forms its cocoon. It then spins its own cocoon within that of its host and in doing so, it pushes the remnants of the cadaver to the bottom of the host cocoon.

For the most part, *D. insulare* is intrinsically superior to the other two parasites (Harcourt 1963, Bolter and Laing 1983). In southern Ontario, it is not uncommon to find hosts containing immature specimens of both *D. insulare* and *D. subtilicornis*, which attacks the prepupae and newly-formed pupae. Figure 4, which is based on twice-weekly counts from July to October, is typical of the interaction between the two parasites. Although *D. insulare* was responsible for the bulk of the parasitism, at times the curve for this species departs markedly from the curve of total parasitism. The curve for *D. subtilicornis* follows these departures very closely.

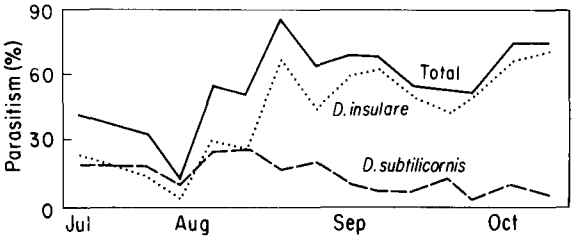

Figure 4.
Parasitism of DBM by *D. insulare* and *D. subtilicornis*. Merivale, Ontario (Harcourt 1960)

A parallel situation (Figure 5) exists with respect to *M. plutellae*, which lays its eggs in the second and third larval instars (Harcourt 1960). According to Bolter and Laing (1983), its ability to detect eggs of *D. insulare* deposited in the host within the previous 24 h is poor. Except when eggs of both species are laid simultaneously, *M. plutellae* is suppressed or killed by *D. insulare*. During the 11 years, percent mortalities caused by the three parasites were as follows:

Stage interval	Parasite	Mean	Range
Large larvae	*M. plutellae*	15	0-38
Prepupae	*D. insulare*	38	0-89
Pupae	*D. subtilicornis*	19	0-49

Reduced fecundity Moth fecundity declined in successive generations each year. The decline was gradual, numbers of eggs per female averaging 180, 142, 112, 51, and 31 in the five generations, respecitvely (Figure 6, p.10). Studies by Harcourt and Cass (1966) showed that fecundity was related to photoperiod, which decreases from ca 16 h in June to ca 13 h in September. Thus, the feeding larvae are exposed to declining day lengths as the season progresses. During the 11 years, reduced fecundity accounted for an average female moth mortality of 49%, individual 100 qx values ranging from 0 to 94.

Analysis of population change

The life tables were analysed to identify the stages in the life cycle that made the greatest contribution to population trend. To convert the data into a suitable form for

analysis, we used k-values (Varley and Gradwell 1965) to assess the impact of the various mortality factors. A k-value is defined as the difference between the successive values for log *lx* and is thus a logarithmic measure of the killing power of a mortality factor. Thus, total mortality (K) is the sum of the individual mortalities:

$$K = k_1 + k_2 + k_3 + k_4 + k_5 + k_6 + k_7 \quad (2)$$

where

k_1 = infertility
k_2 = mortality from rainfall
k_3 = parasitism by *M. plutellae*
k_4 = parasitism by *D. insulare*
k_5 = parasitism by *D. subtilicornis*
k_6 = sex ratio
k_7 = reduced fecundity

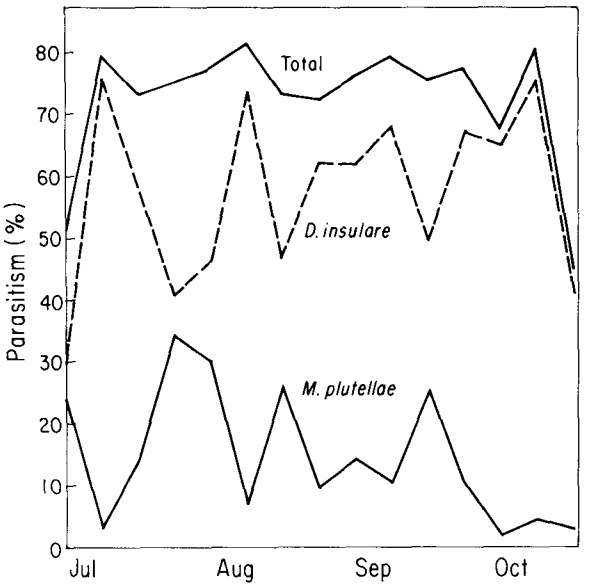

Figure 5.
Parasitism of DBM by *D. insulare* and *M. plutellae*. Twin Elm, Ontario, 1969

Varley and Gradwell (1968) proposed that the key factor, viz the factor most responsible for population change, could be identified by studying plots of K and k_i for all of the life tables. A visual comparison between the separate mortalities will thus reveal those making the greatest contribution to population trends. Figure 7 shows these plots for the present data; since only k_4 (parasitism by *D. insulare*) and k_7 (reduced fecundity) follow the same fluctuating course as K, mortality from these factors is clearly most important.

To shed further light on possible key factors, each of the k_i was regressed against total K as suggested by Podoler and Rogers (1975). The magnitude of the slopes thus provide a measure of the relative importance of the submortalities. Table 3 shows that most of the variance in generation mortality was attributable to variability in k_7, closely followed by k_4. These were followed in turn by k_2 (rainfall mortality), k_3 (parasitism by *M. plutellae*), and K_5 (parasitism by *D. subtilicornis*). Mortalities from other factors were relatively invariant.

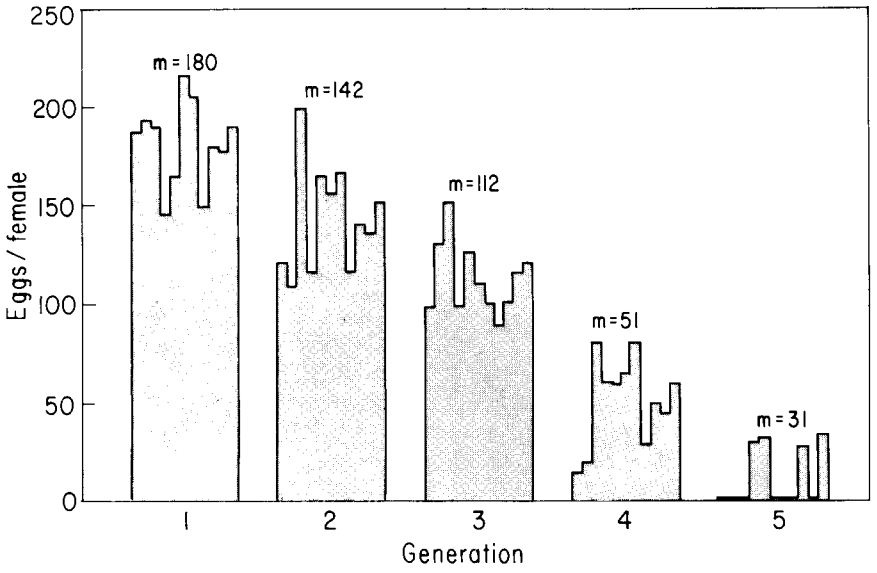

Figure 6. Fecundity of DBM in successive generations, 1960-1970. Values within a generation are for successive years

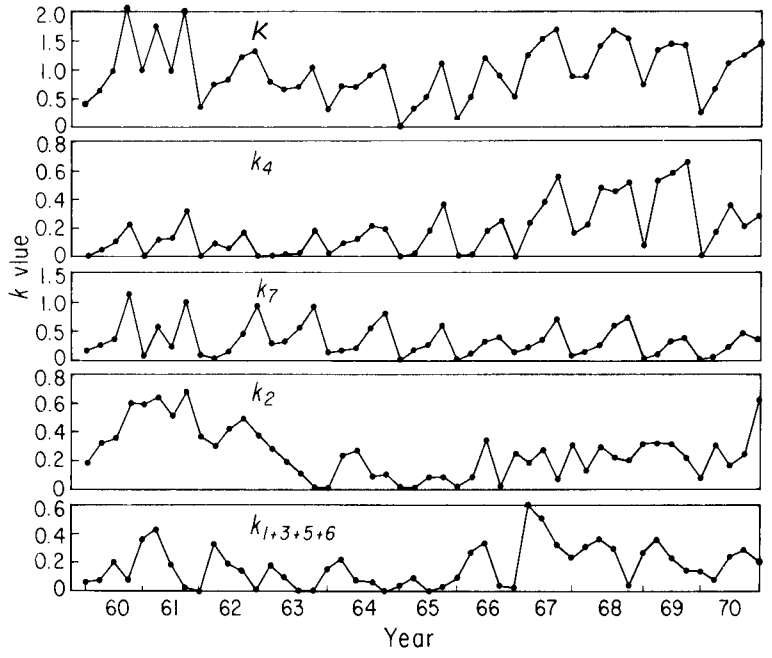

Figure 7. Key factor analysis for DBM populations in southeastern Ontario. See text for explanation of symbols. k-values for 1965-70 are means for two locations

Table 3. Key factor analysis for DBM; regression coefficients for k_1 on K

Stage interval	Cause of mortality	Value of b
Eggs	Infertility (k_1)	0.003
Small larvae	Rainfall (k_2)	0.183
Large larvae	*M. plutellae* (k_3)	0.101
Prepupae	*D. insulare* (k_4)	0.312
Pupae	*D. subtilicornis* (k_5)	0.040
Moths	Sex ratio (k_6)	0.003
Females	Reduced fecundity (k_7)	0.358

Following Mott (1967), we further investigated the sources of variation to study the interactions between components; for convenience, our notation is in terms of k-values instead of Mott's log survivals. Thus,

$$\text{var}\ (K) = \sum_{i=1}^{7} \text{var}\ (k_i) + 2 \sum_{i=1}^{6} \sum_{j=i+1}^{7} \text{cov}\ (k_i k_j) \qquad (3)$$

This equation shows that the variance in K can be broken down into the variances of the individual k-values plus twice the covariance of each pair of independent k's. Therefore, a variance-covariance matrix of the k-values will reveal the sources of variation in total mortality.

The variances and covariances for equation 3, expressed as a percentage of the total variance in K, are given in Table 4, which lists all of the variations associated with each variable and the interactions among variables. The top values in each column represent the variances of the associated variables. The other values in the column represent covariances for variables that can be indexed from the top and slides. Each entry in the column of covariances for K is, by definition, equal to the sum along the row to the diagonal and down the column.

Table 4. Variances and covariances amongst the k-values as a percentage of K

	K	k_1	k_2	k_3	k_4	k_5	k_6	k_7
K	100.00							
k_1	0.32	0.00						
k_2	18.29	0.06	12.66					
k_3	10.11	0.02	1.27	5.09				
k_4	31.24	0.11	0.46	3.28	19.37			
k_5	3.99	0.05	1.06	1.02	0.63	2.95		
k_6	0.33	0.00	-0.36	0.40	0.02	0.22	0.93	
k_7	35.75	0.09	3.18	-0.96	7.47	-2.00	-0.92	28.93

Examination of Table 4 shows that the principal contribution to variation in K came from k_7 (28.93) followed by k_4 (19.37) and their covariance (7.47). The contribution of k_2 (12.66) is also noteworthy.

From these data, it is evident that reduced fecundity and parasitism by *D. insulare* are the most important factors regimenting generation survival of the diamondback moth in southeastern Ontario. Together, k_4 and k_7 explain 48% of the total variation in K; including their interaction, the total contribution rises to 56%. Including k_2 and its interactions with k_4 and k_7 raises it to 72%. Including k_3 and k_5 and their interactions with k_4 extends it to 84%.

Mortality from rainfall (k_2) made only a modest contribution to the variation in survival despite the large numbers of small larvae drowned during the course of a generation ($m = 600$). This is because it sets the stage for other variables that act later in the lifecycle; it should be noted, however, that rainfall has immediate impact on damage potential of the pest because it destroys the larvae before they reach their peak of feeding activity. Similarly, k_3 and k_5 (the parasites *M. plutellae* and *D. subtilicornis*) had little impact on generation survival because they are dominated by *D. insulare* (k_4). However, they reinforce the activity of k_4, by compensating during periods of low *D. insulare* activity.

Density dependent relationships

To examine the properties of the various mortality factors, log numbers entering each stage (log N_t) were plotted against log number of survivors (log N_s) and a two-way regression analysis was conducted to test for the effect of spurious correlations. Provided that both slopes are significantly different from unity and lie on the same side of $b = 1$, density dependence may be taken as real (Varley and Gradwell 1970, Southwood 1978). A slope of unity indicates that density related mechanisms are not operating (viz there is no feedback); a slope of greater than unity indicates positive feedback; and a slope of less than unity indicates negative feedback. For convenience, log N_t for moths was plotted against log N_s for 'normal' females, thus eliminating sex ratio from the calculations. Table 5 shows that mortality of the prepupae, caused by *D. insulare*, was density dependent and that mortalities caused by all other factors were density independent.

Table 5. Tests of density dependence for six stages of the diamondback moth

	Regression coefficients	
Stage interval	log N_s on log N_t	log N_t on log N_s
Eggs	0.998 ($P > 0.05$)	1.002 ($P > 0.05$)
Small larvae	0.967 ($P > 0.05$)	1.001 ($P > 0.05$)
Large larvae	1.010 ($P > 0.05$)	0.961 ($P > 0.05$)
Prepupae	0.929 ($P < 0.05$)	0.934 ($P < 0.05$)
Pupae	1.007 ($P > 0.05$)	0.977 ($P > 0.05$)
Moths	0.976 ($P > 0.05$)	0.984 ($P > 0.05$)

The slopes of the regression coefficients for prepupae reflect undercompensating density dependence on the part of *D. insulare*. This means that the parasite has the ability to stabilize populations of its host but that the process will be gradual—and unlikely to be achieved, given the limited number of host-parasite interactions that can occur during the course of a single season in southern Ontario. However, as earlier noted, its rate of attack is reinforced by those of the other two parasites.

In previous studies, we showed that the number of hosts attacked by *D. insulare* increases at a diminishing rate with increasing host density (Harcourt 1963). The same phenomenon has since been documented by Putnam (1968). Reasons for this limitation in behaviour are not known, although it is probable that the number of hosts attacked per female decreases with increasing parasite density owing to mutual interference between searching females. Further examples of this type of functional response (type II) have been reported by Rogers (1972), Varley et al (1974), and others.

The causes and significance of reduced fecundity

The regression analyses showed that reductions in fecundity were density independent. This implies that the factor, or factors, causing variations in fecundity are

abiotic and, however important, cannot be regarded as regulatory (Harcourt and LeRoux 1967). Nonetheless, fecundity plays an important role in the seasonal decline of DBM populations in southeastern Ontario.

Although photoperiod is related to fecundity, this relationsip may not be causal. In fact, day length is more likely to *mediate* changes in fecundity than to *cause* them—by altering the quality of the food plant. The first evidence of a dietary link was noted during our flight chamber studies in 1965 when we observed that moths from larvae reared on young cabbage produced more eggs than those reared on older more mature plants. Moreover, there were subtle differences in skeletal size of the larvae, and moths from larvae fed on the younger plants appeared to be larger and more fit.

To shed light on this phenomenon, measurements of head capsule widths of 50 larvae in each instar were recorded in each generation during 1966. Table 6 shows that the size of the head capsule decreased in successive generations during the year and that this decrease mimicked the decline in moth fecundity. Similar results were obtained in 1967. This discovery prompted investigations on the quality of the food plant.

During 1969 and 1970, samples of cabbage foliage were collected from the study plots at peak fourth instar. These were analysed on a dry-matter basis to determine the crude protein, fat, and fiber content of the leaves, and compared to moth fecundity. Figure 8 shows that fecundity was directly related to the level of crude protein contained in the leaves. The following equation explains 95% of the variation in fecundity (F):

$$F = 10.69x - 134.18 \qquad (4)$$

where x is the crude protein content. None of the other plant constituents was important.

Table 6. Fecundity of DBM in relation to instar size, Merivale, 1966

Generation	Numbers of eggs per female	Width of head capsule in mm (n = 50)			
		I	II	III	IV
1	202	0.156 ± 0.001	0.240 ± 0.002	0.379 ± 0.002	0.597 ± 0.002
2	165	0.156 ± 0.001	0.243 ± 0.001	0.366 ± 0.002	0.591 ± 0.003
3	99	0.154 ± 0.001	0.233 ± 0.002	0.365 ± 0.003	0.569 ± 0.003
4	81	0.152 ± 0.001	0.230 ± 0.001	0.361 ± 0.003	0.564 ± 0.004

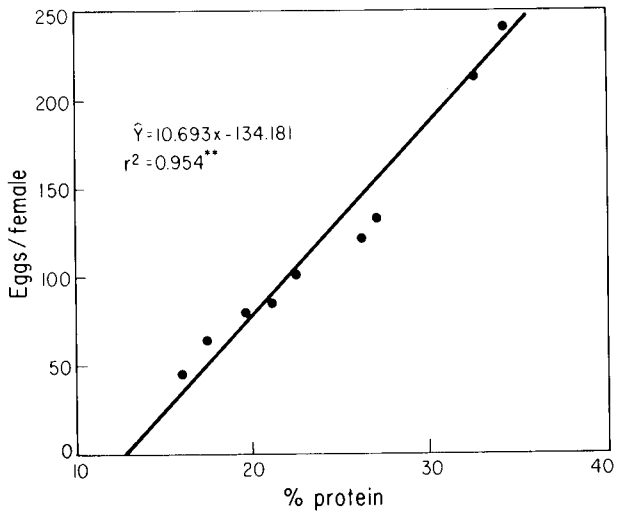

Figure 8.
Fecundity of DBM in relation to crude protein content of cabbage leaves

Conclusions

Based on these and the earlier studies (Harcourt 1963), certain generalizations can be made regarding the dynamics of DBM populations in southern Ontario. There are three factors of critical importance: the first is weather, which is density independent, and responsible for most of the variation in survival when viewed throughout the lifecycle. Hence, it may be regarded as the principal factor that causes fluctuations in the population (or instability in the life system), and induces outbreaks. The second is fecundity, also density independent, which is related to the crude protein content of the food plant and which declines on a gradual basis throughout the crop season. The third is the parasite *D. insulare*, which acts in a density dependent manner and which tends to stabilize populations.

Appraisal of the total array of life tables compiled since 1958 permits the following conceptual model of the DBM life system. Following the annual immigration of moths from the southern United States, populations increase to very high numbers owing to high survival rates during the first two generations which are triggered by a combination of factors: a high intrinsic reproductive capacity which is at its peak due to the high protein content of the food plant early in the season; maximal egg deposition by gravid females owing to benign weather conditions during oviposition; and minimal activity of *D. insulare* which does not pass the winter in association with its host and must search for it anew each spring. During the third and subsequent generations survival rates begin to decline: *D. insulare* acts in concert with the other two species of parasites to gradually overtake its host; fecundity of the moth decreases as the host plant matures and its protein content drops; and ovipositing females are increasingly grounded by hostile cold and windy weather which prevents them from depositing their eggs.

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Studies on Diamondback Moth in Venezuela with Reference to other Latinamerican Countries

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Abstract

Diamondback moth is a serious pest of cruciferous crops throughout the world. The insect is also a very important pest in South America, especially in Venezuela. In Venezuela it attacks a wide range of crucifers including *Brassica* weeds. Under variable temperature (12 to 25°C) and relative humidity (45 to 96%) conditions, the mean duration of lifecycle in Venezuela was 76.14 days. One parasite, *Diadegma* sp, attacks diamondback moth larvae in Venezuela. Malathion and diazinon are widely recommended for the control of this insect. Besides Venezuela, diamondback moth also attacks crucifers in Argentina, Brazil, Chile, Colombia, Cuba, the Dominican Republic, Jamaica, Peru, and Trinidad and Tobago.

Introduction

One of the many important lepidopterous insect pests of cultivated plants is the diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae). This insect is widely distributed and is a serious pest of cruciferous crops in many parts of the world (Salinas 1975, 1977). The adaptability of the insect to different climatic conditions and its recognised status as a major pest in temperate and tropical regions make the study of DBM important from the economic as well as the biological point of view. Talekar et al (1985) list 1016 papers dealing with this pest published up to mid 1984.

Descriptions of egg, larval instars, prepupa, pupa, and adult stages of this insect has been illustrated by many authors and have been summarized by Salinas (1977). There are slight but insignificant variations in biological and morphological parameters of these stages at different locations. More evidence is, however, necessary before definite conclusions can be drawn. The life history of DBM has been studied in varying detail in most parts of the world from the Equatorial Tropics to the Polar Circles. Salinas (1974) gives a general summary of the ecology of various life stages of this insect in various parts of the world, as well as his data for his studies of DBM in England at constant 20°C and at variable temperatures (average 18°C).

Studies on DBM in Venezuela

Distribution

Generally speaking, DBM can be found in all parts of Venezuela where cruciferous crops are grown. The geographical limits of its distribution are as follows: Caripe, Sucre State (10° 20N; 63°30W) in the east to Rubio, Tachira State (7°40N; 72°20W)

in the west; and from Antimano, near Caracas (10°30N; 67°00W) in the north to Rubio, Tachira State in the south. The range of altitude of DBM occurrence in Venezuela also varies. We have found this insect at Maracay, Aragua State, at 400 m above sea level to Mucuchies, Merida State at 3,100 m above sea level. The range of temperatures for DBM occurrence in Venezuela is from a mean temperature of 12°C at Macuchies to 30°C at Tocuyo, Lara State.

Host plants

The range of host plants that DBM attacks in Venezuela is restricted to the members of family Cruciferae and within it exclusively to introduced cultivated species of genus *Brassica*, including wild mustard *B. juncea*, a common weed at altitudes above 1000 m. Spanish colonizers imported these crucifers to Venezuela more than 400 years ago. The most common species attacked by DBM are: *B. oleracea* var *gemmifera*, *B. oleracea* var *botrytis*, *B. oleracea* var *capitata*, *B. pe-tsai* Bailey, *B. napus*, and *Raphanus sativus* (Salinas 1967).

Life history

The life history of DBM in Venezuela has been studied under constant and variable conditions by Salinas and Pena (1976) at Merida in the Andes. The insects were collected from the highlands around Merida.

Variable conditions The temperature and relative humidity were not controlled in this case. The average temperature was 18°C (range 12-25°C) and relative humidity 70% (45-96%); main light source, 10 h/day, was 40 W fluorescent tubes. The cages, the plants and other experimental conditions are described in Salinas (1974, 1984) and Salinas and Pena (1976).

Each plant received special treatment to maintain it in the best possible condition. Adults of both sexes were placed in the cages provided with sufficient honey-water solution to maintain normal activities. The plants were observed daily and those on which eggs were deposited were separated into individual cages so that the incubation period could be recorded. When the eggs hatched, each larva was placed on a tender leaf in a small individual cage, in order to record the duration of the larval stages. The food was changed as soon as it appeared to have deteriorated. Any external disturbance was avoided. The adults from these larvae were paired in individual cages, especially made for that purpose. Every day each pair of adults was tranferred to a new cage to record the number of eggs laid daily.

Results of this study are summarized in Table 1. The mean duration of the lifecycle of DBM under variable conditions was 76.14 days. The egg incubation period was 6.48 days. The larval duration was 21.68 days. The pupa lasted 13.38 days. The adult longevity was 35.00 days.

The adults started copulating almost immediately after emerging from the pupae. It was evident that the females produced a strong sex pheromone which attracted the males. Several males were observed trying to copulate with a piece of cotton over which an young female had just passed (Salinas 1972). The copula lasted for about 1 h 30 min. In studies in Britain the pre-oviposition period varied from less than one day for mated females in the presence of the host plant to one day in the absence of the host plant (Salinas, 1972). In Canada the pre-oviposition period ranged from 4.2 days for mated females to 8.6 days for virgin ones (Hillyer and Thorsteinson 1969). In Venezuela, the pre-oviposition period was 5 days (Salinas and Pena, 1976). The oviposition period varied from 6.4 days in Canada (Harcourt 1957) to 18.6 days in Great Britain (Salinas 1972).

Table 1. Life cycle of DBM in Venezuela

Stage	Variable temperature[a]			Constant temperature[b]		
	No. of observations	Range (days)	Time in days (mean ± S.E.)	No. of observations	Range (days)	Time in days (mean ± S.E.)
Egg	50	6-7	6.48 ± 0.54	19	5-7	5.79 ± 0.85
Larva						
1st instar	50	4-8	6.18 ± 0.83	19	2-6	4.47 ± 1.02
2nd instar	50	3-8	5.10 ± 1.15	18	1-4	2.78 ± 0.65
3rd instar	50	3-7	4.52 ± 0.97	18	3-4	3.39 ± 0.50
4th instar	50	3-6	4.88 ± 0.75	18	4-6	4.50 ± 0.71
Pupa	06	11-16	13.38 ± 1.41	15	8-10	9.07 ± 0.70
Adult	06	22-52	35.00 ± 11.35	6	13-19	17.67 + 2.34

[a] Mean 18°C. [b] 20°C.

The range in Great Britain was 5 to 27 days. In Venezuela the mean oviposition period was 14.7 days with a range from 11 to 19 days (Salinas and Pena 1976).

The longevity of the adults shows great variability from location to location. The largest range (and the extreme longevity) was recorded by Harcourt (1957) in Canada, where the males lived from 3 to 58 days (probably the record for the species) and the female lived 7 to 47 days. In Great Britain the lifecycle duration of females was 8 to 16 days in the presence of the host plant, and 11 to 27 days in the absence of the host plant (Salinas 1972). In Venezuela, Salinas and Pena (1976) found that at 18°C, the females lived 30.6 days (range 22 to 43 days) and the males 39.3 days (range 28 to 52 days); the combined average longevity was 35.0 days (range 22 to 52 days). At 20°C constant temperature the longevity was 17.7 days (range 13 to 19 days). In an experiment in which females were fed with honey solution, Salinas and Pena (1976) found that the females lived on average 49.8 days (range 29 to 57 days). The 57 day figure is probably the longest duration recorded for a female of this species. In another experiment, the same authors showed that males kept isolated and without food lasted 23.8 days (range 22 to 26 days).

The fecundity of DBM depends on many factors: genetic factors, the nutritional condition of the larvae, the nature of the host plant, the climatic conditions, the mating, and the presence or absence of host plants on which to oviposit. Mean number of eggs per female vary from 139 (range 55 to 226) in the USA at 26°C (Biever and Boldt 1971) to 246 (range 95 to 602) in Great Britain at 20°C (Salinas 1972). In Venezuela, at 18°C, the mean number of eggs per female was 162.6 (range 161 to 168) (Salinas and Pena 1976).

The preference for location of oviposition in the experiments was as follows: 110.6 eggs (range 79 to 131 eggs) on the glass walls of the cages, and 52.0 eggs (range 30 to 80 eggs) on the host plant leaves. The overall sex ratio was male:female = 1:1.5.

Constant conditions The experiments under constant conditions were carried out in a Gallenkamp IH-330 incubator. The temperature was maintained at 20 ± 1°C and 75% relative humidity. There was total darkness inside the incubator. The eggs and later the larvae were observed directly in the incubator. Once a day, the cages with eggs and/or larvae were taken outside the incubator for detailed observations or for replacement of the food (leaves). The cages and other materials and methods were similar to those described for the variable conditions experiments. The results are summarized in Table 1.

The mean duration of the lifecycle of DBM under constant conditions was 47.08 days. The egg incubation period was 5.79 days, larval duration was 15.14 days, and the pupal stage lasted 9.07 days. The adult longevity was 17.67 days.

Discussion

From the above results, it can be seen that an increase in temperature results in a decrease in the developmental time of all the different stages from egg to adult. This agrees with the observations made in other countries. The smallest difference was found in the fourth instar: 4.88 days at 18°C variable temperature and 4.50 days at 20°C constant temperature. The largest difference was found in the adult stage: 35.00 days at 18°C variable temperature and 17.67 days at 20°C constant temperature. The number of eggs per female also decreased with increasing temperatures.

There seems to be little doubt that an increase in temperature, even as little as 1 or 2°C, can be highly significant in shortening the developmental time of the different stages of DBM. The most probable reason for this decrease is an increase of the metabolic rate with rising temperatures; as metabolic rate increases life processes accelerate. The use of energy to cope with the increased metabolic functions probably explains the differences in fecundity as expressed by the number of eggs per female. The more the energy used in going from one stage to the next, for example from egg to larva or from pupa to adult, the less of it is left to develop all the potential eggs in the female.

Parasites

In general, DBM has few parasites, although some of them can be highly effective depending on specific conditions. This is best illustrated by the results of Salinas (1972) in England, who found *Nythobia* (= *Horogenes*) *eucerophaga plutellae* Kurdj (Hymenoptera: Ichneumonidae), as being responsible for 60% of pupal mortality in some instances, and yet for no mortality at all in some other instances in the same year and in the same field.

In Venezuela, Salinas and Pena (1976) reports that a parasite, *Diadegma* sp (Hymenoptera: Ichneumonidae), lays its eggs in DBM larvae and, after completing its larval stage inside the larvae emerges from the DBM cocoon.

Chemical Control

There is a great deal of information published on the chemical control of DBM around the world and every year more information appears on new products and methods. This is probably due to the species becoming resistant to insecticides. In fact, as early as 1953 DBM was the first Lepidoptera reported to be resistant to DDT and probably the first crop pest reported to be so. This was just a few years after the commencement of the commercial use of DDT (Anskersmit 1953).

In Venezuela there are no records of the first products used in DBM control, but probably inorganic products such as the arseniates were used by the 1930s and DDT after 1946. In 1957 TDE and DDT, both organo-chlorines of long persistence, were recommended as dusting powder at dosages of 30 kg/ha. Gonzalez et al (1973) reported on the same product but increased the dose to 35 kg/ha, and also recommended DDT 25EC at 1% in water (0.25% AI) or endrin 19.5EC at 0.33% in water (0.07% AI), spraying any of them at 500 l/ha of the emulsion.

In experiments using several products, in the states of Aragua and Lara in Venezuela (1965-1968), and later in the state of Merida in the Venezuelan Andes (1973-1983), we have found (Salinas, unpublished data) good results with the use of malathion 50EC sprayed at dosages of 0.1-0.2% AI, and diazinon 60EC sprayed at dosages of 0.2-0.3% AI. Those products and dosages are still in use and are widely

recommended by private as well as public agricultural agencies. In the Trujillo state, also in the Andean region of Venezuela, there have been some experiments on the use of synthetic pyrethroid insecticides, with the best results obtained using permethrin 5EC at the rate of 0.07%.

Biological Control

Biological control has been attempted in Venezuela only with the use of Dipel, a commercial product containing *Bacillus thuringiensis*. The results have been good but the price is too high compared to the chemical products (malathion and diazinon).

No predators or parasites have been introduced in Venezuela for the control of DBM, although this approach is being experimented in Trinidad, West Indies, a few miles from Venezuela, with some positive results.

DBM in South America

There are relatively few references to DBM in the neo- tropical area and even fewer for South America.

Argentina

This country marks the southernmost limit of DBM occurrence in the New World. Brethes (1923) gives a very short description of the species. Bourquin in 1939 described the lifecycle of DBM. Chiesa-Molinari (1953) reported the presence of DBM on cruciferous crops. Margheritis and Rizzo (1965) referred to the lifecycle but without data, and described the damage, mainly to cabbage, kale, rape, and so on; they also cite *Apanteles alexanderi* (Brethes) and *Angitia leontiniae* (Brethes) as parasites.

Brazil

Bertels (1956) reported DBM infesting cabbage in southern Brazil and gave description of the damage and the different life stages. He mentions six generations of this insect per year, approximately 35 days a generation: egg, 6 to 7 days; larva, 14 to 18 days; pupa, 12 to 14 days. Bondar (1928) could be regarded as the second author to write about DBM in South America, when he reported it as a serious pest of cabbage in Bahia, in northeast Brazil. Costa-Lima (1936) mentioned DBM on kale and cabbage in Bahia State, Minas Gerais and Rio de Janeiro. The same author, in his 1945 work on the insects of Brazil written in 11 volumes, gives the general characteristics of the family Plutellidae, citing that 200 to 300 species are described; he describes the adult and the damage of DBM on cruciferous plants.

Chile

Gonzalez et al (1973) report DBM in Chile as a pest of cauliflower, rape, cabbage and brussels sprouts.

Colombia

Posada et al (1970) mention DBM damaging *Brassica* sp in Colombia.

Cuba

Cook and Horne (1908), as far as we know, were the first authors to write about DBM in the Neotropics, when they published a paper on 'Insects and Diseases of Vegetables' in Cuba. They briefly described larva, pupa and adult, and mentioned that the insect was abundant on cabbage and rape, where it caused considerable yield loss.

Dominican Republic

Salinas and Pena (1976) stressed the importance of DBM in Venezuela and in the Dominican Republic. In their paper they indicate that the most serious damage to cruciferous crops is in the area of Constanza de la Vega. Santoro (1960) mentions DBM as a pest of cruciferous crops in the Dominican Republic. He refers to the parasites of that species, namely *Angitia fenestralis* Holm (Hymenoptera: Ichneumonidae). and *Diadromus subtilicornis* Grav (Hymenoptera: Ichneumonidae) and *Apanteles ruficornis* Nees (Hymenoptera: Braconidae). Unhappily he does not mention the country from where those parasites were recorded and it is dubious that they were from the Dominican Republic.

Jamaica

Edwards (1930) referred to DBM in Jamaica, but he misnamed the species as 'the small green cabbage worm, *Plutella cruciferarum* Zell.'

Peru

Wille (1952) reports incidence of DBM on cauliflower, radish, mustard and other crucifers in Peru. He describes the adult and the damage, and mentions important economic losses in seedbeds and newly planted fields. In dry and hot weather the insect also attacks the older plants. The author cites that in Lima there are eight generations a year; in summer there are four generations of about 18 days each. He estimates 300 eggs per female. The same author cites two parasites: *Angitia* (*A. plutellae* ?) and *Meteorus* sp.

Trinidad and Tobago

The Commonwealth Institute of Biological Control (CIBC) in Trinidad has been carrying out research on parasites of DBM, which is a very important pest of cruciferous crops, mainly cabbage and cauliflower, in that island. The work includes the introduction and release of parasites from other countries as well as their shipment to other countries; for example *Tetrastichus sokolowskii* from India, and *Apanteles plutellae* to Barbados (CIBC 1977).

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Diamondback Moth in Malaysia

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Abstract

The diamondback moth, *Plutella xylostella* (L), has been recorded in Malaysia since 1925. Since 1941, it has been the major pest of crucifers grown in the Cameron Highlands and in the lowlands. The length of the lifecycle is shorter in the lowlands than in the highlands, being 13 days and 27 days, respectively. There are usually four larval instars. A female moth may lay on an average 288 eggs in its life time. The insect occurs in higher numbers in the drier part of the year. Initially, nicotine extract was used to control diamondback moth. However, with the introduction of synthetic organic insecticides, farmers relied entirely on these insecticides. By 1957, the insect was found to be resistant to DDT and BHC. In the next seven years, malathion, diazinon and dieldrin proved ineffective. Within the next five years, endrin, telodrin, and trichlorfon had to be replaced. By 1972, the cost of pest control accounted for about 30% of the cost of production of cabbages in the Cameron Highlands. Resistance to insecticides was found to be common and the resistance factor to malathion was 2096. Farmers had by then resorted to mixing two or more insecticides at high concentrations and spraying at frequent intervals. An ecological approach was adopted in Malaysia in the early 1970s. A search for natural enemies resulted in the discovery of *Apanteles plutellae* Kurdj, *Tetrastichus ayyari* Rohw, an entomogenous fungus, *Entomophthora sphaerosperma* (Fres), syrphids and an unidentified chalcid parasitoid. However, existing natural biological control was very variable. Attempts were made to improve the situation by introducing four exotic parasitoids. Both *Thyraella collaris* Grav and *Diadegma eucerophaga* Horstm have established in the Cameron Highlands. Studies have also been conducted to evaluate entomogenous pathogens and other novel control measures. Attempts have been made to develop a pragmatic pest management program for the crucifer farmers. The challenge facing the implementation of such a program is in educating the farmers to adopt the integrated pest management approach.

Introduction

Few agricultural insect pests are as cosmopolitan as the diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae). This insect has been recorded beyond latitude 60°N in Iceland, in the temperate zone, and in the tropics. It thus has an ability to survive a wide range of temperatures. According to Hardy (1938), DBM prefers a warmer environment for its development, and he suggested the Mediterranean region as its most probable original habitat. The complex of natural enemies present in the European continent and the effective natural control reported lends support to the case.

DBM is an oligophagous insect and will feed on plants that contain mustard glucosides (Thorsteinson 1953). An important economic group of plants with mustard glucosides are members of family Cruciferae, which are essentially temperate climate crops. However, the crucifers, in particular the genus *Brassica*, have been spread from their original home to other regions. It is very likely that DBM spread along with the

spread of the crucifers. These plants were probably introduced into Malaysia from China, India, and European countries.

This review attempts to trace the history of the DBM in Malaysia, to highlight problems in controlling this pest and to discuss strategies in managing it in Malaysia.

Occurrence in Malaysia

The earliest record in the Department of Agriculture of DBM occurrence in Malaysia is a record from Fraser's Hill dated 30 September 1925 (Collection No 2798). By 1934, the insect was recorded from the Cameron Highlands, which had newly been opened up for cultivation. This area was marked for cultivation of temperate climate vegetable species. By 1941, Corbett and Pagden (1941) reported that the DBM was an important pest of cabbages in the Highlands and after the Second World War, it continued to be a serious pest of *Brassica* in Malaysia.

It is strongly believed that the DBM is an introduced insect (Ho 1965). This is supported by the following observations: (i) the preferred hosts are imported plants, (ii) the origin of the insect has been suggested to be in the Mediterranean region, (iii) there are few endemic natural enemies of the DBM in Malaysia and (iv) the genus *Plutella* in Malaysia is poorly represented and only one species hitherto is known.

The first sample of DBM collected from Fraser's Hill was recorded as *P. sera* Meyr and Milsum and Grist (1941) even reported that several species of the insect were present in the country. However, examination of the insects labelled as *P. sera* and collected on 30 September 1925 showed that they were misidentified. They were actually *P. xylostella* (Ooi 1979a).

P. xylostella has been recorded from both the highlands and lowlands where cabbage or other crucifers are grown. In the lowlands the common host plant is *Brassica juncea* Czern and *B. rapa* L.

Biology

The lifecycle of the DBM in Malaysia varies considerably depending on the environment under which it develops. In the lowlands the incubation period is about three days, the larval period requires about six days, and the pupal period lasts about four days (Ho 1965, Ooi and Kelderman 1979, Wan 1970). However, in the highlands the incubation period is about six days, the larval period takes about 14 days and the pupal period about seven (Ho 1965). In all cases, the number of larval instars recorded was four. The rates of growth in successive instars were found to be 1.65, 1.53 and 1.44, and the average ratio was 1.54 (Ooi and Kelderman 1979). In the lowlands, the caterpillar grows to about 8 mm long while in the highlands, larvae may grow slightly longer.

The number of eggs recorded per female moth varies among different reports. Ho (1965) reported that each female could lay between 81 to 379 eggs, Wan (1970) reported 7 to 318 eggs per female, while Ooi and Kelderman (1979) reported the number of eggs from 124 to 414 with a mean of 288 eggs per female.

In the laboratory, the moths were found to prefer the upper surface of the host leaves for oviposition (Chua and Lim 1979; Ooi and Kelderman 1979). In the field, however, observations support Robertson's (1939) view that eggs were largely found on the underside of cabbage leaves.

The DBM caterpillars feed by scraping the epidermis of the crucifer plants, and in cases of a large number of caterpillars feeding on the leaves these quickly become

skeletonised. Young plants would not survive such defoliation. When the caterpillar is fully grown, it selects a suitable site on the plant and spins an open-net silken cocoon which is open at both ends, and pupates within.

Laboratory studies showed that adult female DBM survived for 6 to 26 days with a mean of 16 days when fed on a diluted honey solution while males survived for 8 to 27 days with a mean of about 13 days.

Ecology

In an ecological study in the Highlands, it was found that the mean population density of the DBM varied from 2 to 78 immatures per plant (Ooi 1979b). A maximum of 160 immature DBM per plant was recorded from a site in the ecological study in 1976 (Ooi 1979b). Wan (1970) reported a mean level of 477 immature DBM per plant at the peak of an outbreak in Sarawak.

An examination of the incidence of DBM at four sites in the Cameron Highlands from 1976 to 1978 showed that the DBM population peaked in the months of February and March (Figure 1). This coincided with the drier part of the year in Cameron Highlands. In very dry periods, the population of DBM could rise higher. This indicates that dry weather favors a population build up by DBM (Ooi 1979b).

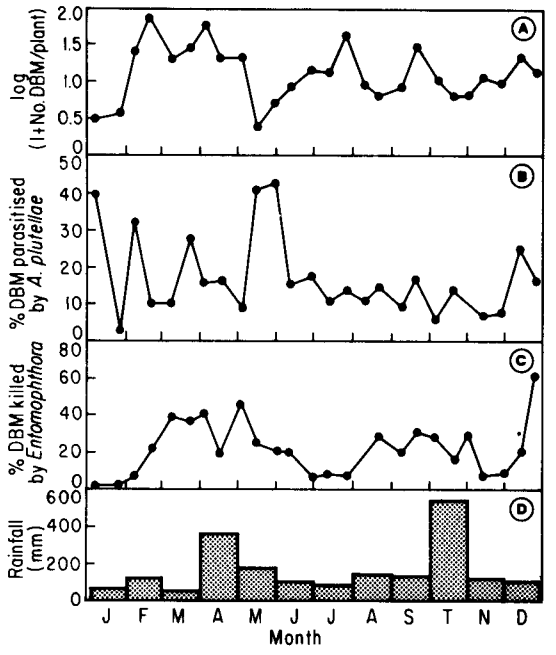

Figure 1.
A Number of DBM (larvae + pupae) per plant, (B) per cent parasitism by *Apanteles plutellae*, (C) per cent larvae infested by *Entomophthora sphaerosperma*, and (D) monthly rainfall. The data were recorded from a plot planted continuously to cabbage in Tanah Rata, the Cameron Highlands, Malaysia (adapted from Ooi 1979b, 1981)

It was also found that while the DBM attacks cabbage plants from seedlings to mature plants, the larvae of DBM prefer the younger leaves found in the middle and inner portion of the plant (Ooi 1979b). Chua and Lim (1979) found that under laboratory conditions, the larvae had an aggregated distribution.

Ho (1965) reported that no parasitoid of the DBM was recorded in Malaysia. However, Lim and Ko (1975) reported that the larvae of the DBM, in both the highlands and lowlands, were parasitised by *Apanteles plutellae* Kurdj (Hymenoptera: Braconidae).

Further work resulted in the discovery of a pupal parasitoid, *Tetrastichus ayyari* Rohw (Hymenoptera:Eulophidae) (Ooi and Kelderman 1977). Ooi (1979c) also reported the presence of the entomogenous fungus *Entomophthora sphaerosperma* (Fres) killing the caterpillars, syrphid larvae feeding on the caterpillars and a single instance of an unidentified chalcid parasitoid feeding on a caterpillar (Table 1). Thus, contrary to the report by Ho (1965) natural enemies do occur although at times they do little to prevent the DBM from becoming a serious pest, especially in the dry season.

Table 1. The natural enemy complex affecting DBM in Malaysia

Local natural enemies	Introduced parasitoids	Secondary parasitoids
Apanteles plutellae Kurdj	*Diadegma eucerophaga* Horstm	*Hemiteles* sp
Entomophthora sphaerosperma (Fres)	*Thyraeella collaris* Grav	*Tetrastichus* sp
Tetrastichus ayyari Rohw		*Mesochorus* sp
Unidentified chalcid		*Ceraphron* sp
Syrphid		Parasitoid 21036
		Parasitoid 21044
	Eupteromalus parnarae Gahan	
		Mockerzeckia (?) indica Subba Rao

The results of regular fortnightly samplings at four different ecological sites in the Cameron Highlands showed that the most common parasitoid of DBM was *A. plutellae* (Ooi 1979b). The average parasitism rates recorded were 12.3%, 18.5%, 18.2% and 19.1% (Ooi 1979b) (see also Figure 1). The highest level of parasitism was 78.8% at a larval + pupal population of about three per plant. Lim (1982) in his study in the Cameron Highlands reported an average parasitism by *A. plutellae* of 29.6%. This high level of parasitism is probably due to a lower population of the host. The results of field studies would suggest that *A. plutellae* has limited ability to control DBM. This was further supported by a preliminary study by Ang (1976) which indicated that *A. plutellae* had poor searching ability. However, under laboratory conditions, Lim (1982) found that the DBM population was reduced by 47 fold in the presence of *A. plutellae* and the action of *A. plutellae* was density dependent. *A. plutellae* certainly constitutes an important mortality factor although its effectiveness is reduced under field conditions.

Another important mortality factor affecting DBM in the Cameron Highlands is the fungal disease caused by *E. sphaerosperma*. The disease was recovered regularly in field samples (Figure 1). The disease was found to increase as pest population increased (Ooi 1981). During the course of the ecological study, no large scale epizootic was observed and this would support the view of Ullyett and Schonken (1940) that in areas with abundant rainfall and a high mean temperature the fungus would be a constant mortality factor.

Of the other natural enemies, it is suggested that these are incidental and would be insignificant as mortality factors.

Among the reasons for the limited control of the DBM achieved by *A. plutellae*, is the effect of its hyperparasitoids (Ooi 1979a, Lim 1982). A total of eight hymenopterous hyperparasitoids were reared from field collected cocoons of *A. plutellae* (Table 1). The most common hyperparasitoid recorded was *Hemiteles* sp. (Hymenoptera: Ichneumonidae) (Ooi 1979d). The average levels of hyperparasitism recorded from four

sites in the Cameron Highlands were 16.9%, 23.3%, 26.6% and 11.7% (Ooi 1979d). Lim (1982) reported an average hyperparasitism of about 21%.

Control

Being an introduced pest and removed from effective natural control, it is easy to understand how the DBM became a serious pest of cabbages when cultivation of this vegetable was developed in the Cameron Highlands in the 1930s (Bunting and Milsum 1930, Bunting 1932). By 1947, vegetable production in the Cameron Highlands was a viable industry (Lowe 1947). Corbett and Pagden (1941) reported that nicotine extract was effective in controlling the DBM caterpillars. With the introduction of synthetic organic insecticides in the early 1950s the use of natural insecticides was abandoned. No attempt was made to look for alternatives. This became a classic case of complete dependence on the use of insecticides to control DBM. This approach is similar to the one reported for the Canete Valley of Peru (Boza Barducci 1972). Invariably, resistance to insecticides developed in DBM and Henderson (1957) reported that the insect was resistant to DDT and BHC. Instead of looking for alternative control strategies, trials were conducted to look for insecticides which could replace the ineffective ones. Studies by Henderson (1957) resulted in the recommendation of malathion, diazinon and dieldrin. After about seven years, Ho (1965) reported that existing insecticides were ineffective in controlling the DBM and trials showed that endrin, telodrin and trichlorfon were effective and economical. About five years later, Ho and Ng (1970) carried out trials to identify newer insecticides to replace the ineffective ones and phenthoate, DDVP and matacil were found to be effective. Ho and Ng (1970) also reported that the microbial insecticide, *Bacillus thuringiensis* Berliner, was very effective. By this time, cabbage farmers in the Cameron Highlands were very much occupied with controlling DBM and Lim (1974) reported that nearly 70% of the vegetable farmers were still unsuccessful in controlling DBM effectively although the cost of pest control accounted for about 30% of the cost of production. Lim (1974) also reported the plight of the vegetable farmers and that farmers were changing insecticides to replace ineffective ones. Table 2 provides a history of insecticide usage in the Cameron Highlands and traces the continual search for newer insecticides to replace ineffective ones.

The problem of resistance is very real and a study by Sudderuddin and Kok (1978) reported high resistance factors for a wide range of insecticides. They reported that in the case of malathion, the resistance factor was 2096 (Table 2). A survey by Ooi and Sudderuddin (1978) showed that mixing two or more insecticides together in sprays ('cocktails') was a common practice by the farmers in the Cameron Highlands. In addition, most farmers used dosages of insecticides in excess of the recommended rates and sprayed frequently, sometimes three times a week. What Teh et al (1982) summed up for the future of synthetic pyrethroids holds true for all insecticides in that '..the massive and regular use of a variety of insecticides without any possibility of relent..' will make the future of effective chemical control of DBM bleak. Nevertheless, there have been more studies to screen for effective insecticides to control DBM (Mohamad et al 1979, Mohamad et al 1980, Mohamad and Baharom 1984).

With this background it appears that an ecological approach is necessary. From the early 1970s, ecological studies were carried out, especially in the more seriously affected area of the Cameron Highlands. Most of the ecological information reported in the previous section was obtained from such studies. One of the conclusions was that existing natural control was not sufficient to control the DBM. From 1975, attempts were made to introduce effective parasitoids of DBM to increase the level of natural control. It is recognized that for a high priced short term crop, such as cabbage, really

Table 2. History of insecticide usage for control of DBM in Malaysia

Insecticides	Year introduced	Status
	before	
Nicotine and Derris	1950	replaced by synthetic organic insecticides
DDT	1950	resistance suspected by 1956, resistance factor (rf) = 529.6
Gamma BHC	1950	resistance suspected by 1956 rf = 64.4
Dieldrin	1950	not used on cabbages after 1956
Malathion	1956	used in combination with other insecticides rf = 2096.0
Dimethoate	1956	used mainly for leafminer control
Diazinon	1956	used in combination with others
Trichlorfon	1964	poor control by 1966
Isobenzan	1964	usage stopped by 1966
Dichlorvos	1966	used in small amounts rf = 40.0
Methomyl	1967	used reduced by mid-1970s rf = 12.3
Aminocarb	1969	resistance suspected by 1970
Quinalphos	1969	poor control by 1970
Leptophos	1970	poor control by 1971
Methamidophos	1970	used at high dosage and in combination with other insecticides rf = 6.2
Cartap	1973	poor control by 1975 rf = 15.5
Bioresmethrin	1974	good initial control but unpopular
Fenvalerate	1975	usage reduced by 1979 rf = 4.5
Prothiophos	1976	farmers used high dosage by 1979
Permethrin	1978	used in combination with other insecticides rf = 754.5

Adapted from Lim (1974, 1982), Ooi and Sudderuddin (1978), Sudderuddin and Kok (1978) and Teh et al (1984).

effective biological control would be difficult to achieve. Thus the strategy of introducing exotic parasitoids was to improve natural biological control and hence reduce the pest level, which would allow other control measures to be integrated with it.

Four parasitoids were introduced into Malaysia between 21 October 1975 and 22 January 1978. These parasitoids were *Diadegma eucerophaga* Horstm (Hymenoptera: Ichneumonidae), *Thyraella collaris* Grav (Hymenoptera: Ichneumonidae), *Macromalon orientale* Kerr (Hymenoptera: Ichneumonidae) and *Tetrastichus sokolowskii* Kurdj (Hymenoptera: Eulophidae) (Ooi 1980, Ooi and Lim 1983). The first two parasitoids were established in the Cameron Highlands, the third failed to survive laboratory breeding and was not released, while the eulophid parasitoid was recovered only for a short period and has not been recovered since. *D. eucerophaga* was introduced from New Zealand and Indonesia while *T. collaris* was introduced from India, New Zealand, and Australia. Both *M. orientale* and *T. sokolowskii* were introduced from India. At present, the level of parasitism by the introduced parasitoids is found to be low and this had been attributed to excessive use of insecticides on cabbage crops in the Cameron Highlands.

Managing DBM in Malaysia

Once the futility of a unilateral approach to controlling DBM was recognized, ecological studies were initiated which will aid an integrated pest management (IPM) approach to controlling this pest (Lim 1974, Ooi 1979a). Table 3 summarizes various developments in DBM control in Malaysia and the accumulation of information that has led to the present situation. As Lim (1982) pointed out, the initial approach to

Table 3. History of DBM in Malaysia

Year	Event
1925	First record of DBM
1934	Recorded in the Cameron Highlands
1941	Important pest of cabbages in Cameron Highlands
1950	Introduction of synthetic organic insecticides
1957	Resistance to DDT and BHC reported
1965	Biology of DBM reported and more insecticide resistance suspected
1970	Newer insecticides to replace ineffective ones for control of DBM
1972	Survey in the Cameron Highlands showed problems in DBM control
1973	Ecological studies initiated and *Apanteles plutellae* discovered
1974	Problems in DBM control reported and suggestion for an integrated pest control approach
1975	*Entomophthora sphaerosperma* and *Tetrastichus ayyari* discovered
1976	Exotic parasitoids introduced and released resistance to insecticides quantified
1977	*Diadegma eucerophaga* and *Thyraeella collaris* established
1978	Biology and ecology of DBM parasitoids studied
1979	Effects of chemosterilants on DBM reported
1980	Effects of insect growth regulators on DBM studied
1981	Assessment of cabbage losses caused by DBM
1982	Public outcry over possible insecticide residues on cabbages following DBM control
1983	Trials to evaluate an integrated pest control or management program for DBM
1984	Report of granulosis virus for DBM control

managing DBM in Malaysia should hinge on spraying only when necessary. In order to achieve this, the most rational step is to develop pest threshold levels so that farmers have a criterion to follow before deciding on a spray operation. Even utilizing a tentative threshold level would lead to a reduction in number of sprays applied. The study by Jusoh et al (1982) has contributed to an understanding of yield loss caused by DBM and this information has been refined and applied in the IPM trials carried out by Sivapragasam et al (1984). The results showed that the IPM approach could reduce the number of sprays and yet secure marketable crops. More effective pesticide application technology would help in encouraging farmers to reduce their wastage in excessive dosage and spraying (Sivapragasam 1982).

Another factor to consider in the IPM approach is the encouragement of biological control. The importance of biological control has been shown by Lim (1982) and Ooi (1979a). Apart from improving the environment to facilitate existing natural biological control (Lim 1982), there is also the possibility of introducing more exotic parasitoids to complement the existing ones. Attempts to do this have been reported by Ooi and Lim (1983) and more work is needed.

As noted in Table 3, development of other control methods for DBM has also been reported. Choi and Sudderuddin (1979) reported encouraging results with chemosterilants while studies by Tan (1981) have given encouragement to the approach of incorporating insect growth regulators in a pest management program. Laboratory studies by Hussan (1984) also showed that the granulosis virus of DBM could be used to control the pest. All these possibilities should now be pursued actively to improve the present IPM program. As a first step, there should be an urgent attempt made to consolidate all these research efforts.

However, research information alone is insufficient in the implementation of a DBM management program. Bringing the information to the crucifer farmers is equally important but this is an area which is very much neglected (Sivapragasam 1982). For the successful implementation of a DBM management program, the farmer must

understand and accept its concept. To achieve this, Sivapragasam et al (1984) proposed that studies be carried out to understand the attitudes and behavior of the farmers. This will facilitate the education of the farmers as well as the education of the scientists as to the needs of the farmers. It is this understanding and co- operation between farmers and scientists that will eventually determine the success and failure of the DBM management program.

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Diamondback Moth in Indonesia

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Abstract

Investigations into diamondback moth in Indonesia were started during colonial times by Dutch entomologists. In the early 1950s there was renewed interest in research into control of this pest by the introduction of parasites, and Vos's classical publication gives the details of this work. In 1968 there was a large scale outbreak of this insect which gave further impetus to the investigation of diamondback moth. The author reviews the research carried out so far on the biology, ecology, population monitoring, biological control, and chemical control of diamondback moth.

Introduction

Although diamondback moth (DBM) (*Plutella xylostella* L) (Lepidoptera: Yponomeutidae) has been reported to be a pest of crucifers in Indonesia since the beginning of this century (Vos 1953), our research group became interested in it only in 1968 when there was a severe outbreak of the pest in Lembang, the major vegetable growing highland area of West Java. Until then DBM was under control and was considered as a secondary pest of many crucifers. The renewed interest in this insect led to the initiation of several basic studies, specifically related to its control. This paper reviews the research work conducted on DBM since 1968.

Population Studies

Monitoring

The purpose of this study was to determine the seasons when diamondback moth causes damage to crucifers. This work was similar to and partly inspired by Robertson's studies in New Zealand (Robertson 1939). Data of this nature gives valuable information about specific local importance. After 1968, weekly monitoring of DBM populations was carried out in the Lembang area in order to study the causes of the insect outbreak. Besides monitoring of DBM populations, observations were also recorded on crop damage, the level of parasitism, local weather, possible alternate hosts, and insecticide application by local growers. In the first three years of monitoring, the results showed that the DBM population was at epidemic level. The level of parasitism of *Diadegma eucerophaga* Horstm (Hymenoptera: Ichneumonidae) was below 30%. During the years of monitoring, two dry months—September and October—appear to trigger the outbreaks. This was corraborated by further work by Sudarwohadi (1974) which revealed that rainfall is a major limiting factor for DBM populations.

Crop stages and population trend

In a further population study, Yuwono (1975) studied the correlation between crop growth stage and population trend, especially the proportion of various immature stages

of the insect. Within a crop season of 70 days data were recorded at 10, 16, 21, 26, 31, 36, 52, 63 and 65 days after transplanting, on the total number of insects per plant and on the composition of the population at larval instars and pupa stages. The study indicated that within the 70-day growing period, the DBM population peaks at 45 days after transplanting. The distribution of immature stages revealed that there were two generations and considerable overlapping of these generations (Figure 1). Given the continuous availability of the host, the insect is likely to continue breeding throughout the year.

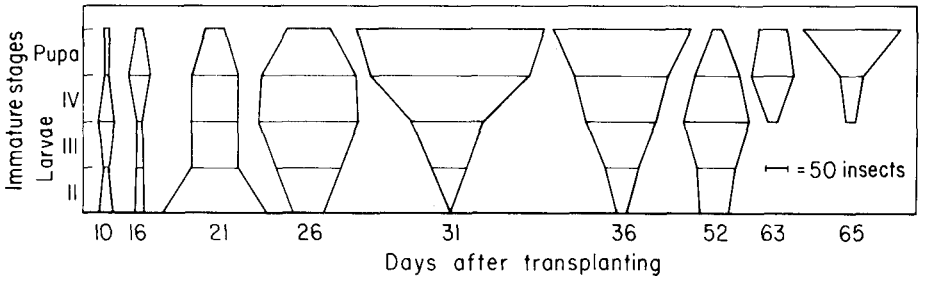


Figure 1 Age composition of DBM population in a cabbage field within a growing season at Bandung, West Java (Yuwono 1975)

Insect pest community

After the initial few years of observations, it was deduced that DBM is not the only pest that attacks crucifers in Java. Weires and Chiang (1973) investigated the relative abundance of *Spodoptera* sp, *Hellula undalis, Heliothis armigera, Plusia orichalcea, Agrotis ypsilon, Crocidolomia binotalis* and DBM to decide the status of various pests and the position of DBM in the pest community. The number of insects of each species was recorded per unit sampled plants for up to 16 weeks in an insecticide-free field near Bandung. Among seven locations with relatively small distance between them, DBM was found to be dominant at only three locations. Other insects such as *C. binotalis, H. armigera, A. ypsilon* and *P. orichalcea* were much more dominant at other locations.

Biological Control

The introduction of a parasite, *Diadegma eucerophaga* by Vos (1953) from New Zealand for DBM control in Java was the continuation of Dutch entomologists' efforts to control important agricultural pests in Indonesia by parasitoids and predators (Eveleens 1976). Since then the research in this field has been confined to monitoring of the level of DBM parasitism by *D. eucerophaga* (Sastrodihardjo 1970, Sudarwohadi 1977, Janarti 1982). Sudarwohadi (1981) has also attempted mass rearing of the parasitoid and release in cabbage fields in other parts of the country.

Apparently *D. eucerophaga* has well adapted to an environment increasingly treated with insecticides. Data obtained from the laboratory and field study indicated that *D. eucerophaga* may have developed low levels of resistance to commonly used chemicals. In a laboratory study, Santoso (1979) treated DBM larvae and *D. ecucerophaga* adults with commonly used insecticides and mortality counts were recorded at intervals over a one-week period. The results of the mortality counts are summarized in Figure 2.

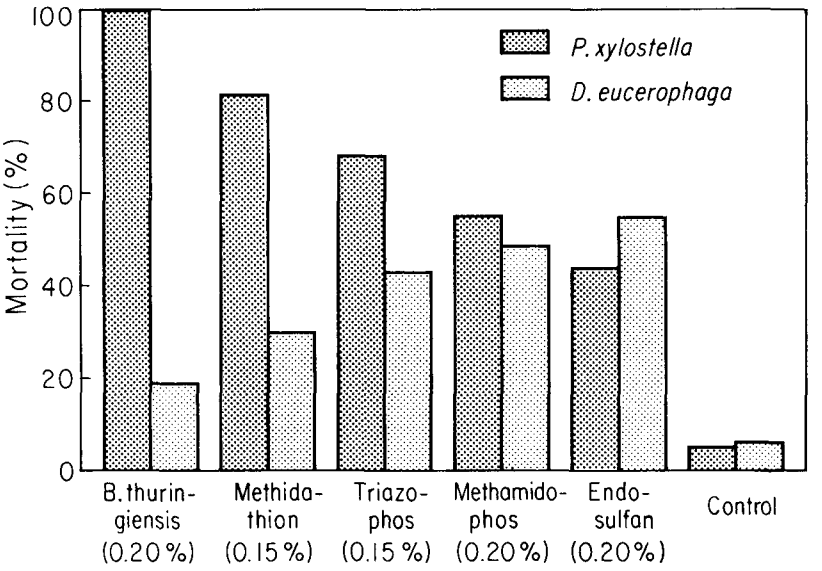


Figure 2. Toxicity of selected insecticides to DBM and its parasite, *Diadegma eucerophaga*, seven days after treatment, laboratory study (Santoso 1979)

In general, parasites and predators tend to be more susceptible to insecticides than do the host insects. In Santoso's study, however, mortality of *D. eucerophaga* was equal to or less than that of DBM. Dipel, a *Bacillus thuringiensis* formulation, was especially selective against DBM. Endosulfan caused slightly greater mortality in *D. eucerophaga* than in DBM. Janarti (1982) surveyed DBM and *D. eucerophaga* populations in untreated and insecticide treated plots. His survey (Figure 3) indicated a similar pattern in population changes in both untreated and treated field, indicating that these insecticides are not excessively harmful to *D. ecucerophaga*. Conversely, as indicated by laboratory studies, it can be deduced that *D. eucerophaga* has developed a degree of resistance to insecticides.

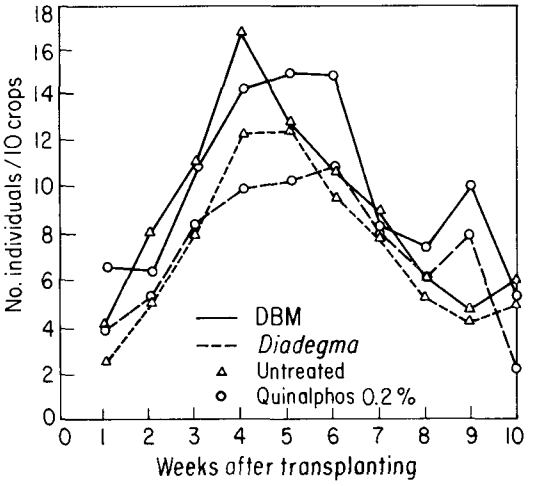


Figure 3.
Population trends of DBM and its parasite, *Diadegma eucerophaga*, in untreated and insecticide-treated plots (Janarti 1982)

Various strains of *Bacillus thuringiensis* imported from Japan have been screened against DBM by Sjamsuriputra et al (1976). His results showed that among 20 strains belonging to various serotypes, all strains of variety *aizawai* namely aizawai IH-A, aizawai HA-3, and aizawai T36-L4, were superior to others in effectiveness against DBM. Investigations on the preference of cabbage foliage by DBM indicated that DBM larvae always preferred younger leaves even if they were covered with *B. thuringiensis* (Sukarman 1982).

A preliminary study by Subiana (1973) on mating behavior of DBM indicated the possible existence of a sex pheromone. However, no further research has been done into this.

Chemical Control

Use of insecticides is the most common method of DBM control in Indonesia. Before the introduction of synthetic organic insecticides, arsenates were used for insect pest control. Arsenates were later replaced by Derris powder which gave effective control of this pest (van der Vecht 1936). After the Second World War, DDT was the chemical most frequently used by growers to control cabbage pests. Probably the first report of any agricultural pest becoming resistant to organic insecticides involved DBM to DDT in Java (Angkersmit 1953). Ever since that report, insecticide resistance in DBM has become a routine phenomenon. In recent years organophosphorus and carbamate insecticides have replaced organochlorines practically all over Indonesia (Sudarwohadi 1974). In the early 80s synthetic pyrethroids were introduced and became popular because of their quick action, but DBM developed resistance to these chemicals more quickly than expected. Very little basic work on the physiological effect of insecticides on DBM and on the mechanism of insecticide resistance has been done. Laksana (1974) and Suradinata (1979) studied the effects of organophosphorus insecticides on the development and respiration of DBM larvae. Treatment with 10 ppm quinalphos reduced the relative growth rate by 60, 50, and 30% respectively of 1st, 2nd, and 3rd instar larvae. Oxygen consumption in 3rd instar larvae increased by 20% half an hour after treatment with 0.1% quinalphos, and this was followed by a 50% reduction thereafter.

Resistant Cultivars

Very little research effort is devoted to searching for DBM resistance in crucifer species, or to breeding of resistance in horticulturally desirable cultivars. In one study at the Bandung Institute of Technology, Gunawan (1975) studied the resistance of six commercial cutlivars: RvE-37, Osena, Yoshin 1, Yoshin 2, KY Cross and KK Cross. Plants were grown for seven weeks and observations on the number of DBM larvae present on each cutlivar were recorded at weekly intervals. In general KK Cross was less infested than the others and RvE-37 was the most heavily infested, especially in later growth stages.

Sterile Insect Technique

The severity of the DBM problem has attracted the attention of the National Atomic Energy Agency. A special committee was formed in 1972 which decided to explore the possibility of using the sterile male technique to control several agricultural pests, including DBM. Several basic and applied investigations were carried out with a view to controlling DBM.

In order to raise large numbers of pupae for irradiation and eventual release in the field, several mass rearing techniques, including use of synthetic diets as well as various host plants, were tried (Subiana 1973, Sugiyanto 1973, Sutomo 1974). Comparisons were made in respect of percentage survival, duration of each immature stage, pupal weight, adult longevity and sex ratio between the insects raised on synthetic or semi-synthetic diets and those raised on natural host plants. Natural host plant, cabbage, proved to be better than other diets. Laksana (1974) explored the use of ^{32}P and ^{35}S radioisotope tagging to study the dispersal of DBM in the field. She was able to detect quite high level of radioactivity in the larvae of which had been fed on a diet containing ^{32}P and ^{35}S. This basic information was useful in deciding upon the release of sterile males. In other radiation-related basic studies, Hutabarat (1976) observed a direct relationship between gamma radiation dosage and ovarial damage in DBM. Ovarioles of adults emerging from pupae that had been treated with 15 to 20 krad were 2 mm shorter than the ovarioles of normal adults. The effect of the irradiation was more marked during vitellogenesis, wherein large vacuoles were observed at the alpha oocyte stage (Figure 4). A quite intensive study on mass sterilization (^{60}Co source) and release of sterile males in a small scale field was carried out by Hudaya (1976, 1983). A dose of 30 krad applied to pupae was able to induce optimal sterility in adults without impairing adult emergence (Figure 5). In a cage experiment where plants were intentionally infested with DBM, release of sterile males (9 sterile: 1 normal) reduced DBM populations by 61% by the next generation. However, further research is still necessary to make this technique practical for the control of DBM in the field.

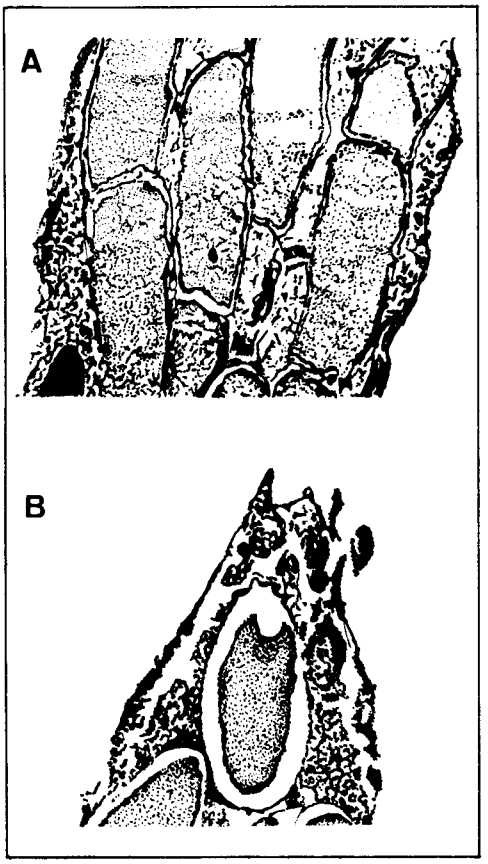
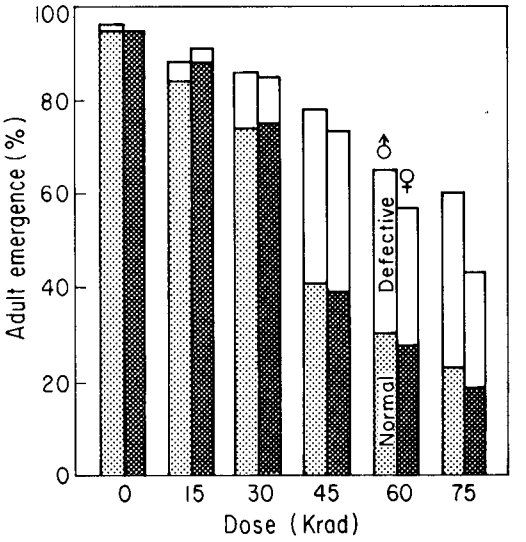


Figure 4.
(A) Ovarioles of normal DBM female (255X) and (B) of female whose pupa was exposed to 17.5 Krad of gamma rays (85X) (Hutabarat 1976)

Figure 5.
Influence of gamma ray irradiation on emergence of DBM adults from irradiated pupae (Hudaya 1983)



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Diamondback Moth and its Control in Japan

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Abstract

The diamondback moth, *Plutella xylostella* (L), is a serious pest of cruciferous vegetables, particularly of cabbage, grown extensively in the spring and early summer. Diamondback moth larvae usually infest and cause injury more or less throughout the country. The insect infests the crop all the year round in the southern parts and warm areas of the central parts of Japan. In the cooler mountainous regions of the central and the northern parts of country, diamondback moth appears only from the spring to autumn. A synthetic pheromone lure is now available for trapping to survey the diamondback moth populations. The data of moth catches by pheromone traps within cabbage fields is useful in assessing subsequent larval population trends. This is expected to permit a reduction of the number of insecticide spray applications without loss of yield and marketability.

Introduction

In Japan diamondback moth, *Plutella xylostella* (L) (DBM) (Lepidoptera: Yponomeutidae) was not a serious pest before 1965. However, for reasons as yet unknown, this insect has now become the most notorious pest of important crucifers such as cabbage, Chinese cabbage, and radish throughout the country. Since 1970, extensive research has been carried out on this pest in Japan. The present paper outlines salient features of biology, ecology, and control of DBM based on recent findings in Japan.

Developmental Biology

The duration of development from egg to adult of DBM at different temperatures was determined by Umeya and Yamada (1973), Nakagome and Kato (1975), and Yamada and Kawasaki (1983). According to Yamada and Kawasaki (1983), the duration from egg to adult was approximately 23 and 16 days at 20°C and 25°C respectively (Table 1). This indicates that from the late spring to early summer, when monthly mean temperatures are around 20°C, one generation takes about three weeks. This favors rapid increases in DBM population in cabbage fields. Table 2 summarizes the approximate threshold temperatures for development from egg to adult and the effective thermal totals. The developmental threshold temperatures, as well as the effective thermal totals, do not seem to differ significantly among the localities from the south to the north in Japan.

According to Yamada and Kawasaki (1983), rates of egg hatching, pupation, and adult emergence, were relatively high at 17.5°, 20°, 22.5°, 25° and 27.5°C and low at 30° and 32.5°C (Table 3). Fecundity of the adults seemed to be affected by temperature conditions under which the insects were reared from egg to adult. Numbers of eggs laid per female moth were more numerous when insects were reared at temperatures ranging from 22.5°C to 27°C than at 17.5 or 30.0°C (Table 4). Yamada and Kawasaki (1983)

Table 1. Development of DBM reared under different temperature conditions[a]

Temperature (°C)	Developmental period in days		
	Egg	Larva	Pupa
32.5	— [b]	7.8±0.4[c]	3.9±0.6
30.0	2.4±0.1	7.8±0.2	3.2±0.2
27.5	2.5±0.1	8.3±0.1	3.5±0.1
25.0	3.0±0.1	9.2±0.2	3.8±0.2
22.5	3.1±0.1	11.7±0.5	4.8±0.2
20.0	4.1±0.1	13.5±0.2	5.4±0.3
17.5	5.7±0.1	19.1±0.4	9.6±0.3

[a] Source (Yamada and Kawasaki 1983) [b] Missing data. [c] mean ± standard deviation.

Table 2. Approximate threshold temperatures for development from egg to adult and effective thermal totals of DBM

Locality	Threshold temperature (°C)				Effective thermal total (day-degree°C)			
	Egg	Larva	Pupa	Total	Egg	Larva	Pupa	Total
Tsu[a]	7.2	8.5	9.8	—	52	161	61	—
Nagakute, Aichi[b]	7.6	7.9	9.1	—	45	148	83	—
Sapporo[c]	7.3		8.2	7.4	238		79	313
Hiratsuka, Kanagawa[c]	9.2		8.7	9.5	174		65	229
Kagoshima[c]	6.7		9.8	7.5	233		61	294

[a] Yamada and Kawasaki (1983). [b] Nakagome and Kato (1975). [c] Umeya and Yamada (1973).

Table 3. Rates of hatching, pupation and adult emergence in DBM reared under different temperature conditions

Temperature (°C)	Rate of hatching[a] (%)	Rate of pupation[a] (%)	Rate of adult emergence[a]
32.5	— [b]	18.0	7.0
30.0	83.8	30.8	26.2
27.5	94.8	61.9	46.2
25.0	96.0	48.7	48.0
22.5	94.1	55.8	53.4
20.0	96.1	51.8	42.9
17.5	100.0	54.0	42.0

[a] In percent of eggs laid. [b] Missing data. Source: Yamada and Kawasaki 1983.

also give survivorship curves of the DBM from egg to adult under different temperatures (Figure 1). Theoretical estimation showed that the population grew rapidly at a steady rate with the rise of temperatures from 17.5°C to 27.5°C. At 30°C, the population growth was obviously retarded (Table 5). Rates of hatching, pupation, and adult emergence were not affected by the level of humidity (Table 6).

The longevity of female moths did not differ signficantly from that of males. Adult longevity became shorter with the rise of temperatures. The longevities ranged seven

Table 4. Longevity and fecundity of adult DBM reared under different temperature conditions

Temperature (°C)	Longevity (days)[a]		Fecundity (No. of eggs)
30.0	male	2.3 + 0.6	30.8 + 44.3
	female	4.6 + 2.4	
27.5	male	5.0 + 0.7	75.6 + 21.7
	female	4.0 + 0.4	
25.0	male	6.5 + 0.8	62.6 + 14.6
	female	6.2 + 0.1	
22.5	male	7.0 + 1.1	77.4 + 14.5
	female	6.5 + 0.2	
17.5	male	6.6 + 1.5	45.6 + 11.8
	female	6.9 + 0.8	

[a] Distilled water was supplied to the adults. Source: Yamada and Kawasaki 1983.

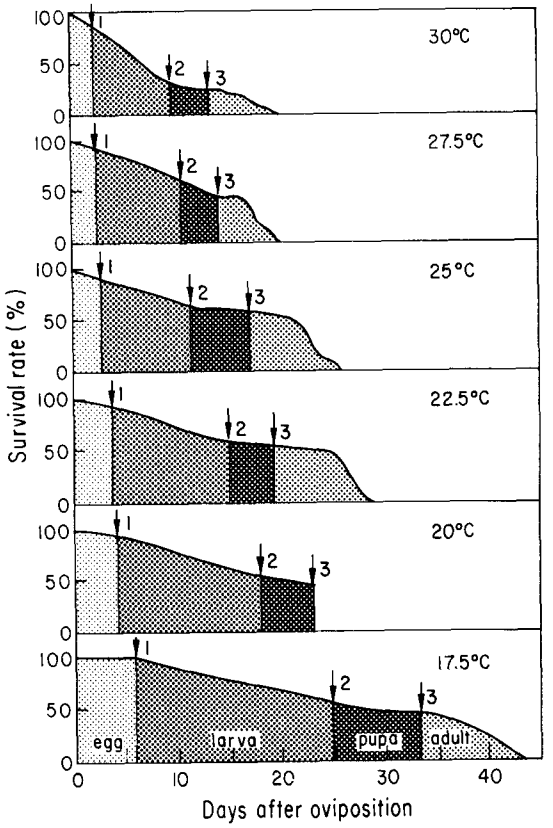

Figure 1.
Survivorship curve of DBM at different temperatures. 1: hatching. 2: pupation, 3: adult emergence (Yamada and Kawasaki 1983)

to nine days at 22.5°C (Table 7). According to Sakanoshita and Yanagita (1972), female moths began to mate soon after the emergence. Mated female moths tended to live for a shorter period than unmated ones (Figure 2). Mated females lived for around nine days and laid most of the eggs in one to five days after emergence at 22.5°C (Yamada 1978).

Table 5. Theoretical estimation of multiplication of DBM reared under different temperature conditions

Temperature (°C)	Rg[a]	T[b]	r/f/ day[c]	r/f/ month	e^r/ month[d]
30.0	3.979	17.594	0.078	2.34	1.04×10
27.5	15.932	15.654	0.177	5.31	2.02×10^2
25.0	16.285	18.807	0.148	4.44	8.48×10
22.5	18.801	21.891	0.134	4.02	5.57×10
17.5	9.139	36.678	0.060	1.80	6.05

[a] Rg: net reproductive rate per generation. [b] T: mean generation time. [c] r/female/day: intrinsic rate of natural increase per female per day. [d] e^r/month: multiplication per female per month. Source: Yamada and Kawasaki 1983.

Table 6. Rates of hatching, pupation and adult emergence of DBM reared under different humidity conditions

Relative humidity (%)	Rate of hatching (%)	Survival rate of 4th-instar larva (%)	pupation pupation (%)	Rate of adult emergence (%)
30	96.4	81.0	77.1	75.9
40	98.0	91.4	90.2	86.2
60	96.6	91.5	91.5	85.0
80	93.9	83.9	77.9	70.1
98	98.0	93.8	90.2	85.0

Source: Yamada and Kawasaki 1983.

Table 7. Longevity and fecundity of adult DBM reared under different temperature conditions[a]

Temperature (°C) during the immature stages	Longevity (days)	Fecundity (No. of eggs)
30.0	male 9.2 ± 1.4 female 6.3 ± 0.9	99.0 ± 32.1
27.5	male 6.7 ± 0.9 female 5.4 ± 0.5	105.2 ± 31.3
25.0	male 7.3 ± 0.9 female 6.3 ± 0.7	95.2 ± 25.0
22.5	male 9.1 ± 0.9 female 7.2 ± 0.7	129.5 ± 22.5
20.0	male 8.9 ± 1.1 female 7.1 ± 0.6	116.8 ± 23.5
17.5	male 6.3 ± 1.0 female 5.9 ± 0.8	78.7 ± 19.4

[a] Prematuare insects were reared under different temperature conditions but adults were observed at a fixed temperature of 22.5°C Water containing ca 2% of sugar was supplied as food. Source: Yamada and Kawasaki 1983

The quality of food seems to affect the development and fecundity of the DBM. Yamada et al (1980) reported that adult emergence and fecundity were lower when larvae were fed on leaves of matured cabbage plants than on younger cabbage leaves (Table 8).

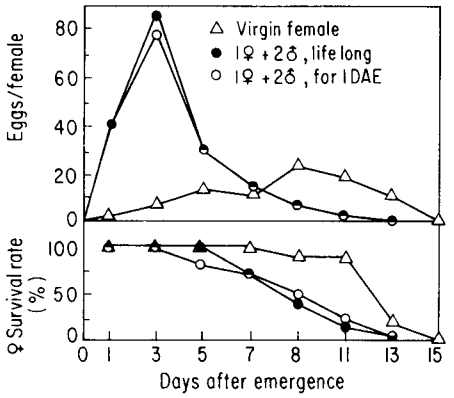

Figure 2.
Changes in the number of eggs laid and survival rate in female DBM. One day old moths were used. DAE = Days after emergence. (Source Yamada 1979)

Table 8. Development and fecundity of DBM reared on cabbage leaves of different growth stages

Developmental period (days)		Longevity of adult (days)	Rate of pupation (%)	Rate of adult emergence (%)	Fecundity No. eggs per female
larva	pupa				
Early vegetative growth stage					
14.5 ± 0.3	5.9 ± 0.2	9.5 ± 7.1 7.6 ± 4.1	73.3	59.3	75.3 ± 17.5
Just before head formation					
14.1 ± 0.3	5.7 ± 0.2	10.9 ± 4.4 7.0 ± 1.3	64.7	60.7	107.3 ± 17.0
After head formation					
15.0 ± 0.9	5.9 ± 0.2	6.9 ± 2.3 6.9 ± 1.5	27.3	22.0	23.8 ± 13.9

Source: Yamada et al 1980.

Seasonal Abundance

In Japan, DBM commonly appears all year round in the central and the southern parts of the country. Even in the winter, larvae are observed feeding in crucifer fields during daytime when the daily maximum temperatures is around 10°C. On the other hand, in some mountainous regions of the central parts of the country, with altitudes of about 1000 m or more above sea level, and in northern parts, DBM appears only from the spring to autumn. No published information exists on how DBM survives the winter in these cool areas. In the northern areas of Honshu, the so far known northern-most limit for DBM overwintering, Maeda (1980) reported that the monthly mean temperatures of approximately 0°C or less from December to February might limit the survival of this insect through the winter.

According to the aforementioned research by Yamada and Kawasaki (1983), the thermal accumulation required for development from egg to adult of DBM was approximately 274 day-degrees at the threshold of 8.5°C. In the southern and warm temperate parts of central Japan, therefore, DBM seems to have 10 to 12 generations annually, based on its thermal day-degree accumulations during the year. As shown in Figure 3, in the central and the southern parts of Japan, seasonal population trends

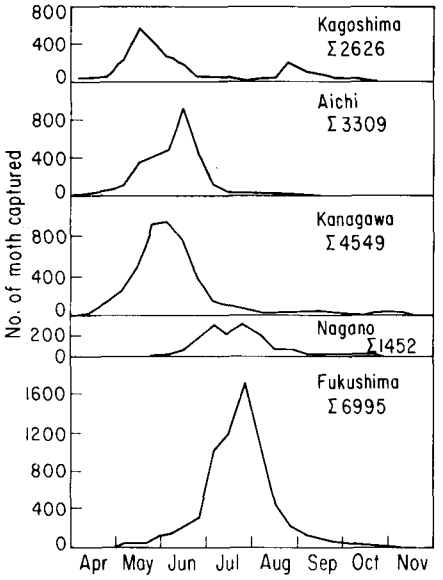

Figure 3.
Seasonal changes in DBM catches by light trap in different areas of Japan. Mean numbers of moths captured per 10-day period from 1970 to 1975 are shown. Data came from each of the five prefectural agricultural experiment stations. Figures indicate mean numbers of moth captured in a year

of DBM are basically similar between locations, although the population densities differ, and the populations are usually most numerous from spring to early summer. Figure 4 gives an illustration of annual fluctuation in DBM population densities observed in warm temperate areas. The population density in cultivated areas may sometimes be affected by unusually cold periods in winter and/or drought in summer. On the other hand, in some mountainous regions of the central Japan and in the northern parts of the country, possibly five or six generations occur from spring to autumn. The population is highest in mid-summer.

Nakagome and Kato (1974) noted that the sex ratio of DBM captured in light traps was 0.9:1, females to males. According to Yamada and Umeya (1972), the length of DBM forewings varies from season to season. As shown in Figure 5, the adult moths which appeared in the summer had shorter forewings. Yamada and Umeya (1972) also found that female moths collected from cabbage fields in August were short- lived and laid fewer eggs, while the female moths collected from December to March were long-lived and laid more eggs (Table 9).

Table 9. Seasonal changes in longevity and fecundity of DBM[a]

	Jan	Mar	Apr	Aug	Oct	Dec
Longevity (days)	9.8	6.1	5.1	3.3	6.8	7.4
Fecundity (no. of eggs/female)	272.3	259.6	178.6	102.6	216.4	268.5

[a] Pupae were collected from cabbage fields, and resultant female adult moths were reared at 25°C. Source: Yamada and Umeya 1972.

Much attention has been paid to factors affecting the above-mentioned summer decline in the seasonal population trend of DBM in warm temperate areas of the southern and central parts of Japan. As described earlier, it was theoretically demonstrated that the multiplication of DBM population was highest around 27.5°C, and lowest at 30°C.

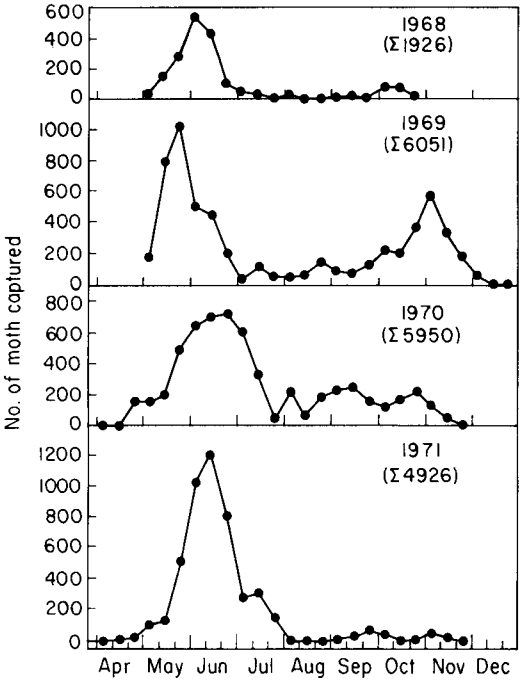

Figure 4.
Changes of DBM catches by light trap in Hiratsuka, Kanagawa, by year. Numbers of moths captured in two light traps per 10-day period. (Source: Yamada and Umeya 1972)

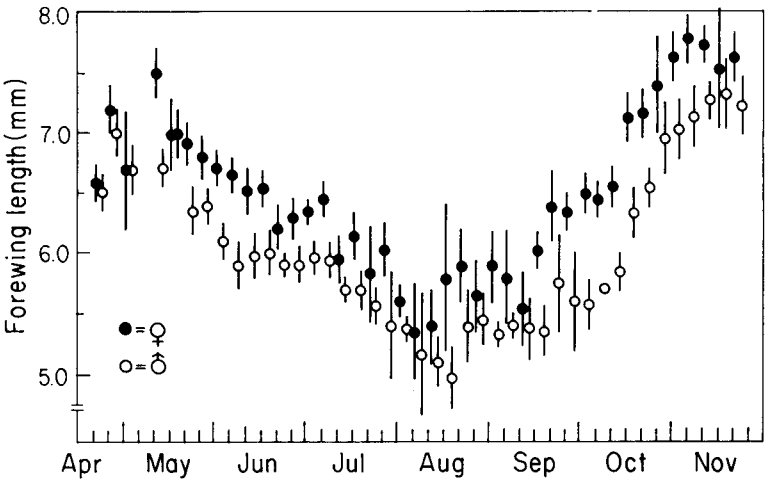

Figure 5. Seasonal changes of forewing length in DBM collected from cabbage fields from April to November in Hiratsuka, Kanagawa (Source: Yamada and Umeya 1972)

Yamada and Kawasaki (1983) pointed out that in Japan, daily mean temperature during mid-summer (August) seldom exceeds 27.5°C, and therefore it is unlikely that the marked summer decline of DBM population could be explained by high temperatures in this season. In the summer in warm temperate areas of the central and southern parts of Japan, commercial cultivation of cruciferous vegetable crops has decreased. This is

because the monthly mean temperature rises to around 27°C which is too hot for successful cultivation of most crucifers. Almost all of the cruciferous weeds also disappear in the cultivated areas during this period. This obvious decrease in vegetation, therefore, might be one important cause for the marked summer decline of DBM population. On the other hand, in cool areas of the mountainous regions of the central parts of Japan and in the northern parts of the country, there is snow from December to February. Therefore, commercial cultivation of cruciferous vegetable crops is confined to the period from May to September. With the monthly mean temperature of around 23°C, this season favors rapid multiplication of DBM population.

Yamada and Yamaguchi (1984) noted that the DBM had more than six hymenopterous parasites. These include: egg parasites, *Tricogramma* spp; two larval parasites, *Apanteles plutellae* Kurdjumov and *Diadegma* sp; and three pupal parasites, *Diadromus collaris* Gravenhorst, *Coccygomimus nipponicus* Uchida, and *Tetrastichus* sp. Among these, *A. plutellae*, *Tetrastichus* sp, and *D. collaris* are the most important. These species are predominant in the summer. Some predator species were also discovered. Among these, four coleopterous species, *Chlaeninus micans* Fabricius, *Paederus fuscipes* Curtis, *Philonthus wusthoffi* Beruk, and *Labidura ripara* Pallas, and seven species of spiders, are important. Granurosis virus is also important. This virus disease is prevalent mostly in the early summer and fall. It is believed that natural enemies are an important factor in the regulation of DBM populations. However, details of their role have not yet been studied.

Population Dynamics Within and Around Cabbage Fields

Seasonal population trends of DBM adults around cabbage fields, and population growth during the cabbage-growing period within the fields, were recently investigated using pheromone traps (Koshihara, unpublished).

DBM female sex pheromone components, z-11-hexadecenal and z-11-hexadecenyl acetate, were isolated and identified by Tamaki et al (1977). The effectiveness of the sex pheromone components to male moths was examined in detail by field trapping tests in a cabbage field. The mixture of synthetic sex pheromone components, z-11-hexadecenal and z-11-hexadecenyl acetate, and the parent alcohol, z-11- hexadecenol, in the ratio of 5:5:0.1 coated on a rubber septum (0.1 mg/septum) was found to be more attractive to male moths in all seasons (Koshihara et al 1978, Koshihara and Yamada 1980, 1981). This synthetic pheromone lure is now commercially available in Japan and is used mainly for surveying DBM populations. Techniques for surveying DBM populations by using pheromone traps have been in use in vegetable pests forecasting programs organized by the Government since 1980.

By using pheromone traps, Koshihara (unpublished) indicated that the seasonal population trends of the DBM around the cabbage fields are similar among locations, despite large variations in the population densities among them. DBM population growth on cabbages was caused mostly by infestation of adults derived from crucifers around the cabbage fields. During about 70-day cabbage growing period in the spring there were three generations. This was as expected from the thermal day-degree accumulations necessary for development from egg to adult. The population in the cabbage fields grew independently of the temporal population trend around. As shown in Table 10, there were significant correlations between moth catches of every 5-day period within the cabbage fields during the first half of the growing season and the density of the larval population on cabbages with timelags of 0 to 15 days. Therefore, the data of moth catches in pheromone traps within the cabbage fields are expected to be useful in assessing subsequent larval population trends.

Table 10. Correlation between numbers of DBM adult catches per pheromone trap per five-day period during the first half of cabbage growing period and subsequent numbers of larvae per cabbage plant[a]

Year (Date)	Correlation coefficients with timelags of (days)					
	0	5	10	15	20	25
1983 (16 Apr - 20 Jun)	0.893***	0.862***	0.905***	0.771**	0.670*	0.279
1984 (6 May - 20 June	0.770*	0.930**	0.884**	0.834*	0.703	0.408

[a] Moth catches and larval numbers were counted every five-day period of calendar months, and correlations between moth catches and subsequent larval numbers with timelags were examined. Figures with asterisks show significances at 5% (*), 1% (**) and 0.1 % (***) levels respectively.

Control Measures

In Japan, besides DBM there are two other major lepidopterous pests infesting the most important cruciferous leafy vegetables such as cabbage and Chinese cabbage. They are the common white, *Pieris rapae crucivora* Boisduval, (Lepidoptera: Pieridae) and the cabbage armyworm, *Mamestra brassicae* Linne (Lepidoptera: Byralidae). Table 11 shows major growing periods of cabbage and Chinese cabbage and the important pests attacking them during each growing period. Particularly on cabbage grown extensively not only in the autumn but also in the spring and early summer, pest occurrences are serious.

Table 11. Major cropping types of cabbage and Chinese cabbage and insect pests on them in Japan[a]

Insect pest	Cabbage			Chinese cabbage
	Spring cropping Plant-Harvest Apr-May Jun-Aug	Fall cropping Plant-Harvest Aug-Sep Nov-Apr	Winter cropping Plant-Harvest Oct-Nov Apr-May	Fall cropping Plant-Harvest Aug-Sep Nov-Jan
Plutella xylostella L	+ + ~ +	+ ~ ±	+ ~ ±	+ ~ ±
Hellula undalis F	−	+ + ~ ±	−	+ ~ ±
Mamestra brassicae L	+ + ~ +	+ + ~ +	−	+ + ~ +
Pieris rapae crucivora Boisduval	+ + ~ +	+ ~ ±	+ ~ ±	+ ~ ±
Brevyicoryne brassicae L	+ + ~ +	±	±	±
Lipaphis erysimi Kaltenbach	±	±	±	+

[a] Insect infestation levels: ++ = heavy, + = moderate, ± = little, − = nil.

In temperate areas of the central and the southern parts of Japan, namely the southern half of Honshu, Shikoku, and Kyushu, the common white has five to six generations in a year. The cabbage armyworm has only two generations in a year. On the other hand, DBM has 10 to 12 overlapping generations in a year. Therefore, growers need to be more alert to infestations of DBM than those of the common white or the cabbage armyworm. On cabbages, mature larvae of the common white and the cabbage armyworm occasionally cause much heavier visual leaf damages in the growing period prior to head formation. The DBM larvae on the other hand prefer to infest the central leaves of young plants and retard their vegetative growth. The larvae also infest the outer leaves of the cabbage head, and consequently these cabbage heads may be rendered unmarketable. However, the nature of DBM damage to cabbages has not been evaluated

thoroughly. Plant resistance to DBM has been not recognized among the cabbage cultivars currently grown.

For controlling pests on cruciferous vegetables such as cabbage and Chinese cabbage, growers are relying primarily on insecticides. Growers concerned about leaf damage, even of a few holes, tend to spray insecticides intensively. Table 12 shows the main insecticides currently in use for controlling DBM on cabbage and Chinese cabbage in Japan. Dichlorvos was the first and almost the only insecticide used against DBM for the years after 1965. Following dichlorvos, acephate, prothiophos, dimethylvinphos, phenthoate, and cartap have come to be used since around 1975. However, control achieved with some of the aforementioned organophosphorus compounds has become gradually less satisfactory over the past few years in various parts of the country. Table 13 gives an illustration of the present situation on the reduction of insecticidal efficacy against DBM. Joint research on the reduction of insecticidal efficacies against DBM, sponsored by the Japan Plant Protection Association, was carried out at six prefectural agricultural experiment stations from 1980 to 1982. It revealed that DBM has developed resistance to some organophosphorus insecticides, particularly to dichlorvos, acephate, prothiophos, and a few others (unpublished data). Fenvalerate was the first synthetic pyrethroid introduced in 1983. DBM shows high susceptibility to fenvalerate. In practice DBM can be controlled at relatively low rates of fenvalerate. A preparation of *Bacillus thuringiensis* also came into use in 1983. The preparation contains crystal toxin, delta-endotoxin.

Table 12. Major insecticides currently in use for controlling DBM in Japan

Insecticide	Formulation
Organophosphorus	
Acephate	50WP, 5G
Dimethylvinphos	50EC, 50WP
Phenthoate	50EC, 40WP
Pirimiphosmethyl	45EC
Prothiophos	45EC
Tertiary Amine	
Cartap	50SP
Pyrethroid	
Fenverelate	10EC, 10WP
Bachillus thuringiensis	
Preparation	containing crystal toxin, WP

Table 13. Effectiveness of some insecticides against the DBM on common cabbage[a]

Insecticide	No. DBM larvae per/10 palnts		
	Prior to	5 DAS[b]	11 DAS
Dichlorvos EC 0.05%	136.0	56.3	205.3
Prothiophos EC 0.045%	103.7	17.0	45.0
Cartap SP 0.05%	141.7	6.7	88.0
Cypermethrin EC 0.003%	132.0	1.7	1.0
Untreated	140.0	69.3	167.3

[a] Insecticides were applied on 17 June, 1983. A field test at the Vegetable and Ornamental Crops Research Station, Ano, Mie, Japan. [b] DAS: Days after spray.

At present, growers spray relatively large amounts of insecticide for cabbage pest control at a frequency of once every 7 to 10 days in the spring and early summer. Therefore, research needs to be geared to finding ways of reducing the number of insecticide applications without significant loss in yield or marketability. To this end

accurate surveying systems are required, based on the use of pheromone traps, in order to monitor the temporal population density of DBM larvae infesting cabbage crops. A proposal for an action threshold to reduce the number of insecticide applications without significant loss in yield or marketability would also be worthwhile.

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Bionomics of the Diamondback Moth in the Northwestern Himalaya

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Abstract

The paper presents the bionomics of the diamondback moth, *Plutella xylostella* (L), in the northwestern Himalaya. Diamondback moth is one of about two dozen insect pests which are harmful, or potentially harmful, to cruciferous vegetables in the region. Laboratory observations on its life history have shown that lifecycle of the female and the male moth on average respectively last 35.65 and 27.95 days in the first and 29.50 and 25.30 days in the second generation, when temperature and relative humidity fluctuated from 16.1° to 34.1°C and from 29.0 to 63.5%. In the field, the pest was observed seriously damaging the cabbage seed crop during September and October in dry cold areas but was seen in small numbers on off-season cabbage and cauliflower crops grown during wet months (June through August) and on the cauliflower seed crop from December to May. *Apanteles plutellae* and *Diadegma fenestralis* were found parasitizing larval and pupal stages of the moth.

Introduction

Amongst the lepidopterous pests of cruciferous crops, especially cauliflower, *Brassica oleracea* var *botrytis* (L) and cabbage, *B. oleracea capitata* (L), the diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae) is the most serious and widely distributed pest throughout the world (Bonnemaison 1965). Its resistance to many of the commonly used insecticides makes it one of the most difficult pests to manage (Ankersmit 1953, Mo 1959, Sudderuddin and Kok 1978, Cheng 1981, Liu et al 1982).

In the northwestern Himalaya, cauliflower (especially Snowball group cultivars) and cabbage are grown mainly for seed production during winter through spring to summer. In addition, these crops are also grown as off-season vegetables during summer under rainfed conditions. Cultivation of these crops has come to stay and is now the most remunerative enterprise for cultivators of the northwestern Himalayan states in India.

Although DBM has not been reported to cause extensive damage to cruciferous crops in the temperate Himalayan region, yet it has a potential to establish itself as a serious pest. Some work on the bionomics of the DBM has been done in other localities in india, for example in Kodaikanal (Abraham and Padmanabhan 1968), Jabalpur (Rawat et al 1968), and in Jobner (Sachan and Srivastava 1972, Yadav et al 1974). However, no attempt has been made to study the pest in the northwestern Himalaya. Detailed studies have been made in other countries (Ullyett 1947, Harcourt et al 1955, Oatman and Platner 1965, Weires and Chiang 1973, Ru and Workman 1979, Borcan 1979, Ko and Fang 1979). This article deals with the bionomics of the DBM under northwestern Himalayan conditions.

Materials and Methods

Life history study

Investigations on DBM biology were carried out in the laboratory of the Department of Entomology and Apiculture, Himachal Pradesh Krishi Vishva Vidyalaya, Solan, India. Temperature during the period varied from 16.1 to 34.1°C, and relative humidity from 29.0 to 63.5%, respectively. Initial culture the moths were raised for the study from caterpillars collected during February 1984, from cabbage and cauliflower crops grown at the University farm. They were released onto cabbage seedlings grown in the laboratory in plastic pots (12.5 x 10.2 cm), which were covered with glass chimneys (20 x 30 cm). Freshly emerged moths were sexed and kept in pairs on potted cabbage plants enclosed within glass chimneys. The adults were provided with 10% sugar solution. Total numbers of eggs laid were counted daily.

Eggs were then transferred to petri dishes (diam 4 cm), containing wet blotting paper at the bottom, so that the incubation period could be recorded. Newly hatched larvae were transferred to petri dishes containing fresh cabbage leaves. First and second instar larvae were observed for moulting. Mature larvae were kept in separate petri dishes for pupation. All measurements were made under a microscope fitted with an ocular micrometer. Data on two generations were recorded. Caterpillars and pupae of the moth were collected from the field and maintained in petri dishes for the emergence of parasites. Identification of parasites was carried out at the Indian Agricultural Research Institute, New Delhi.

Seasonal incidence

Observations over more than 10 years on the seasonal incidence of DBM were made on cauliflower crops, cultivar Snowball, transplanted in early October for seed production. A 0.1 ha plot was established and cauliflower was transplanted with a distance of 60 cm between plants and between rows. All recommended cultural practices were followed for raising a pesticide free crop. Population counts and incidence records were made on between 50 to 100 randomly selected plants at 7 to 10 day intervals starting from October through early May when the crop was finally harvested. The meteorological data were recorded daily during the period of study.

Observations and Discussion

Life history

Data on the life history and biometrical studies are presented in Tables 1 to 3.

Oviposition and fecundity Oviposition took place in the evening and during the night. The eggs were generally laid singly or in groups of two to four on the underside of leaves, often along the mid-rib or principal veins and sometimes on the walls of rearing jars. The oviposition period averaged 5.2 days in the first generation and 4.9 days in the second. Females each laid 220 to 315 (average 284) eggs in the first generation and 177 to 318 (average 243) in the second. The maximum oviposition per day by a female ranged from 78 to 89 (average 80.8) eggs in the first generation and 74 to 89 (average 81.5) eggs in the second. Egg viability averaged 95.7 and 80.0% in the first and second generation, respectively. In the third generation, no female oviposited when laboratory temperatures exceeded 34°C.

Egg The eggs were minute, yellowish white to yellowish green, cylindrical to oblong with average dimensions of 0.48 x 0.25 mm. Mean incubation periods were 3.10 and 2.27 days in the first and second generation respectively.

Table 1. Pre-oviposition, oviposition, post-oviposition periods, and fecundity of DBM[a]

Particulars	First generation		Second generation	
	Mean	Range	Mean	Range
Pre-oviposition period (days)	3.1	3-4	2.5	2-3
Oviposition period (days)	5.2	5-7	4.9	4-6
Post-oviposition period (days)	7.4	5-9	5.9	4-7
No. of eggs per female (per day)	47.88	44-63	49.61	44-63
Maximum number of eggs laid by a female in a day	80.77	70-89	81.50	74-89
Total number of eggs/female	284	220-315	242.80	177-318

[a] Data based on 10 pairs.

Table 2. Measurements of different stages of DBM[a]

Stage	Length (mm)		Breadth/wing expanse (mm)	
	Range	Mean ± S.E.	Range	Mean ± S.E.
Egg	0.46-0.49	0.48 ± 0.001	0.245-0.259	0.25 ± 0.003
Larva				
I	1.22-1.34	1.30 ± 0.036	0.16-0.20	0.18 ± 0.004
II	2.78-3.53	3.10 ± 0.286	0.23-0.25	0.24 ± 0.040
III	4.05-5.92	4.67 ± 0.883	1.09-1.18	1.03 ± 0.040
IV	6.72-9.92	8.62 ± 0.241	1.32-1.50	1.13 ± 0.680
Pupa				
Internal	4.50-6.00	5.15 ± 0.150	1.00-1.25	1.17 ± 0.337
Cocoon	7.50-8.50	7.90 ± 0.144	2.50-3.00	2.52 ± 0.144
Adult				
Male	4.75-5.0	4.97 ± 0.033	12.25-13.00	12.97 ± 0.160
Female	4.75-5.25	4.98 ± 0.034	12.75-13.25	13.06 ± 0.170

[a] Data based on measurements of 10 individuals.

Larva The freshly hatched larva was whitish yellow to pale green with a pale brown head, and on average measured 1.30 x 0.18 mm. Young larvae initially wandered over the leaf surface and then fed like miners. The larvae underwent three moultings resulting in four instars. Full grown larvae averaged 8.62 mm in length and were light green, moderately stout, and smooth with short scattered hairs. At the slightest disturbance, the larvae wriggled actively and dropped down the leaf, suspending themselves by silken threads. Total larval period averaged 11.3 days (range 9 to 13 days) in the first and 10.3 days (range 9 to 12 days) in the second generation.

Pupa The mature caterpillar formed a beautiful gauzy, loosely spun cocoon. Thereafter, it shortened its body longitudinally but remained active. The newly formed pupa was yellowish green, but in a day or two it became brownish and gradually attained a dark brown color by the time of adult emergence. Its mean length was 5.15 mm. The average pupal period in the first and second generations lasted 5.85 and 4.63 days respectively. The pupal mortality was 3.25% in the first generation and 7.8% in the second generation.

Adult The moths were slender and greyish brown and measured 12.97 (male) and 13.0 mm (female) in wing expanse. The male to female sex ratio worked out to be 1.60 : 1 and 1.60: 1.35 in the first and second generations, respectively. Average longevity of the male and the female was 7.7 and 15.40 days in the first generation and 7.1 and 12.3 days in the second. The respective pre-oviposition, oviposition and post-oviposition periods averaged 3.1, 5.2 and 7.4 days in the first and 2.5, 4.9 and 5.7 days in the second generation.

Lifecycle

The lifecycle from egg to adult stage of the female and the male on average took 35.65 and 27.95 days in the first and 29.50 and 25.30 days in the second generation respectively.

Table 3. Lifecycle of DBM under laboratory conditions at Solon, Himalchal Pradesh, India

Item	Generation[a]	
	First	Second
Oviposition period (days)	3.1 (3 - 4)	2.3 (2 - 3)
Egg viability (%)	95.7 (91-97)	80.0 (76-85)
Larval period (days)		
1st instar	3.2 (3 - 4)	2.0 (2 - 3)
2nd instar	2.9 (2 - 3)	2.4 (2 - 3)
3rd instar	2.8 (2 - 3)	2.6 (2 - 3)
4th instar	2.4 (2 - 3)	3.3 (3 - 4)
Total	11.3 (9 -13)	10.3 (9 -12)
Larval mortality (%)	16.7	11.5
Pupal period (days)	5.9 (4 - 6)	4.6 (3 - 5)
Pupal mortality (%)	3.3	7.8
Adult longevity (days)		
Male	7.7 (6 - 9)	7.1 (6 - 8)
Female	15.4 (13-17)	12.3 (10-15)
Lifecycle (days)		
Male	28.0 (22-32)	24.3 (20-28)
Female	35.7 (29-40)	29.5 (24-35)
Sex ratio (male:female)	1.6:1.0	1.35:1.0

[a] Numbers in the parenthesis indicate range.

The life processes of this insect are highly influenced by environmental conditions. Harcourt (1957) in Canada, Ho (1965) in Malaysia, Abraham and Padmanabhan (1968) in southern India, Lee (1968) in Hong Kong and Yadav et al (1974) in northern India have reported that the lifecycle of the DBM took 14 to 21, 10.8 to 27, 24 to 35, 22 to 37 and 25.28 to 27.15 days, respectively. Even in the same region, as in one case reported by Ko and Fang (1979) in Taiwan a single generation took only 9 to 10 days under the most favorable temperature conditions, while during winter one generation could take as long as 110 days. Present findings are more less in agreement with those of Abraham and Padmanabhan (1968), Lee (1968) and Yadav et al (1974). During March to May, 1984, only two overlapping generations of the insect were observed in the present study.

Host plants

DBM was found seriously damaging cabbage seed crops during dry cold September to October in northwesten Himalaya. However, the pest was observed feeding only in small numbers on cabbage and cauliflower grown as off-season vegetables during the wet summer months (June through September) and on cauliflower seed crops from December to May. No other popular cruciferous crops such as turnip, radish, knolkhol, kale, and mustards were found infested by the pest in the region.

Seasonal incidence

DBM larvae were present on the cauliflower seed crop throughout the winter from December, 1973 onward despite extreme temperatures. The population increased gradually and a comparison of temperature records with population growth suggested that daily minimum temperature ranging from 5 to 12°C and daily maximum between 21 and 36°C favored insect multiplication. The peak population was reached by mid-April. Subsequently there was sudden reduction in numbers. The reason could well be that the larvae had pupated, and when the moths emerged they were no longer attracted to this crop as it was almost mature by then. Similar trends in population were observed during 1975-76 and 1978-79 on the seed cauliflower crop.

On the plains of India, where cabbage and cauliflower crops are grown during almost the same period as seed cauliflower in the temperate northwestern Himalaya, the insect seems to exhibit a strikingly different pattern of population build-up on these crops. For example, on the plains Verma et al (1972) observed a serious infestation in cauliflower fields around Hissar (Haryana) during August, whereas Sachan and Srivastava (1972) reported DBM to be active at Jobner (Rajasthan) from September to March. Although the peak activity period was found to be different during the present studies, the multiplication behavior of the moth was found to be similar to that reported by Sachan and Srivastava (1972) so far as the larval population in relation to temperature and humidity was concerned. Lall (1939) observed the threshold of development in DBM was 10°C. This may account for the presence of larvae in cauliflower fields during December-January, when there was considerable fall in the minimum temperature which fluctuated between 0 to 1.0°C while the maximum temperature ranged from 21 to 24°C.

The incidence of attack in northwestern Himalaya varied widely. Between 3% and 73% plants were infested with larval population of between 3 and 415 per 100 plants. Morgan (1929), Prasad (1963) and Sachan and Srivastava (1972) also made similar observations and reported that infestation of plants varied from 5% to 100% during their experimental crop growth seasons.

Natural enemies

During the course of this study, bracond, *Apanteles plutellae* Kurdj (Hymenoptera: Braconidae) parasitized on an average 31% of DBM larvae. Simmonds and Rao (1969) recovered this parasite from DBM from Kashmir and many workers have reported its occurrence from other parts of India (Patel and Patel 1968, Joshi and Sharma 1976, Nagarkatti and Jayanth 1982). The parasite is of widespread occurrence in the world (Yarrow 1970, Chin 1974, Rusinov 1977, Yaseen 1977, Ooi 1979). An ichneumonid, *Diadegma fenestralis* Holmgren (Hymenoptera: Ichneumonidae) was found parasitizing on average 29.37% pupae. Dutt (1925), Abraham and Padmanabhan (1968), and Rusinov (1977) have reported it as an important larval parasite from elsewhere.

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Bioecology and Management of Diamondback Moth in India

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Abstract

In India, the diamondback moth, *Plutella xylostella* (L) infests cabbage, cauliflower, radish, knol khol, turnip, beetroot, mustard, and amaranthus. Cauliflower and cabbage are the most preferred hosts. Eggs are minute, whitish yellow, and incubation lasts for three to four days. There are four larval instars and the total larval period including prepupal stage extends for 10 days in the hot and rainy seasons and 12 to 15 days in the cold season. The larva pupates in a silken cocoon and pupal period ranges from four days in the hot and rainy seasons and from four to five days in the cold season. Adult longevity lasts for 6 to 13 days. Moths lay eggs in depressions on the leaf along the midrib and larger veins. Eggs are laid on the day of emergence soon after mating. Thirteen to fourteen generations have been observed in a year in the southern part of India. *Apanteles plutellae* is the dominant larval parasitoid. It is widespread in distribution and parasitizes up to 72% of the larvae. The major mortality factors recorded through life table studies are parasitization due to *A. plutellae* throughout the larval stage, predatory ants, birds, spiders, and rainfall in 1st and 2nd larval stages. The presence of 10 3rd or 4th instar larvae up to one month after planting, or 20 medium sized larvae/plant between one and two months after planting, is identified as the economic threshold. Effective control of the pest is achieved by synthetic pyrethroids such as permethrin or fenvalerate at 75 g AI/ha. Spraying with Dipel (0.5 kg product/ha) is also effective against the larvae. Planting tomato 30 days earlier than cabbage in an inter-cropping pattern reduces the larval damage significantly. A strategy to manage the diamondback moth utilizing the threshold, selective insecticide application, suitable cropping pattern, and natural enemies is discussed.

Introduction

Diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), is an important pest of cruciferous crops and enjoys worldwide distribution (CIE 1967). Hardy (1938) stated that the pest could breed and develop between 10°C and 40°C and that the adults were active at up to 50°C. Young pupae and the adults survived for several months and the eggs and pupae for two and six weeks, respectively, at 0°C. In India, DBM was first recorded in 1914 (Fletcher 1914) on cruciferous vegetables and a perusal of literature reveals that this species is distributed all over India wherever crucifers are grown. It is one of the more thoroughly studied pests in India.

Host Range

DBM in India infests important crucifers viz: cabbage, cauliflower, radish, khol rabi (knol khol), turnip, beetroot, mustard, *Brassica campestris* var *toria*, and *B.*

campestris var *sarson* (Chand and Choudhary 1977, Dube and Chand 1977, Jayarathnam 1977; Singh and Singh 1982). Non-cruciferous crop like *Amaranthus virdis* L has also been reported to be the host of this species (Vishakantaiah and Visweswara Gowda 1975).

Studies on the food plant preference of DBM have revealed that among several crucifers, the pest exhibits a marked preference for cauliflower and cabbage. This is probably due to the fact that both plants possess fleshy and succulent leaves compared to rest of the crucifers tested, and this probably provides olfactory and gustatory stimuli for successful host selection and development (Chand and Choudhary 1977, Dube and Chand 1977, Singh and Singh 1982).

Life History

The biology of this pest has been studied in the laboratory (Patil and Pokharkar 1971, Jayarathnam 1977) and under natural conditions in relation to ecological factors (Abraham and Padmanabhan 1968, Jayarathnam 1977).

Egg stage

Eggs are minute, whitish yellow, 0.5 mm in size. The incubation period ranges from three to six days (Abraham and Padmanabhan 1968). Patil and Pokharkar (1971) report an incubation period of four to six days under laboratory conditions. Jayarathnam (1977) records an incubation period of three to four days under both laboratory and field conditions.

Larval stage

Newly hatched larvae are pale white with a pale brown head while the fully grown caterpillars are light green, measuring 10 mm in length. The 1st instar larvae mine into the leaf. Total larval period extends from 14 to 21 days (Abraham and Padmanabhan 1968). Patil and Pokharkar (1971) observed five larval instars and a larval period of up to 11 days. However, Jayarathnam (1977) reported that there were only four instars. The 1st instar occupied three days in the hot season, 3 to 4 days in the rainy season and 4 to 5 days in the cold season. The larvae generally stay in the mines for about two days. The 2nd instar stage extends for two days in the hot and rainy seasons and 2 to 3 days in the cold season. The 3rd instar larvae generally feed on mature leaves for two days in the hot and rainy seasons and for two to three days in the cold season. The 4th instar larvae, excluding the prepupal period, consume the largest quantity of leaf tissue and last for two days in the hot season, two to three days in the rainy, and three to four days in cold season. The pre-pupal period lasts for one day in all three seasons. The total larval and prepupal period are estimated as 10 days in the hot and rainy seasons and 12 to 15 days in the cold season.

Pupal stage

Pupation takes place in a loose mesh of silken cocoon spun by the caterpillar. The mature pupae are 6 mm long and of light brown colour. The pupal stage ranges from 7 to 11 days (Abraham and Padmanabhan 1968). However, Patil and Pokharkar (1971) report the pupal period to vary from three to seven days, with an average of five days. Jayarathnam (1977) report the pupal period to last up to four days in the hot and rainy seasons and four to five days in the cold season. These results show significant variation in pupal period in different parts of India, possibly due to climatic variations.

Adult

Adults are grey moths with a wing expanse of 14 mm. Their longevity ranges from 3 to 11 days (Abraham and Padmanabhan 1968). Patil and Pokharkar (1971) report the lifespan of male and female to be 10.4 and 12.1 days respectively. Jayarathnam (1977) found adults to survive for three to six days without food and for 11 to 16 days provided with food. Adults were found to emerge during the evening and rarely in the morning hours.

Mating, oviposition, and fecundity

The moths mate at dusk on the day of emergence. Oviposition begins in the evening and lasts up to 7 pm; during the rest of the night, the moths are not active (Jayarathnam 1977). Jayarathnam further observes that the individuals in a copulating pair face opposite directions and hang downwards with the female above. Mating lasts one to two hours and females mate only once. Typically, eggs are laid in depressions on the leaf along the midrib and larger veins or on concave surfaces near smaller veins. On average, 63.4% eggs are laid on the upper leaf surface. Most females (90%) lay eggs on the same day of emergence. The oviposition period extends to 10 days with peak oviposition occurring on the day of emergence. Patil and Pokharkar (1971) report that the fecundity ranges from 71 to 203 eggs/female. Atwal (1955) investigated the factors influencing fecundity and reports that females reared at low temperatures (7 to 24°C) laid more eggs than those reared at higher temperatures (28 to 35°C). The fecundity of adults increased when exposed to increased photoperiod.

Number of generations

Jayarathnam (1977) observed that DBM completed 13 to 14 generations per year in Bangalore, India. He also postulated that if the eggs were to be laid by the adults of each generation on the same day as emergence, up to 16 generations per year could be completed.

Natural Enemies

Parasitoids

In Coimbatore, Tamil Nadu, Cherian and Basheer (1938) observed 59.9% parasitization by *Brachymeria excarinata* Gahan and 18.2% parasitization due to *Tetrastichus sokolowskii* Kurdj. Simmonds and Rao (1960) reported *Voria ruralis* (Fall) and an *Angitia* (*Horogenes*) sp from Srinagar, Jammu and Kashmir. *Thyraeella collaris* Grav and *Macromalon orientale* Kerrich were recorded as larval parasitoids in Shillong, Meghalaya (Chacko 1968). Patel and Patel (1968) reported *Apanteles* sp. (glomeratus group), *Chelonus* sp (possibly *C. versatilis* (Walker)), *Hockeria tetraceitarsis* Gram, *Th. collaris*, and *M. orientale*, the latter being the dominant larval parasitoid at Anand, Gujarat. Manjunath (1972) found that *Trichogrammatoidea armigera* Nag could be successfully reared on DBM eggs but it is not known if it would attack eggs of this pest in the field. Yadav et al (1975) studied the seasonal activity of *A. plutellae* at Anand. They also reported that this parasitoid appeared along with the pest in the last week of July and that the highest parasitization of 71.7% occurred in the first week of September. Heavy rains received during the last week of September reduced populations of both the pest and the parasitoid. In Bangalore, Karnataka State, Jayarathnam (1977)

records *A. plutellae* and *T. sokolowskii* causing 16 to 52% mortality and 28 to 96% parasitization of 2nd instar DBM larvae. Nagarketti and Jayanth (1982) subsequently confirmed the occurrence of both the parasitoids at Bangalore. They also observed *A. plutellae* as the dominant larval parasitoid and *T. sokolowskii* to occur at low levels. They inferred from seasonal incidence studies that a clear density-dependent relationship existed between *A. plutellae* and the host. During their study, a large number of secondary hymenopterous hyperparasites were also recorded. They were: *Anastatus* sp (Eupelmidae), *Aohanogmus fijiensis* Ferriere (Ceraphronidae), *Brachymeria excarinata* Gahan (Chalcididae), *Diaglyptidea* sp (Ichneumonidae), *Eurytoma* sp (Eurytomidae), *Hockeria atra* Masi (Chalcididae), *Pediobius imbreus* (Walker) (Eulophidae), *Pteromalus* sp (Pteromalidae), *Tetrastichus sokolowskii* (Eulophidae), *Tetrastichus* sp (miser group) (Eulophidae). *B. excarinata* and *T. sokolowskii* acted as facultative hyperparasites. The hyperparasites, according to their study, appeared from August to October with a low (3.13%) parasitism in October and a high parasitism (39.13%) in September, the latter coinciding with peak parasitism by *A. plutellae* on the primary host.

Predators

Yellow wagtails (*Motacilla flava*) were found to feed on DBM larvae in Bangalore during cold season (Jayarathnam 1977). Jayarathnam further observed that the ants, *Tapinoma melanocephalum, Pheidole* spp and *Camponotus sericeus* were carrying away DBM larvae in the field.

Pathogen

During a two-year study on the population dynamics of major pests of cabbage and of their natural enemies in Bangalore, Nagarkatti and Jayanth (1982) collected two diseased larvae affected by nuclear polyhedrosis virus. Incidence of diseases appears to be very low and to our knowledge natural epizootics have not been reported from India.

Natural Mortality Factors

Jayarathnam (1977) studied the population dynamics of the pest by preparing life tables for 10 generations (five in rainy season and five in cold season). Major mortality factors were parasitization by *A. plutellae* in the larval period, predatory ants, birds and spiders in the 1st and 2nd larval instars, and rainfall in the 1st and 2nd larval instars (Tables 1 and 2). The major mortality factor at the pupal stage was parasitization by *T. sokolowskii*. Parasitization by *T. sokolowskii* was identified as the key mortality factor throughout all 10 generations. Infestation by the cabbage webworm, *Hellula undalis* Zell, resulted in considerable reduction of oviposition sites for DBM.

Table 1. Major mortality factors of DBM during the rainy season (July-October)[a]

Stage	Mortality factors	Mortality (%)
Egg	Infertility	6.6
1st larval instar	Rainfall (39 mm)	11.0
	Predators: ants and spiders	59.3
2nd larval instar	*A. plutellae*	52.0
	Predators: ants and spiders	13.9
3rd larval instar	*T. sokolowskii*	4.0
Pupa	*T. sokolowskii*	32.0
Adult	Sex: 45% female	9.2

[a] Source: Jayarathnam 1977.

Table 2. Major mortality factors of DBM during the winter season (November-February)[a]

Stage	Mortality factors	Mortality (%)
Egg	Infertility	14.3
1st larval instar	Predators: ants, birds, and spiders, heavy dew	60.0
2nd larval instar	*A. plutellae*	20.0
	Predators: ants, birds, and spiders	59.2
3rd larval instar	*T. sokolowskii*	8.0
Pupa	*T. sokolowskii*	72.0
Adult	Sex: 41% female	18.0

[a] Source: Jayarathnam 1977.

Seasonal Incidence

Seasonal incidence of DBM on cabbage has been studied in India at Kodaikanal, Udaipur, Anand, and Bangalore (Abraham and Padmanabhan 1968, Sachan and Srivastava 1972, Yadav et al 1975, Jayarathnam 1977, Nagarkatti and Jayanth 1982). High build-up of larval populations has been reported during February-March (late winter) and April-August (summer and mid rainy season) (Abraham and Padmanabhan 1968, Sachan and Srivastava 1972). However, Jayarathnam (1977) and Nagarkatti and Jayanth (1982) found significantly high build- ups of larval populations during the rainy season (July- September) as compared to other seasons (Figure 1).

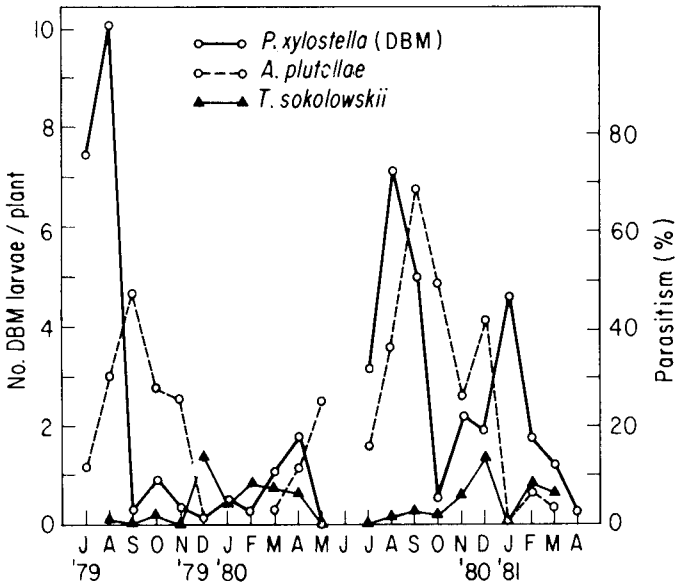

Figure 1. Seasonal incidence of DBM and its natural enemies (Nagarkatti and Jayanath 1982)

Economic Thresholds

Prasad (1963) reported that seven weeks after transplanting, cabbage could sustain populations of 20 larvae/plant before significant economic injury and yield reduction

were detected. Based on crop loss estimation studies conducted in Bangalore, Jayarathnam (1977) found that a population of four or more medium sized larvae (3rd or 4th instar) could render a seedling untransplantable and 10 medium sized larvae/plant up to one month after planting and 20 medium sized larvae/plant between one and two months after planting necessitated insecticide application.

Crop Loss Estimation

Krishnakumar et al (1984) estimate a 52% loss in marketable yield due to DBM attack on cabbage. Based on path coefficient analysis, the same authors estimate that DBM infestation at 55 days after planting has the maximum negative direct effect in reducing yield. DBM larval populations at 20, 30, 40, 50, and 60 days after planting and the marketable yield showed significant negative relationship for insect count taken at 40, 50 and 60 days after planting (Srinivasan 1984). The multiple linear regression equation for these larval populations in relation to loss of marketable yield was: $Y = -168.79\ X_1 + 84.33\ X_2 - 98.43\ X_3 - 21.19\ X_4 - 115.92\ X_5$ where X_1, X_2, X_3, X_4, and X_5 corresponds to populations on 20, 30, 40, 50 and 60 days after planting (Srinivasan 1984).

Management

Adoption of visual damage thresholds

Successful cultivation of cabbage is hampered due to the incidence of DBM and *Crocidolomia binotalis* Zeller on cabbage in Bangalore (Nagarkatti and Jayanth 1982). Even though economic thresholds for both pests are on record, they are not adopted by growers who lack training or time to count and identify insects accurately. However, use of a threshold based on quick visual ratings (as revealed by the appearance of holes in leaves caused by feeding of caterpillars of both species) would require little formal training and time. After the application of a blanket spray to protect the primordia/head formation stage, further sprayings could be restricted to the number necessary to keep damage to no more than one hole on average per wrapper leaf of the cabbage. This approach is reported to be an effective alternative to reliance on regular weekly or fortnightly sprays (Srinivasan 1984). The adoption of visual damage thresholds on wrapper leaves of cabbage also results in considerable reduction in the number of sprays (three to five) compared to the weekly spraying adopted currently by growers (Srinivasan 1984). Srinivasan further reports a definite possibility of eliminating pre-heading sprays, since the larval populations causing damage to either outer leaves, or to leaves about to cover the head, do not reduce marketable yield significantly.

Use of insecticides

Cabbage One of the early recommendations for DBM control on cabbage involved application of malathion, carbophenothion, parathion or phosphamidon (Verma and Sandhu 1967, Abraham and Padmanabhan 1968). Gupta and Sharma (1971) obtained excellent control of this species with one application of endrin at 0.25 kg AI/ha followed by two sprays of dimethoate at 0.5 kg AI/ha. A spray schedule of one spray of endrin three weeks after planting followed by two applications of dimethoate at every three weeks has also been reported to be the most effective and economical control measure (Joshi and Sharma 1976). Sachan and Srivastava (1975) conducted several field experiments for the control of this pest and observed the best protection following fortnightly

sprays until harvest of either 0.03% endrin or 0.075% lindane or 0.20% carbaryl. Singh et al (1976) reported that application of quinalphos at the rate of 0.25 kg AI/ha resulted in 100% mortality of larvae within 48 h of spraying. Three spray applications of 0.06% phenthoate at fortnightly intervals beginning 20 days after transplanting was found to reduce the incidence of the pest (Gowda et al 1977). Rajamohan and Jayaraj (1978) reported that applications of fenthion, endosulfan, fenitrothion, dichlorvos, and carbaryl were effective for upto 10 days in reducing larval population and damage (Table 3). Ramasubbaiah and Lal (1978) found phosphamidon applied at 0.05% effectively controlled the DBM larvae on cabbage. In other studies the application of quinalphos, methamidophos, dioxathion or endosulfan at 0.5 kg AI/ha gave effective control of larvae (Krishnaiah and Jagan Mohan 1977). Excellent control of the larvae has also been reported using spray applications of the following insecticides: chlorpyriphos, dioxathion (0.5 kg AI/ha), monocrotophos (0.3 kg AI/ha), phosalone, phenthoate, and methomyl (0.5 kg AI/ha) (Krishnaiah et al 1978). Srinivasan and Krishnakumar (1982) have observed that permethrin or fenvalerate applied on early cabbage varieties at 75 g AI/ha 30 and 40 days after planting provided effective control. Carbofuran at 1.5 kg AI/ha is reported to protect the crop against DBM for up to 45 days after planting (Sarode and Kumar 1983). Shah et al (1984) recommend application of permethrin (0.2 kg AI/ha), or fenvalerate (0.1 kg AI/ha), sulprofos (1.0 kg AI/ha) or prothiophos (0.75 kg AI/ha) for the control of this pest.

Table 3. Efficacy of different insecticides and *Bacillus thuringiensis* (*Bt*) on the control of DBM[ab]

Treatment	Dosage (kg AI/ha)	No. larvae /plant befor treatment	Larval population reduction % at DAT[c]			Leaf damage (%) at 10 DAT
			1	2	10	
Malathion	0.50	3.5	53	77	61	43cd
Dichlorvos	0.50	4.2	58	75	65	24ab
Phoxim	0.50	3.8	44	68	60	41cd
Endosulfan	0.35	4.5	69	77	54	22a
Fenitrothion	0.50	3.6	58	78	76	23ab
Fenthion	0.50	4.8	53	73	65	20a
Carbaryl	0.50	2.9	61	80	65	30abc
BHC	1.25	3.0	47	69	21	46de
Carbaryl	2.50	3.9	44	71	34	34bcd
Bt	2.50	4.1	77	83	25	36cd
Control	—	3.8	+[d]	+	+	55e

[a] Source: Rajamohan and Jayaraj 1978. [b] Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test. [c] DAT: Days after treatment. [d] Population increased.

Cauliflower Control of DBM on cauliflower has been achieved by sprays of 0.025% diazinon, 0.1% trichlorfon, 0.1% mevinphos, 0.08% malathion or 0.2% carbaryl (Verma and Sandhu 1968). The authors also opined that application of either mevinphos or malathion was more suitable for control on cauliflower, especially at the time of curd formation, owing to the short residual toxicity of the compounds. Among 20 insecticides tested as direct sprays for the control of DBM, treatment with 0.025% diazinon, 0.15% chlorfenvinphos, 0.1% trichlorphan or 0.01% mevinphons is reported as effective, resulting in 100% mortality of the larvae within 24 h (Verma et al 1973). Evaluation of insecticides on cauliflower grown as a seed crop has showed that sprays of phosalone at 0.05% or phenthoate at 0.05% are effective against DBM larvae (Regupathy and

Paranjothi 1980). Sprays of phosalone at 0.05% and 0.1% for the control of this pest on cauliflower have been reported to reach below tolerance limit of 2 ppm in 5.91 and 8.95 days, and the half life values to be 3.15 and 2.83 days, respectively (Murthy et al 1982). The effectiveness of synthetic pyrethroids viz cypermethrin at 60 and 80 g AI/ha, fenvalerate at 80 and 100 g AI/ha, permethrin at 125 g AI/ha and deltamethrin at 10 g AI/ha for the control of larvae was reported by Awate et al (1982) and Gandhale et al (1982).

Use of bacterial pathogens

The effectiveness of *Bacillus thuringiensis* Berliner (Thuricide) applied in the form of dust, wettable powder, or emulsion for the control of DBM under laboratory, field, and glasshouse conditions has been reported (Narayanan et al 1970). Varma and Gill (1977) tested the effectiveness of four commercial preparations of *B. thuringiensis* along with NPV specific to DBM under laboratory conditions. They found Thuricide HPSC and Dipel WP to be more promising at 1 and 1.5 g product/1 of water than Bactospeine or Thuricide 90 TS. Rajamohan and Jayaraj (1978) reported the effectiveness of Biotrol for the control of larvae, with a persistence effect of about 10 days. Weekly sprays of Dipel (0.5 kg product/ha) were quite effective in controlling larvae on cabbage and the degree of efficacy was also comparable to that of fortnightly sprays of methamidophos and quinalphos (0.5 kg AI/ha) (Krishnaiah et al 1981).

Cultural Practices

Tomato, when intercropped with cabbage, has been reported to inhibit or reduce DBM egg-laying (Vostrikov 1915, Buranday and Raros 1973, Sivapragasam et al 1982). The reduction in oviposition and subsequent development of the pest was essentially due to emission of volatile compounds. Srinivasan (1984) conducted experiments involving different combinations of cabbage-tomato intercropping at Bangalore. He reported that there was no reduction in the incidence of DBM larvae when different combinations of cabbage and tomato were planted at the same time (Table 4). According to his study, however, a planting pattern of one row of cabbage and one row of tomato (the cabbage planted 30 days later than the tomato), afforded greater reduction of DBM larvae on cabbage. The reduction in larval incidence was attributed to the release of volatile substances from the late crop growth stages of tomato which inhibited DBM oviposition.

Table 4. Influence of intercropping on the marketable yield of cabbage, in relation to infestation by DBM[a]

Crop combination	Cabbage yield (t/ha)[b] planting time			Mean yield t/ha
	C and T[c] planted together	C planted 15 days later than T	C planted 30 days later than T	
1 row C and 1 row T	0.578a	2.878a	5.333a	2.930a
2 rows C and 2 rows T	0.611a	2.817a	4.300b	2.576a
3 rows C and 2 rows T	0.583a	2.844a	4.322b	2.583a
4 rows C and 1 row T	0.604a	2.773a	1.178c	1.519b
C alone	0.608a	0.650b	0.800c	0.685c
Mean	0.596	2.392	3.187	—

[a] Source: Srinivasan 1984. [b] Means in each vertical column followed by the same letter are not signifciantly different at 5% level according to Duncan's Multiple Range Test. [c] C = cabbage, T = tomato.

The spreading foliage of full-grown tomato plants also hid the cabbage leaves from the female moths and thus reduced oviposition. Srinivasan further opined, however, that this reduction in larval incidence was not manifested in any significant increase in the marketable yield of cabbage compared to the yield recorded from sprayed plots.

Use of selective insecticides

Studies on the relative toxicity of certain conventional insecticides and synthetic pyrethroids has been made against the adults and cocoons of *A. plutellae*, an important parasitoid of DBM larvae. The results indicate that permethrin, fenvalerate, cypermethrin, deltamethrin, and phosalone are safer to adults and cocoons of *A. plutellae*. Quinalphos was found to be detrimental to both stages of this parasitoid. Dichlorvos, monocrotophos, and endosulfan were found to be highly toxic to adults but relatively safe to cocoons of *A. plutellae* (Mani and Krishnamoorthy 1984).

Insecticide resistance

In Punjab, Deshmukh and Saramma (1973) observed that populations of DBM collected from Jullundhar were less susceptible to parathion than those found in Ludhiana. Fairly high tolerance to parathion, fenitrothion, malathion, DDT and endrin was also reported from Punjab by Chawla and Kalra (1976).

Integrated Pest Management Approaches

Based on exhaustive studies conducted on the population dynamics of DBM on cabbage, Jayarathnam (1977) recommends spraying the crop with an organophosphorus insecticide only when the economic threshold was reached. He also recommends sprinkling a 5% jaggery solution in order to encourage the activity of predatory ants like *Tapinoma melanocephalum, Pheidole* sp and *Camponotus sericeus*. Further, the removal of old leaves of cabbage (where 60% of pupation occurrs) is also recommended as one of the cultural practices likely to reduce incidence of pest. Nagarkatti and Jayanth (1982) found parasitism by *A. plutellae* showed a clear density dependent relationship with the host during the rainy and winter seasons at Bangalore. Hence, they suggest spraying a suitable insecticide relatively safer to this parasitoid. Since the population of parasitoids is low during summer months, they suggest inundative release of *A. plutellae* to maintain the pest below economic injury level. These suggestions should be implemented only when cabbage/cauliflower is affected by DBM.

In recent years, increasing levels of infestation of the leafwebber, *C. binotalis*, has also occured on cabbage, along with that of DBM (Nagarkatti and Jayanth 1982, Srinivasan 1984). The late larval instars of *C. binotalis* prefer to feed on primordia and this usually resulted in either aborted heading or multiple heading (Srinivasan 1984). Recognizing a potential need for the development of a suitable management strategy effective against both these lepidopterans, Srinivasan (1984) suggested the monitoring of low damage thresholds on wrapper leaves of cabbage after giving a blanket spray to protect the primordia with phosalone at 0.07%. Phosalone is recommended in view of its effectiveness against both lepidopterans and its relative safety to important natural enemies of the pest complex on cabbage. The adoption of visual damage thresholds also results in considerable reduction in the number of spray applications of phosalone (Srinivasan 1984) (Figures 2 and 3). Superimposition of damage thresholds on the intercrop combination of one row of cabbage and one row of tomato (cabbage planted 30 days

later than tomato) is also advocated as an effective alternative approach to reducing the incidence of both pests and increasing cabbage yields significantly (Table 5).

Table 5. Effect of visual damage threshold linked insecticide application on cabbage yield in cabbage-tomato intercropping[ab]

Treatment[c]	No.of sprays	Marketable yield of cabbage (t/ha)
1 row cabbage (C) and 1 row tomato (T) (C maintained with 0.5 hole in wrapper leaves)	2	9.789a
1 row C and 1 row T (C sprayed at weekly intervals)	9	9.900a
1 row C and 1 row T (C not sprayed till harvest)	—	6.285b
C alone maintained with 0.5 hole in wrapper leaves	4	10.054a
C alone sprayed at weekly intervals	9	10.317a
C alone not sprayed till harvest	—	1.038c

[a] Source: Srinivasan 1984. [b] Means in vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [c] In all treatments, cabbage (C) was planted 30 days later than tomato (T)

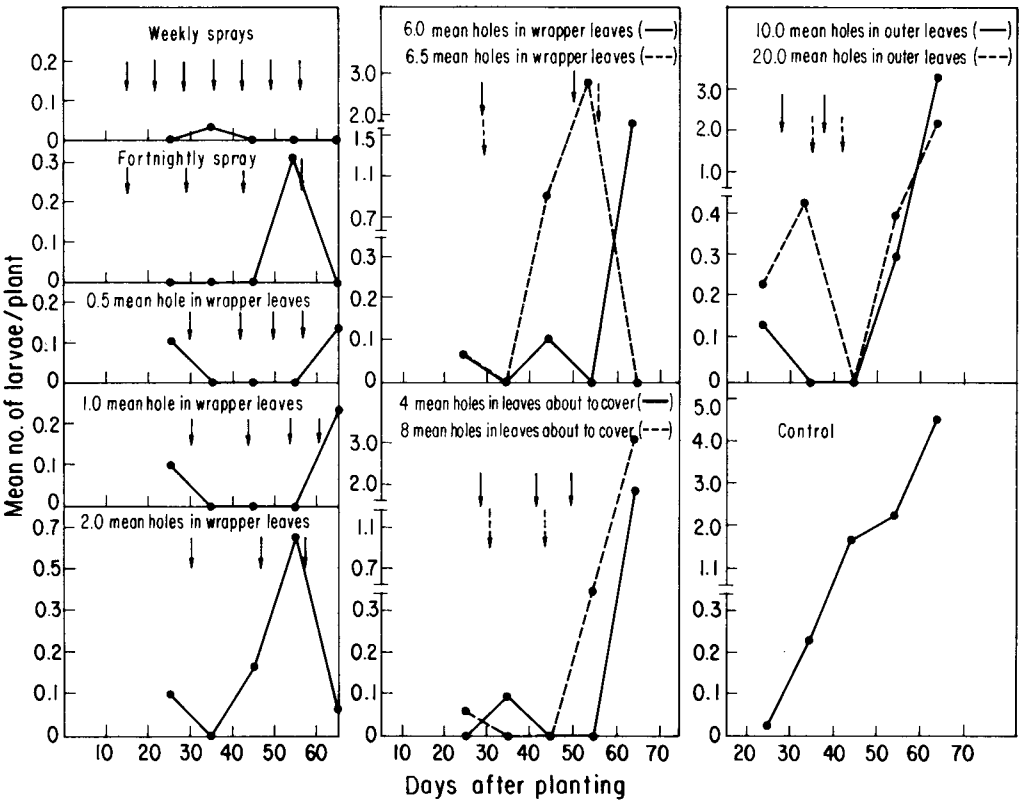

Figure 2. Population of DBM larvae on cabbage at different days after planting in the rainy season 1982. Arrows indicate insecticide application. (Srinivasan 1984)

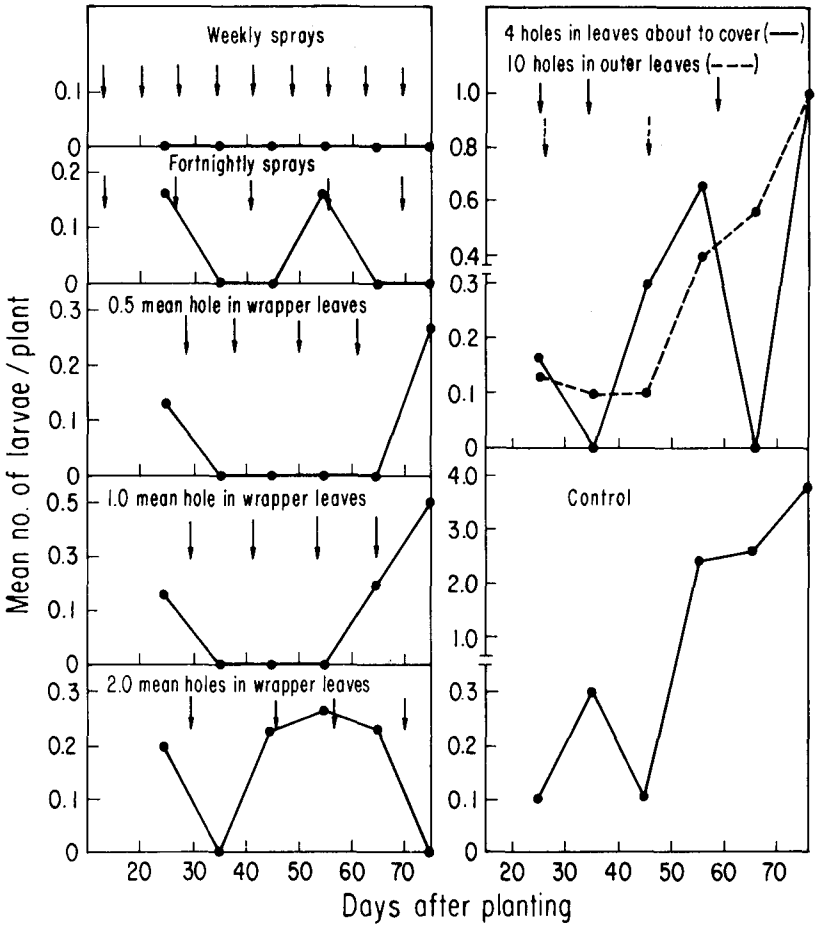

Figure 3. Population of DBM larvae on cabbage at different days after planting in the winter season 1982. Arrows indicate insecticide application. (Srinivasan 1984)

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The Migration of Diamondback Moth

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Abstract

The adults of diamondback moth, *Plutella xylostella* L, are known to have been transoceanic migrants in Europe since ancient times. The insect, which has its origin in Asia Minor, spread to other parts of the world with the spread of the cultivation of its host, the crucifers, and by using its own migrational abilities over long distances. Several large scale transoceanic migrations have been reported in Europe. The moths are known to be able to migrate a distance of over 3000 km in continuous flight for several days. Finland and northwest Russia are the major sites of origin of the migratory moths. The insect also migrates from the United States to Canada. In the Orient, large scale migration has not been observed, but a few moths have been captured out over the East China Sea as far as 500 km away from any major landmass. In the Orient there is considerable variation in certain physiological characters of the moth between various geographical locations.

Introduction

Diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), is a noted defoliator of numerous cruciferous plants in many areas of the world. In some cases, this insect is considered as the most important limiting factor of successful production of cruciferous vegetables. In Taiwan, DBM was first reported as a pest over 75 years ago (Hori and Shiraki 1910).

There are numerous insects which, like DBM, have the a world-wide distribution. These cosmopolitan insects have certain common characteristics which enable them to survive in the varying climatic conditions present over wider areas of their distribution. Besides the potential to colonize under varying conditions, their strong dispersal or migrating capacity is indispensable to the increase of their distribution range. Although the origin of DBM is not clear, judging from its close relationship with the cruciferous plants it is assumed that this insect originated in Asia Minor. From there the moth spread to other areas with the spread of cultivation of cruciferous vegetables. The strong flight ability of the moth helped its distribution to even wider areas. Miyata (1983) classified migratory moths into six categories. He assigned DBM to type F category—the super wide-distributing type—which has an omniphagous habit and strong dispersal capacity (Miyata 1983). While the DBM has a close relationship with cruciferous crops, it is considered as an oligophagous pest. Therefore, the present cosmopolitan distribution of the moth is attributed both to the extended cultivation of its host plant and to its own migration.

It is obvious that the migration of the insect is one of the important factors in the extension of its distribution. Both immigration and emigration result in big changes in the population size in the area concerned. For this reason, the migration of this pest insect requires the close attention of applied entomologists over an extended period. The concept of pest management entails the estimation of the economic threshold of each pest insect based on numbers. DBM's migration characteristics also underline the need

for the establishment of forecasting system which could have a definitive bearing on the integrated management of the pest.

The following brief review on the migration of DBM is compiled with the available information.

DBM Migration in Europe

The DBM has been known as a transoceanic migrating insect in Europe since ancient times. For example, in Britain the moth is recognized as an important insect, and damage is induced by migrated populations. Mass migration of DBM is relatively well studied in England. The earliest record of DBM mass migration was made by Curtis (1860). Ormerod (1891), Harper Gray (1915), and Miles (1924) reported large scale outbreaks due to migration of this insect in 1891, 1915, and 1924, respectively. Theobald (1929), reviewing the history of those attacks, cited 1837, 1851, 1885, 1888, 1891, 1914, 1923 and 1924 as years of heavy losses. Besides these, Mackenzie (1958) cited 1928, 1941, 1946, 1949 and 1958 as years of DBM outbreak. For the last 20 years, 1966 (Shaw and Hurst 1969), 1978 (Lokki et al 1978), 1979 (Lempke 1981), and 1980 (Lorimer 1981) are listed as years of severe DBM attack. Among those, 1891, 1914, 1958 outbreaks were of exceptional severity.

The migrating distance of the moth is generally considered to be over 3000 km (Thygesen 1968, Bretherton 1982). French (1967) reports a migration of 3680 km, with the moths in continuous flight for several days. Lokki et al (1978) also reported mass migration of the moth to Spitsbergen from South Finland and Finnish Lapland, carried by a strong south-southeastern storm. The estimated migration distance was at least 1000 km in one day.

The outbreak of the moth in the coastal area of northeastern England and eastern Scotland in 1958 is well documented by French and White (1960) and Shaw (1959, 1962). According to these reports, the sudden appearance of large numbers of moths occurred in the northern area of Scotland. The moths arrived at Aberdeen during the morning of 28 June (Hulme 1959). According to the survey carried out on 29 June, density was estimated 5 to 10 moths per square inch (approximately 70-140 million per ha), (Mackenzie 1958). Mackenzie described this spectacular phenomenon as follows 'On the evening of June 30, tremendous numbers were reported simultaneously in all the coastal towns from Berwick to Scarborough. Moth entered houses on such a scale as to cause alarm amongst householders; in the open, cyclists hesitated before riding through swarms; car drivers were obliged to stop and clean their windscreens. So great were the numbers, and so sudden in appearance, that the swarming was a major news item in the local press'. This mass immigration caused serious damage to many cruciferous vegetables such as turnip, cabbage, kale and so on. Later a large population of the moth was observed at 58°53'N, 19°10'W by the ocean weather watch ship on 4 July. As to the source of that population, Finland and Estonia are suggested as the areas of their origin. From the analysis of meteorological conditions, an area in northwest Russia, approximately between latitude 55 and 60°N which includs Estonia, Latvia, Lithuania, and the east coast of the Baltic Sea is assumed to be the origining area. In this season, the predominant wind direction is east to west in this area. That would stimulate the take-off of the moths towards the sea coast. While crossing the North Sea, and approaching the coast line, wind velocity is reduced towards the coast line on the far side of the North Sea thus tending to deposit the moths on the coast. This possibility explains the large numbers of moths which settled on the east coast of England and Scotland.

Although this seems to be a reasonable analysis from the meteorological point of view, it still cannot afford an adequate explanation from the DBM life history point

of view. At such a high latitude, the moth is considered to be unable to survive the low temperatures and maintain sufficient numbers to induce mass migration in early June. Therefore, the west coastal area of the Baltic Sea is considered as one of the transit areas for the mass migration and the true areas of its origin should be located further south.

In the Neararctic region, the recent mass migration of DBM in Ontario, Canada, is reported by Smith and Sears (1982). Harcourt (1982) also suggested that the occurrence of the moths in Ontario is due to emigration from southern areas where they can overwinter.

DBM Migration in the Orient

In the Orient, surveys of insect migration lagged far behind that of the European countries, especially before the 1960s. Insect migration studies began in the Orient in 1968. A weather ship collected numerous brown planthoppers (*Nilaparvata lugens*) and white backed rice planthoppers (*Sogatella furcifera*) at point 'Tango' located at 29°N, 135°E in the Pacific Ocean 500 km from the nearest landmass (Asahina and Turuoka 1970). This indicated the importance of the transoceanic migration of pest insects. For the purpose of establishing an improved forecasting system of important paddy insect pests, frequent and strenuous population monitoring especially over the East China Sea, is being carried out. Up to the present, 127 species of insects including 56 species of moth are listed as long distance migrants. (Asahina 1972, JMA 1983, Kiritani 1984). DBM is listed as one of these migrant insects. In Japan, some ecological studies point to the fact that DBM does not overwinter in areas north of Tokyo while it is a ubiquitous insect pest in the northern districts of Japan in summer months. Therefore, the migration of the moth from the southern area during spring and summer is suggested (Yamada and Umeya 1972).

DBM adults were also collected over the ocean far from the landmass; one specimen on 21 August and another on 27-28 August 1968 at 135°E, 29°N. (Asahina and Turuoka 1970). From 1976 to 1978, although 20 moth species were collected over the East China Sea, DBM was not listed in the collection (Hayashi et al 1978, 1979). It is obvious that the migration pattern of DBM in the Orient is quite different from that in Europe. This does not mean, however, that no mass migration of insects occurs in the Orient. Mass migrations of brown planthopper, oriental armyworm (*Pseudaletia separata*), and black cutworm (*Agrotis ypsilon*) are often recorded by entomologists. (Kishimoto 1975, Oku 1984, Oku et al 1975).

It is also worth noting that in the Orient considerable variation exists in DBM populations at various geographical locations. Umeya and Yamada (1973) found variation in the threshold temperature for growth and in the thermal constant for development between the Javanese and Japanese strains of DBM. In addition, Sun (1985) found geographical variation in insecticidal resistance and Maa (1985) reports considerable variation in pheromonal response in various DBM strains of Taiwan. The existence of such a geographical variation provides indirect evidence for the lack of mass migration occurring in this region.

It is worth pointing out that in Europe investigation of migration habits is carried out at latitudes beyond 50°N, while in the Orient monitoring is confined to the temperate zone between 30-40°N. This difference in the area of investigation may show dissimilar migration patterns between Europe and the Orient. For a better understanding of essential mechanisms of the migration of this moth international cooperative studies should be initiated.

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Taxonomic Notes on the Diamondback Moth

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Abstract

A taxonomic account is given of *Plutella xylostella*, a serious pest of crucifers worldwide. The paper lists various changes in the nomenclature from the initial description of this insect by Linnaeus in 1758. A detailed account of morphological characters of mature larva, pupa, and adult is given along with description of a closely related species, *Caunaca sera*, which also feeds on crucifers. Distinguishing characters of *P. xylostella* and *C. sera* are described.

Introduction

Plutella xylostella (Linnaeus 1758)

Plutella Tinea xylostella Linnaeus 1758, Syst. Nat. ed.:538.
Cerostoma maculipennis Curtis 1832, Brit. Entomol. Pl. 420 (expl. p 2).
Plutella cruciferarum Zeller 1843, Stett. Entomol. Ztg., 4:281.
Plutella brassicella Fitch 1856, Rep. Nox. Inst. New York, 1:170.
Plutella limbipennella Clemens 1860, Proc. Acad. Nat. Sci. Philad., 12:6.
Plutella mollipedella Clemens 1860, Proc. Acad. Nat. Sci. Philad., 12:6.
Gelechia cicarella Rondani 1876, Bull. Soc. Entomol. Ital., 8:20.
Tinea galeatella Mabille 1888, Miss. Sci. Cap. Horn, 6:34.
Cerostoma dubiosella Beutenmuller 1839, Can. Entomol., 21:27.

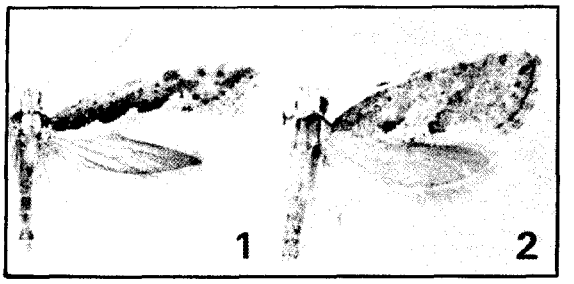
Much confusion in the nomenclature existed between the *Lonicera*-feeder and the smaller species feeding on various cruciferous plants until Zeller in 1843 restricted the Linnean name *xylostella* to the *Lonicera*-feeder, and called the smaller species *cruciferarum* Zeller. In 1897 Walsingham and Durrant pointed out that *Plutella cruciferarum* Zeller is a junior synonym of *Cerostoma maculipennis* Curtis, 1932. Consequently, the diamondback moth (DBM) had appeared in the literature as *Plutella maculipennis* Curtis.

In 1966, Bradley pointed out that the specific name *xylostella* is valid and has a priority over *maculipennis*. Some workers made objections to this. In 1970, Wolff proposed that the International Commission on Zoological Nomenclature (ICZN) should place on the Official List of Names in Zoology the name *xylostella* Linnaeus, 1758 (with the application for the use the plenary powers to designate a neotype for *Phalaena Tinea xylostella* Linnaeus, 1758), and that the name *maculipennis* published in the combination *Plutella maculipennis* Curtis, 1832, should be placed on the Official List of Specific Names in Zoology. Pelham-Clinton in 1970 supported Wolff's proposal, because the DBM, at that time known as *Plutella maculipennis* Curtis, was a widespread pest and extensive published literature listed it under that name.

Wolff's proposal, however, was refused by the ICZN (Opinion 1002) in 1973, and the specific name *xylostella* Linnaeus, 1758, as published in the combination *Phalaena Tinea xylostella*, was placed on the Official List of Specific Names in Zoology with the Name Number 2506.

Description

Adult (Figures 1, 3-5)



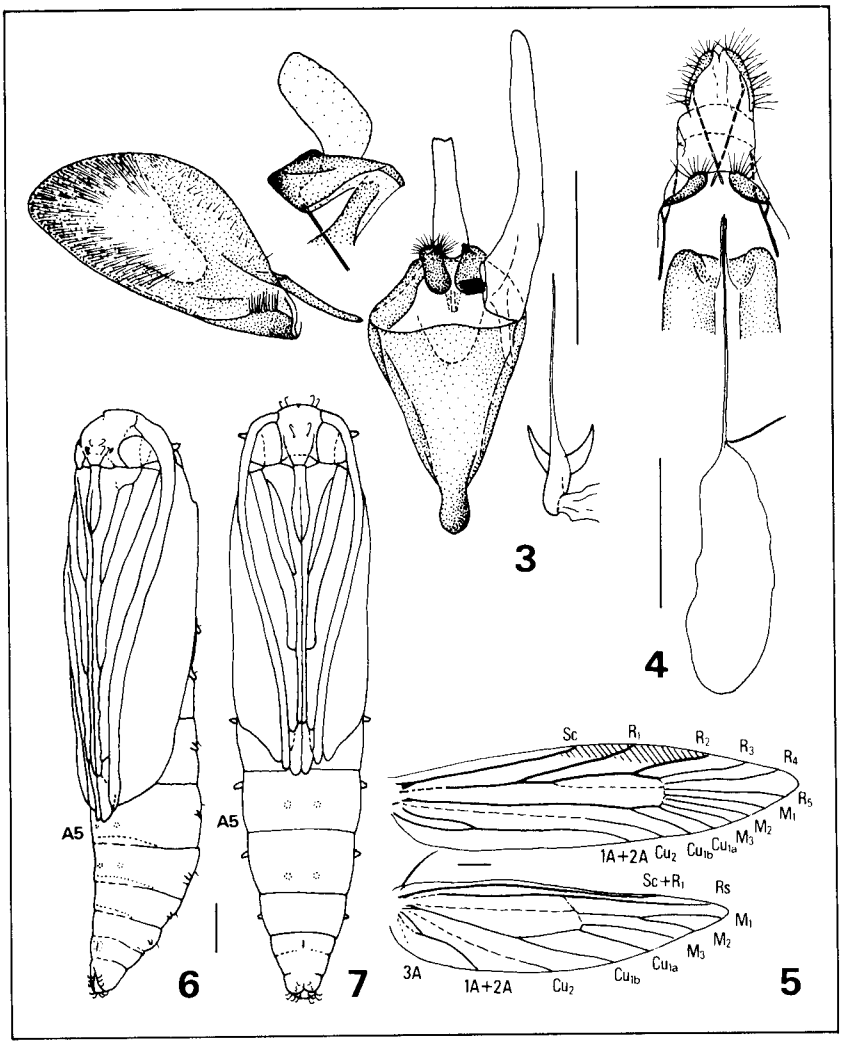
Figures 1-2.
Adults: 1. *Plutella xylostella*, male, and 2. *Caunaca sera*, female

In both males and females wing expanse is 12-15 mm. Venation as in Figure 5. Forewing, in males, with upper (costal 2/3) light fuscous, sometimes partially ochre-tinged, sometimes mixed with whitish scales, and flecked with scanty small blackish dots or spots; lower (dorsal) 1/3 pale ochreous-white, the upper edge being nearly white and thrice sinuate upwards, margined broadly with dark brown or black-brown; in females, light ochreous or light grey-ochreous; the contrast not so pronounced between upper and lower portions in coloration, but the markings, so far as traceable, like those of the male. Genitalia: in male as shown in Figure 3; aedeagus extremely slender in apical 5/8 and strongly bulbous basally, with distinct flanges on each side at basal 1/4. Female genitalia as in Figure 4; antrum weakly sclerotized, long, extremely slender; ductus burse membranous, as wide as and much longer than antrum.

Mature larva (Figures 8-17)

Average length 10 mm. Head capsule (Figure 8) pale ochreous to pale greenish-ochreous, or sometimes pale brown, mottled with brownish and black-brown spots; eye-spot black. Body green, sometimes tinged with pale yellow; rarely pale yellow, pale pinkish-yellow or pale grey (for example, when the larva feeds on whitish inner leaf of the cabbage, the body color fades into paleness); pinacula somewhat paler; prothoracic shield and anal shield a little paler than ground-color, and scattered with small pale brown and brown markings; thoracic legs ochreous, with pale brown claws; peritreme of spiracles ochreous; most setae stout and black. Head (Figure 8) with part of frontoclypeal apotome enclosed by adfrontal sutures extending about 3/4 of distance to vertical triangle; ocelli IV closer to III than than to V (Figure 9). Mandibles as shown in Figure 11, labrum as in Figure 10. Ventral prolegs (Figure 17) elongate, and twice as long as wide; crochets uniordinal, gradually smaller laterally and arranged in a circle, being usually 10 to 13 in number. Anal prolegs with about eight or nine crochets in a semi-circle. Spiracles are round; that of 8th abdominal segment distinctly larger than that of 7th (approximately 4:3) and as large as that of prothorax.

Chaetotaxy (Figures 8-10, 12-16) Cranial setae as in Figures 8-9. AFa not found. Prothorax as in Figure 12; Vl separated from coxa. Mesothorax with SDl very slender and shorter than SD2. Metathorax setose like mesothorax. Abdomen as shown in Figures 14-16; Dl above level of D2; SD2 separated from pinaculum of SD1; SV group unisetose on 8th and 9th, bisetose on 1st and 7th, and trisetose on 2nd-6th segments; SD1 of 9th segment very slender. Anal shield as in Figure 16.



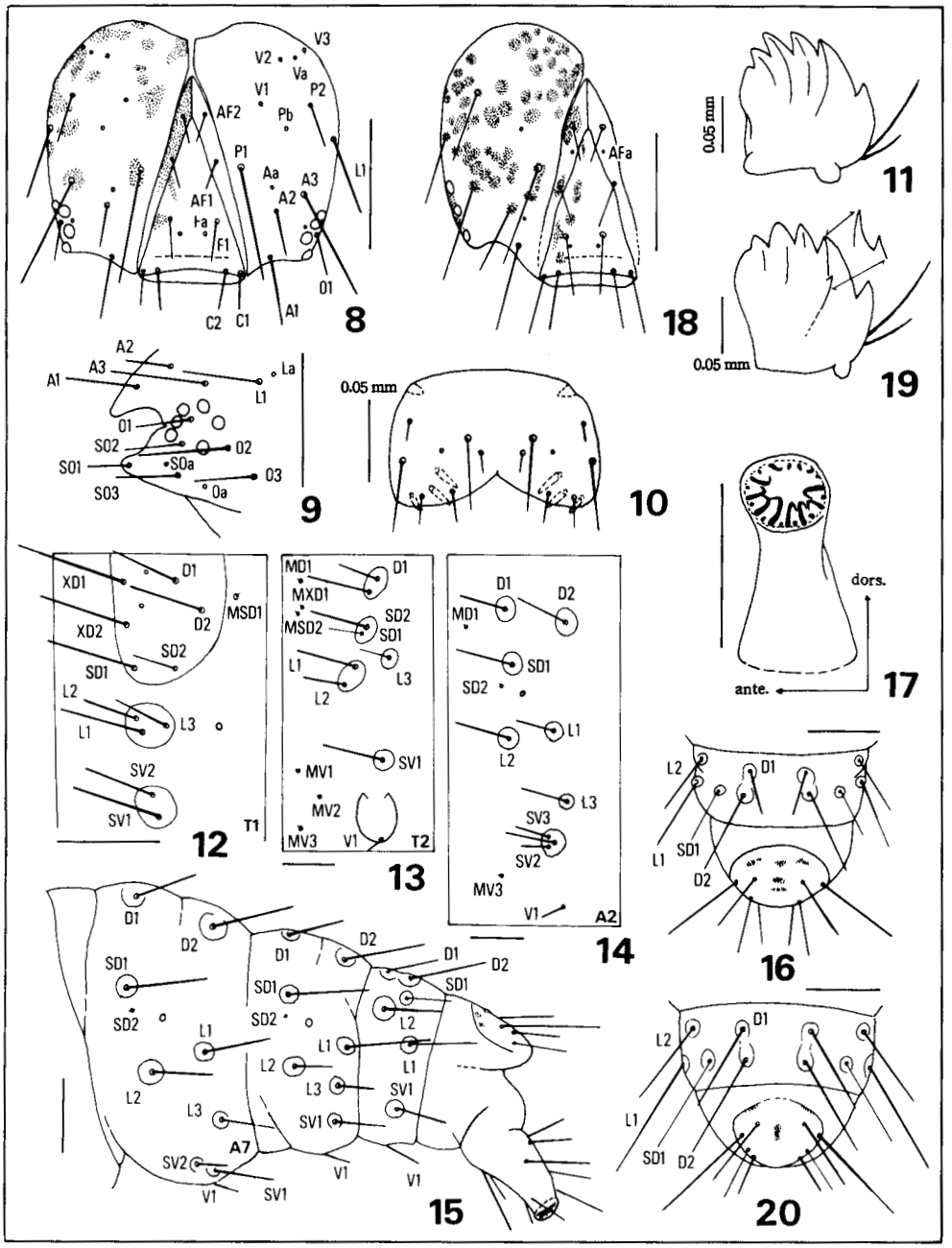
Figures 3-7. Adults (3-5) and pupae (6-7): 3. *Plutella xylostella*, male genitalia, 4. female genitalia, 5. male, wings, 6. male, ventro-lateral aspect; 7. *Caunaca sera*, female, ventral aspect. (scale = 0.5 mm)

Pupa (Figure 6)

Length 5-6 mm, about four times as big as the width. At first pinkish-white to pinkish-yellow, or sometimes green, with blackish subdorsal and subspiracular lines; ground-color later changing to brown. Structure as shown in Figure 6; abdomen with neither teeth nor spines on dorsal surface. Tenth abdominal segment with hooked setae.

Related Species

The adults of *P. xylostella* are not confused with any other plutellid species by the coloration, and are characterized by the peculiarly shaped aedeagus and the extremely slender antrum and ductus bursae.



Figures 8-20. Mature larva, *Plutella xylostella* (8-17): 8. head dorsal aspect; 9. ocellar region; 10. labrum, dorsal aspect; 11. leaft mandible; 12. prothorax; 13. mesothorax; 14. 2nd abdominal segment; 15. 7th-10th abdominal segmants, lateral aspect; 16. 9th and 10th abdominal segments, dorsal aspect; 17. 3rd abdominal segment, left, ventral proleg, mesal aspect. Mature larva, *Caunaca sera* (18-20): 18. head, dorsal aspect; 19. left mandible; 20. 9th and 10th abdominal segments, dorsal aspect. (scale = 0.25 mm, unless stated otherwise)

Plutella porrectella (L) and some species of *Caunaca*[1] (which is allied to *Plutella*) are associated with cruciferous plants in Europe; *P. porectella* on *Hesperis*, *C. seniella* (Zetterstedt) on *Arabis* and *Sisymbrium*, *C. annulatella* (Curtis) on *Cochlearia* and *Cheiranthus*, and *C. incarnatella* (Steude) on *Sisymbrium*. However, the larvae of these species do not attack cultivated cruciferous vegetables belonging to *Brassica* and *Raphanus*. *P. xylostella* can be easily distinguished from them in both adult and immature stages.

Caunaca sera (Meyrick), occurring in Japan, Taiwan, Vietnam, Indonesia, India, Sri Lanka, Australia, and New Zealand, is a pest of cruciferous vegetables (Fletcher 1933, Moriuti 1977). The larva of *C. sera* prefers to feed on brown mustard (*Brassica juncea* Czern et Coss var *integrifolia* Sinskaia), but also feeds on rape (*B. napus* L), cauliflower, cabbage, Chinese cabbage, and radish in Japan; turnip (*B. rapa* L) was recorded as one of the hosts of this pest in India (Fletcher 1933). *C. sera* is also associated with many wild cruciferous plants.

The larvae of *C. sera* coexist with those of *P. xylostella* on the host plants. *C. sera* is easily distinguished from *P. xylostella* on the basis of the following taxonomic characters.

Caunaca sera (Meyrick 1896)

Plutella sera Meyrick 1886, Trans. N. Z. Inst. 18:178.

Adult (Figure 2) Wing expanse 10-14 mm. This species is easily distinguishable from *P. xylostella* by the much broader wings (cf Figures 1 and 2). The genitalia are distinctly different from those of *P. xylostella*.

Mature Larva (Figures 18-20) Average length 10 mm. Head with numerous blackish-brown dots, some of which touch together (cf. Figures 8 and 18); mandible with a small retinaculum on inner surface (cf. Figures 11 and 19). Body green or somewhat tinged with yellow, with a slender red or pale red dorsal, subdorsal, supraspiracular, subspiracular, and basal lines, all of which are interrupted and connected by fine lines of same color extending dorsoventrally; in *P. xylostella* the lines are absent; prothoracic shield with a black brown or nearly black postero-ventral mark, which is absent in *P. xylostella*. Ventral prolegs with a mesal penellipse (an incomplete circle) of about 10 crochets in *C. sera*, but with a complete circle of crochets in *P. xylostella*. Chaetotaxy is very similar to that of *P. xylostella*; cranial puncture AFa present in *C. sera*, but absent in *P. xylostella* (cf Figures 8 and 18).

Pupa (Figure 7) Very similar to that of *P. xylostella* in appearance and structure, differing primarily by the clypeus which is provided with a pair of hooked setae in *C. sera* but with three pairs in *P. xylostella*; further, the maxilla is always shorter than the mid leg in *C. sera* but the former usually slightly longer than the latter in *P. xylostella*.

Ecological notes The lifecycle is not well known, but seems to be similar to that of *P. xylostella*. The larva feeds on the leaf of above mentioned crucifers, making shot-holes all over the foliage. Pupation takes place in an open net-like white cocoon usually on the underside of leaf, and the larval skin is thrown out the open end of the cocoon, as in the case of *P. xylostella*.

[1] According to Bradley (1972), *Caunaca* Wallengren, 1880, is synonym of *Rhigognostis* Staudinger, 1857.

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Mass Rearing of Diamondback Moth

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Abstract

Mass rearing methods on artificial diets and cruciferous seedlings for the diamondback moth, *Plutella xylostella* L, are reviewed and described briefly.

Introduction

Research on the diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), has recently become increasingly important after findings that the insect has developed resistance to various insecticides and that it produces sex pheromone which has potential in controlling the pest. For obtaining reliable and reproducible information from the physiological, toxicological, and pathological experiments of any insect, it is desirable to have uninterupted supply of physiologically homogeneous individuals. Therefore, development of laboratory rearing techniques is necessary. According to Singh (1977), the goal of mass rearing is to produce the maximum number of insects in the shortest possible time and under the most economical conditions such as minimum labor and space. To meet these practical requirements, both rearing materials and equipment should be kept as simple and inexpensive as possible but they must be nutritionally and behaviorally optimal for the insect.

Only limited published information exists on the rearing of DBM on semi-synthetic diets or cruciferous seedlings. The present paper attempts to review the existing literature and to describe the techniques for laboratory and mass rearing of DBM.

Rearing on Semi-Synthetic Diets

Dietary formulation

Most of the diets developed for lepidopterans are formulated as the semi-synthetic containing natural food either fresh or dried. Biever and Boldt (1971) first adopted a semi-synthetic diet (Table 1), which was previously formulated for *Heliothis zea* and *H. virescens* by Berger (1963), for rearing DBM. Later, Hsiao and Hou (1978) modified this diet by adding linseed oil, i-inositol and cholesterol (Table 1). These diets can be regarded as wheat germ-based diets. However, Hou and Hsiao (1979) suggested deletion of formaldehyde from the diet in the presence of antibiotics. Agui et al (1975) formulated two diets for the cabbage armyworm, *Mamestra brassicae*, that could be used for rearing DBM as well. The composition of their diet is shown in Table 2. Both diets contain a large amount of finely chopped cabbage leaves instead of dried leaf powder. The addition of fresh materials may make the dietary effect inconsistent due to variation in water content of fresh leaves in each preparation. Besides, preparation of the diet is impossible when fresh leaves are not available. In comparison, dried leaf powder can be stored for months if kept cool and is thus convenient for dietary preparations.

Table 1. Composiion of semi-synthetic diets for rearing of DBM

Ingredient	Amounts in 100 g diet	
	Biever and Boldt	Hsiao and Hou
Casein, vitamin-free	3.500 g	3.500 g
Alphacel	0.500	0.500
Wesson's salt mixt.	1.000	1.000
Sucrose	3.500	3.500
Wheat germ	3.000	3.000
Methyl-p-hydroxybenzoate	0.150	0.150
Choline chloride	0.100	0.100
Ascorbic acid	0.400	0.400
Aureomycin	0.015	0.015
Cabbage leaf powder	1.250	3.000
Cholesterol	—	0.250
i-inositol	—	0.018
Agar	2.250	2.250
Distilled water	84.00 ml	84.00 ml
KOH (4M)	0.50	0.50
Formaldehyde	0.05	0.05
B-vitamin solution	1.00	1.00
Linseed oil	—	0.65

Table 2. Composition of semi-synthetic diets for *Mamestra brassicae* and DBM[a]

Ingredient	Diet I	Diet II
Water	100.00 ml	100.00 ml
Agar	7.50 g	5.00 g
Potato starch	5.00	5.00
Sucrose	5.00	5.00
Soybean flour	20.00	20.00
Wesson's salt mixture	1.75	1.75
K_3PO_4	0.50	0.50
Citric acid	0.25	0.25
Dried brewers' yeast	7.50	7.50
Cholesterol	0.25	0.25
Soybean oil	1.50	1.50
Powdered filter paper	11.25	—
Wheat germ	—	20.00
L-ascorbic acid	2.00	2.00
Propionic acid	0.35 ml	0.35 ml
Finely chopped cabbage leaves	65.00	75.00

[a] Source: Agui et al 1975.

Preparation of diet

The proper preparation procedure is extremely important in determining whether the diet is acceptable by various stages of insects and is nutritionally optimal for their growth and development. When making a suitable diet, at least two technical factors should be considered: dietary ingredients should be well mixed and should retain all nutrients as far as possible for the final diet. Hsiao and Hou (1978) prepared a diet by mixing solid dietary components, liquids, and anti-mold compounds with a melted

agar solution, and then added vitamins and antibiotics. However, an improved preparation method, involving heating wheat germ before adding to other components and changing the mixing order, resulted in a better diet (Hsiao and Hou 1982). The improved procedure is as follows: Alphacel, cabbage leaf powder, and the heated wheat germ are mixed thoroughly and then cholesterol and linseed oil dissolved in ether are added to this mixture, stirring well to evaporate the ether. Sucrose, casein, methyl-p-hydroxybenzoate, and Wesson's salt mixture are added to the melted agar solution, and the resulting solution is poured together with the solid mixture into a blender. Immediately add aureomycin, ascorbic acid, i-inositol, choline chloride, potassium hydroxide and vitamin B. The whole mixture is ground thoroughly in the blender for 1-2 min and is then ready to be dispensed (Hsiao, M. L. and R. F. Hou unpublished data). The diet can be dispensed in vials, dishes or other appropriate containers for feeding insects. The leaf powder is usually prepared from fresh cabbage leaves by drying at 60°C for 24 h and then grinding up with a blender, The powder is then screened through a 100-mesh sieve before storing at low temperature.

Feeding procedures

Biever and Boldt (1971) found that females were able to oviposit on paper towels; therefore, eggs are very easy to collect. They glued or stapled sections of oviposited towels with about 100 eggs to the lids of 6 oz ice-cream cups containing the diet. Most larvae will pupate on the lids which are then hung on a rod in the adult cage (about 2,160 cm^3) for emergence. Hsiao and Hou (1978) reared 30 newly hatched larvae on 5 ml diet placed in a glass tube (3 × 9 cm). The diet was changed every two to three days.

Growth and development of insects

The diet developed by Biever and Boldt (1971) seemed satisfactory for DBM. The developmental period from egg to adult was only 19 days; egg, 3; larva, 11; pupa, 5 days at 23 + 1°C, 60 + 5% RH. Similar results were obtained when DBM was fed on artificial diets and on host plants in Taiwan (Wu 1968; Hsiao and Hou 1978). However, Harcourt (1957) reported that it took about 30 days from larval to adult stage in Canadian populations. The mean hatchability was 90%, mean larval survival 90%, and pupal survival 86%. It was also indicated that egg viability remained stable after rearing for one year. But Hsiao and Hou (1978) could only obtain about 62% larval survival and about 59% pupation when insects were fed on the Biever and Boldt diet, while both larval survival and pupation were about 83% when insects were fed on the modified diet which in turn was similar to results when the insects were fed on cabbage leaves. Adult emergence from the larvae fed on the Biever and Boldt diet was also poor (Table 3). This difference could possibly be ascribed to variations in the method of dietary preparation and to geographic variation of the insect. Nevertheless, it is conceivable that semi-synthetic diets are useful for laboratory rearing of DBM although they are not more economical than rearing on cruciferous seedlings as will be described in the next section.

Table 3. Survival and development of DBM fed on various diets[a]

Diet	Larval survival (%)	Pupation (%)	Adult emergence (%)
Biever and Boldt	61.9	58.8	26.4
Modified diet	83.4	83.4	83.4
Cabbage leaves	84.8	84.8	84.8

[a] Source: Hsiao and Hou 1978.

Rearing on Cruciferous Seedlings

Chi and Sun (1975) reported a mass rearing method using cabbage heads kept in petri dishes containing water. They were able to obtain 100 mature larvae per head from 30-50 adults which were allowed to oviposit on the head. This method is rather costly and has low productivity. A simple mass rearing technique was developed using rape seedlings germinated densely in plastic vessels by Koshihara and Yamada (1976). Later, Yamada and Koshihara (1978) made some modifications and described the rearing techniques in greater details. This section is intended to summarize their rearing procedures in brief and to elicit a recent modification of this technique by Liu and Sun (1984).

Seedling preparation

Seedlings of rape or radish are used as rearing materials. To prepare the seedlings, seeds are soaked in water for 5 to 24 h, and then treated with disinfectants, for example, Benlate T, Daconil, and Homai for 30 min. Seven to 10 g disinfected seeds are transferred into a small plastic vessel (9.5 cm diam, 5.5 cm deep) with a perforated lid on top and a piece of paper at the bottom on which the seeds are sown. Each vessel is filled with 4 ml water. The seeds begin to sprout after one day, and are ready to feed larvae on their cotyledons in three days.

Rearing procedures

Three pairs of one to two day-old adults are confined in a rearing vessel. They will lay about 150-250 eggs in three days. The seedlings are usually exposed to natural light. The hatched larvae feed on the seedlings and reach 4th instar by 14 days after introduction of parental adults. Most will pupate by 17 days at 25°C, with a 16 h photoperiod, the pupation rate being over 80%. Replenishment of water is not necessary in this system, as the optimal humidity is 60- 70% RH. The mature larvae will pupate on pieces of folded filter paper placed on top of the seedlings; the pupae can be collected easily from the paper.

Mass rearing

It was found that pupation rate and pupal weight varied with the larval density in each rearing vessel. Table 4 shows that the pupation rate is over 90% when feeding 50-100 newly hatched larvae in each vessel, but it reduces drastically if the larval number is increased to 200-300. In this rearing system, 100-140 pupae can be obtained in each vessel, the pupal duration being about four to five days. For mass rearing it is practical to prepare 18 rearing vessels using about 150 g of radish seed, twice a week. By this method some 15,000 pupae will be obtained each month. Since the rate of adult emergence is about 80%, with a sex ratio of 1:1, some 6,000 pairs of adults per month can be obtained by this rearing program.

According to Yamada and Koshihara (1978), continuous rearing was carried out for two years using this technique; however, some wild adults collected from cabbage fields were introduced into the rearing colonies once or twice each year to avoid crossing between genetically related individuals. Rearing was continued for 30 generations with normal development. They did not find any distinct abnormality in pupation of the insects when investigation was carried out up to 21 generations (Table 5). This mass rearing technique has been widely used to rear colonies of DBM for studies on physiology, pathology, toxicology and other factors in Japan and elsewhere (Koshihara and Yamada

Table 4. Pupation and pupal weight of DBM fed on rape seedlings[a]

No. of newly hatched larvae	Pupation (%)	Pupal weight (mg)	
		Female	Male
50	96.0	4.3	3.7
100	93.5	4.9	3.9
200	74.0	3.6	3.4
300	77.9	4.0	3.8

[a] Koshihara and Yamada 1976.

Table 5. Continuous rearing of DBM on rape seedlings[a]

Generation	No. of rearing vessels	No. of pupae per vessel
4	6	187.2
5	3	87.7
10	12	99.2
12	6	65.2
13	6	107.8
16	6	134.7
18	4	104.8
21	12	74.0

[a] Source: Yamada and Koshihara 1978.

1980, Ishii et al 1981, Liu et al 1982, Miyata et al 1982, Tomiyama and Aoki 1982, Yamada and Kawasaki 1983, Nemoto et al 1984).

A modified rape seedling method

Recently, Liu and Sun (1984) reported a modification in the rearing DBM by Koshihara and Yamada (1976) method. In their procedure they sowed seeds in vermiculite in a rearing vessel (9 cm diam, 4 cm deep) without covering them. This, according to the authors, permitted better air circulation and lesser microbial contamination. Mass oviposition by 100 adults on the seedlings in an egg-laying cage ($20 \times 20 \times 30$ cm) was undertaken to save labor. The oviposited seedlings are transferred into a rearing cage ($30 \times 30 \times 50$ cm) for mass rearing. To collect the larvae, it is necessary only to reverse the rearing vessel and to tap the bottom of it, allowing the larvae to spin down, or they can be helped using forceps or a brush. This rearing method can be carried out without temperature control or critical lighting equipment, and is considered to be more practical and a better technique for mass rearing of the DBM in places where manpower and facilities are limited.

Concluding Remarks

Although mass rearing of DBM has been found feasible using cruciferous seedlings, it seems that microbial contamination in the course of the feeding period may still cause some practical problems. Treatment of seeds with disinfectants and improvement in air circulation by uncovering the rearing vessels containing seedlings have been attempted with satisfactory results.

The semi-synthetic diets with a wheat germ base were formulated for laboratory rearing of DBM; however, dietary composition has to be simplified to meet the

economical assessment. In addition, feeding procedures on artificial diets for the purpose of mass rearing remain to be developed to increase the productivity per unit quantity of diet and time. Theoretically, development of mass rearing methods should be directed toward feeding on artificial diets rather than on natural food, especially when aseptic rearing is essential. It is thus suggested that rearing of DBM on semi-synthetic diets should be encouraged and ought to be considered as a prospective method for mass rearing of experimental colonies.

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Discussion

I. MANTI: I would like to know the role of insecticides in the control of DBM in Canada and any information that might be available on the effect of these chemicals on predators and parasites.
G. S. LIM: You showed data indicating high (70-80%) parasitism of DBM. Is such high parasitism common in farmers' fields over a good number of years?
D. G. HARCOURT: These two questions are related. In southern Ontario, crucifers are attacked by a complex of Lepidoptera that includes the imported cabbageworm and the cabbage looper. In most years, insecticides are routinely applied to control populations of the imported cabbageworm which is the major pest on both early and late crops. These materials also control DBM and have a negative impact on its natural enemies. As a consequence, rates of parasitism are much lower in farmers' fields than in protected plots. However, the parasites tend to build up quickly when pesticides are withheld; in such cases, high rates of parasitism will persist.

G. S. LIM: Is there any significant hyperparasitism that might adversely affect the effective contribution of DBM parasites?
D. G. HARCOURT: In practical terms, the answer is no. In our studies, we occasionally found *D. insulare* to be attacked by *Eupteromalus viridescens* (Walsh) in the late fall. However, the incidence was extremely low.

O. MOCHIDA: What stage(s) does the DBM overwinter in cold or cooler areas of the world?
D. G. HARCOURT: In Canada and the northern US, the DBM does not survive the winter in any stage. In Canada, each year the adults migrate from the southern US.

B. ROWELL: Is DBM capable of long distance migration? If so, is this migration by means of long distance flights or by slow movement through successive crucifer crops?
D. G. HARCOURT: The migration is a long distance phenomenon. During early to mid May each year gravid adults are captured in light traps following two or three days of strong southerly wind flow from the US. Further evidence comes from the simultaneous discovery of freshly laid eggs on cruciferous weeds.

T. H. CHUA: I noticed that the population of *D. insulare* is low during the first and second generations of DBM, but it increases in the third to fifth generation. It is possible to increase the natural biological control of DBM by *D. insulare* by releasing laboratory reared insects. Could you comment on this?
D. G. HARCOURT: *D. insulare* starts showing each year because it must rediscover its host. If laboratory-propagated wasps were released at the appropriate time following discovery of the first generation eggs, we might induce higher rates of attack on the second, third and fourth host generations.

H. CHI: Do generations of DBM overlap? If so, how do you take this into account in the use of life tables?
D. G. HARCOURT: There is some slight overlap, of course. However, with intensive population sampling at two to three day intervals, we had no difficulty in isolating and tracking the generations.

R. REJESUS: Rainfall is one of the major mortality factors which dislodges young larvae from plants. Will overhead irrigation work?
D. G. HARCOURT: It definitely holds promise because the young larvae drown very quickly. However, the key will lie in cost effectiveness and the type of crucifer under protection. This idea is currently being pursued by at least two groups of scientists that I know of.

V. HARRIES: Dr. Harcourt mentioned the DBM immigration to southern Ontario from the US as a long distance phenomenon. Are these data available about the local/short distance distribution/migration of DBM during the mating/pre- oviposition period? What is the active flight distance of the DBM adult?
D. G. HARCOURT: The active flight distance is short. It has not been measured, but light trap studies suggest that the males are pulled from not more than 150 m, and the females even less.

R. REJESUS: Reduced fecundity is attributable to protein deficiency due to plant age. How about the possibility of genetic degeneration due to very high rates of population in a short period of time.
D. G. HARCOURT: I would discount the possibility of degeneration, in fact, our data has included information from all generations.

L. C. CHANG: In certain animals fecundity is influenced by lipid content. Do you think this is true in DBM?
D. G. HARCOURT: There is some evidence that the fat body increases with decreasing fecundity, but this has not been studied in any detail.

O. MOCHIDA: How do you keep the susceptible strain or standard strain?
P. A. C. OOI: The work on quantifying resistance was carried out by Dr. Sudderuddin and his colleagues. He used a susceptible strain from France and maintained the population on insecticide-free crucifer. The insect is available for laboratory breeding.

E. Y. CHENG: Have you ever tried mevinphos for DBM control? In Taiwan mevinphos is a rather resistance-free compound in comparison to other insecticides.
P. A. C. OOI: I believe mevinphos is not yet registered in Malaysia, and hence not used.

A. SIVAPRAGASAM: I wonder what the government is doing in the implementation of the IPM program in Malaysia.
P. A. C. OOI: Recognising the importance of managing the DBM at farm level, greater efforts are being made to intensify extension to the farmers.

H. OOUCHI: What was the distance between control plot and sterile male release plot?
SOELAKSONO S.: There were two types of sterile male release experiments. In one we released the sterile males in a caged field and in the other release was made in the open fields. In the cage experiment, the controls were located in the same plot as the treated ones while in the open field, the distance between the control and the treated plots was 100 m.

T. MIYATA: You showed that certain insecticide application resulted in 60% parasite mortality. At this concentration do you get good control of DBM?
SOELAKSONO S.: Parasitoid mortality of up to 60% occurred with methamidophos (0.20%) and endosulfan (0.20%) treatments. The mortality of DBM was lower than 60%.

O. MOCHIDA: In your last slide you showed that the number of larvae in the dichlorvos plot was greater 11 days after treatment than before treatment, what is the reason?
T. KOSHIHARA: Probably due to degradation of dichlorvos its insecticidal efficacy against DBM was reduced. Hence the larval population remained the same or increased slightly after insecticidal treatment.
E. Y. CHENG (COMMENT): Dr. Mochida raised the question of why dichlorvos treatment has more insects 11 days after treatment than before the treatment. This is because dichlorvos has very short residual life. So the population on the 11th day will depend on the number of DBM eggs laid two to three days after dichlorvos treatment, since larvae will survive due to lack of dichlorvos residue. On the other hand prothiophos has longer residual life and newly hatched larvae will be killed as soon as they emerge from the eggs.

E. Y. CHENG: What is the reason for using WP and granular formulation of acephate in Japan?
T. KOSHIHARA: Acephate EC formulation is not available in Japan. This is possibly due to the technical problems in commercial scale synthesis and EC formulation of this product. Acephate shows systemic activity agaist DBM larvae. Therefore, its granules can be conveniently applied onto young plants and/or on the soil surface soon after planting, or into the soil just before transplanting.

N. S. TALEKAR: You showed that DBM is important only in summer in Japan. What happens to DBM in winter? Do they overwinter? Is there migration from other countries?
T. KOSHIHARA: In the southern and the central parts of Japan, DBM occurs all year round, while in some parts of the central highlands and in cool areas in the north the insect appears exclusively from spring to autumn. Research work on its overwintering in cooler areas and migration from the warmer areas in the south to the north is being carried out now.

O. MOCHIDA: How is the survival of DBM during the winter?
SIVAIPRAGASAM (COMMENT): We are actually doing some experiments at sub-lethal temperatures in order to see whether DBM is able to survive at sub-threshold temperatures of development. But no proper conclusions could be drawn at this moment, although pupation was affected when larvae (3rd- 4th instar) were exposed to ca $5 \pm 1°C$ under laboratory conditions.

E. D. MAGALLONA: The figures on parasitism that you quoted, which are rather high, were they in field-parasitism?
O. P. BHALLA: Yes, under field conditions.

Morphological and Biological Evidence for the Presence of a Male Sex Pheromone of the Diamondback Moth

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Abstract

In the present study, besides morphological evidence, two bioassays, antenna-excision and hairpencil-excision, were used to demonstrate the presence of a male sex pheromone of the diamondback moth *Plutella xylostella* L. Although the antenna-excision bioassay demonstrated that a male aphrodiasic pheromone exists in the diamondback moth, it was proven to be not as important as the female sex pheromone in mating. After the hairpencils of males were excised, the mating success of the females decreased significantly, suggesting that the male hairpencils might play a role in the mating of the female diamondback moth.

Introduction

Hairpencils, highly specialized scales, are present on the integument of the males of various lepidopteran species. They are exposed during the pre-courtship rituals that lead to various species-specific behavior patterns (Grant and Brady 1975, Baker and Carde 1979, Rutowski 1980, Hirai et al 1981). This has been studied in tobacco budworm (*Heliothis virescens*). The release of an airborne chemical by these organs suppresses the emission of the sex pheromone secreted by the female (Hendricks and Shaver 1975). However, Clearwater (1972) reported that *Mythimna separate* (Walker) produced a pheromone from hairpencils and suggested that the major component, benzaldehyde, acted as an arrestant that prevented the escape of the female during courtship. On the other hand, Gothilf and Shorey (1976) found that in cabbage looper (*Trichoplusia ni*) the scent of the male moth was not an essential component in courtship behavior. Recently Baker et al (1981) and Nishida et al (1982) found that a blend of ethyl trans-cinnamate, methyl 2-epijasmonate, methyl jasmonate, and (R)-(-)-mellein, identified from the hairpencils of male oriental fruit moth, attracts sex pheromone-releasing females several centimeters away.

The objectives of the present study were to determine the effect of the hair-pencils of the male diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae) on mating and to demonstrate the presence of a male sex pheromone, if any.

Materials and Methods

Experimental insects

The DBM adults were obtained either from a laboratory where they were reared on kale seedlings, or from field population on cabbage and kale during the pupal or late larval stages. The pupae were kept individually in a 4.5 cm × 1 cm (diam) vial

maintained at 25 ± 1°C in a 16:8 light-dark photoperiod incubator. Newly emerged pre-sexed adults were maintained individually in the same incubator. A 5% sugar solution was provided as food to the adults.

Morphology

Hairpencils were exposed by squeezing the base of the male abdomen and removed with fine forceps. They were fixed by immersion in fixative (3% glutaraldehyde), and then transferred to amyl acetate to facilitate critical pointed drying. They were coated with a 50 nm film of gold in a Polaron Sputter Coater and examined and photographed using a Hitachi 450 Scanning Electron Microscope (Chow et al 1976). For light microscopic observation, the male abdomen tip was dissected out and fixed in Zenker's solution for two hours, dehydrated, and embedded in paraffin. Serial sections, 6-10 u thick, were cut and stained with Harris's hematoxylin as described previously (Chow et al 1976).

Bioassay

Male mating frequency per night One to three day-old adults were used. One male and five female moths were kept in each of the 14, 17 cm × 8 cm (diam) containers. All containers were placed overnight (about 14 h) in a dark room at 22 ± 1°C. The females were anatomized the following day to check for the presence of sphermatophores and the size of bursa copulatrix to judge the success of mating (Yang and Chow 1978, Fujiyoshi et al 1979).

The antenna-excision method One half to four day-old adults were used. The insects were anesthetized by ether. Ten males with excised antennae were paired with 10 normal females, 10 females with excised antennae were paired with 10 normal males, and 10 pairs of adults that served as a control were kept in 17 cm × 8 cm (diam) containers separately. All were kept in a dark room at 19 ± 3°C overnight. The presence of spermatophores and the size of bursa copulatrix were used to judge mating success on the following day (Yang and Chow 1978, Fujiyoshi et al 1979). The data were analyzed by Duncan's multiple range test.

The hairpencil-excision method One half to four day old male moths were separated into four groups. Each group consisted of 19 pairs. In the first group, male moths were anesthetized by ether. Then with the help of forceps covered with a polyethylene tubing the tip of abdomen was pressed tenderly until the hairpencils came out. With another pair of forceps the hairpencils were pulled out.

The second group of insects were treated similarly to the first except that the tip of hairpencil tube was sealed with glue to prevent the secretion of sex pheromone from the inside of the tube. This is termed the tube-sealing group.

The third group of insects was treated in the same way as the first except that the hairpencils were not touched.

The fourth group of insects were normal adult males.

Each group of insects was maintained in a 17 cm × 8 cm (diam) container. A 5% sugar solution adsorbed on sponge was placed in each and the containers were covered with cheesecloth to allow ventilation. All four groups were kept in a dark room at 19 ± 2°C overnight. The following day, the insects were dissected to check the progress of mating by the size of bursa copulatrix and the presence of sphermatophores (Yang and Chow 1978, Fujiyoshi et al 1979). The data were analyzed by Duncan's multiple range test.

Results and Discussion

Morphology

The photomicrograph of artificially extruded hairpencils and accompanying scent brush glands of the male DBM are shown in Figure 1 and the normal non-exposed hairpencils in Figure 2. Morphologically speaking, these hairpencils were identical to those of cabbage looper moth described by Gothilf and Shorey (1976) and of the flour moth described by Corbet and Fook (1977). In Figure 2, small droplets within the hairpencils are easily seen. It is suspected that they secrete the pheromone. Whether the droplets observed by us are identical to small vesicles in noctuid male moths observed by Clearwater (1975) still needs further study.

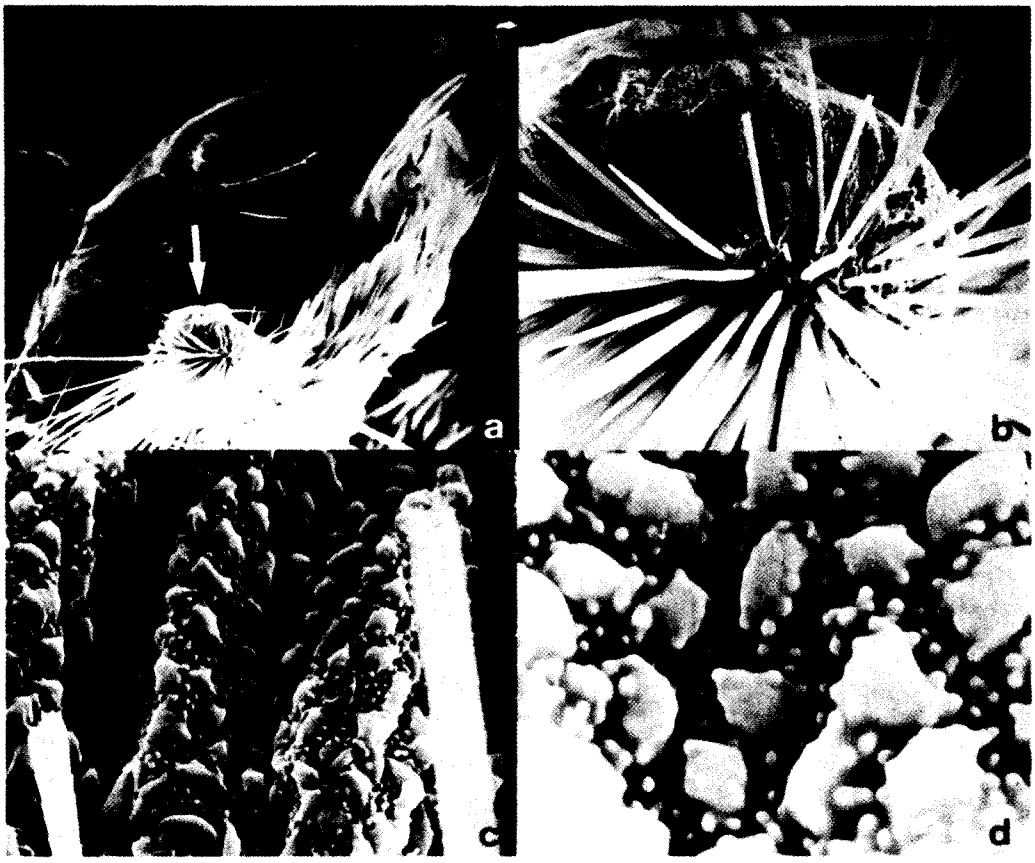

Figure 1. a. A scanning elecronmicrograph of the exposed hairpencils (arrow) of the male DBM showing the position on the abdomen, and the genital clasper (C) (100x). b. Enlarged view of the exposed hairpencils (500x). c. and d. Enlarged view of the exposed scent brush gland (3000x and 15000x)

Bioassay

Mating frequency A male moth mated with only one female per night. This was confirmed by the observation of the size of bursa copulatrix and the presence of spermatophores within bursa copulatrix in females.

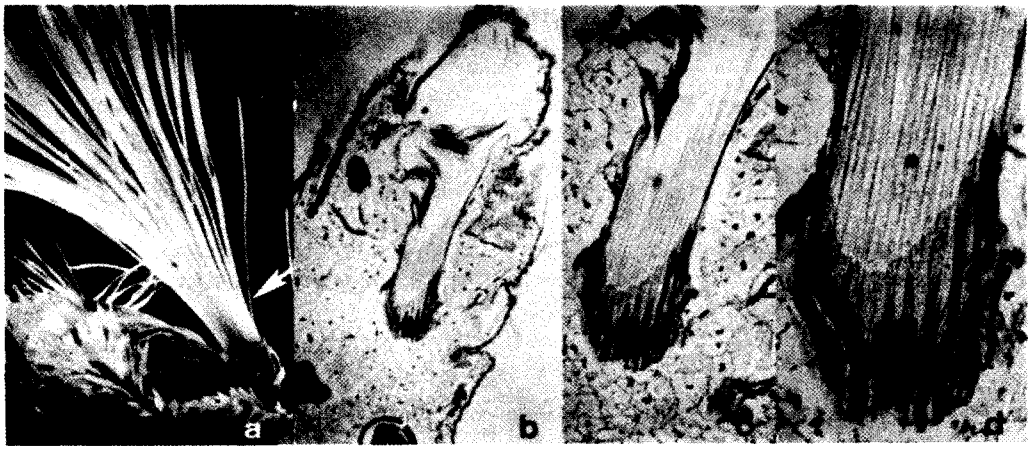

Figure 2. a. A scanning electronmicrograph of the non- exposed hairpencils (arrow) and the infold scent brush gland. b. Photomicrograph of the hairpencils and their scent brush gland (100x). c. and d. Same as b, but with greater magnification (200x and 400x) showing the small droplets within the hairpencils

The antenna-excision method The effect of antenna-excision on mating success is presented in Table 1. The average number of females with spermatophores in the control group was significantly greater than in antenna-excision groups. The number of moths with spermatophores in the female antenna-excision group was significantly greater than in the male excision group. Since electroantennograms (EAG) have been used extensively to identify the female or male sex pheromones (Grant et al 1972, Jacobson et al 1976, Chow et al 1980), the antenna is believed to be the only olfactory receptor of sex pheromone. It has also been established that female sex pheromone in many lepidopteran species, including DBM, plays an important role in mating success. In the present study, our results confirmed this. When the antennae of male moths were excised, the mating success decreased to almost nil. When the antennae of females were excised, the mating success decreased significantly but not as drastically as when antennae of males were excised. This indicates that a male sex pheromone was involved in mating success but it was not as important as the female sex pheromone.

Table 1. The effect of antenna-excision on mating of DBM

Treatment	Mean number of females/10 with spermatophores
Control	8.6a
Female without antenna	5.8b
Male without antenna	0.4c

Means followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test.

The hairpencil-excision method The results of the effect of hairpencil-excision on mating success are presented in Table 2. The average number of females with spermatophores in the normal group was not significantly different from that in the control group. Both groups were significantly different from the hairpencil-excision

group and the tube-sealing group. The tube-sealing group was not significantly different from the hairpencil-excision group.

Table 2. Effect of hairpencil-excision and tube-sealing on mating of DBM

Treatment	Mean number of females/10 with spermatophores
Normal	8.18a
Control	6.18a
Without hairpencils	3.36b
Tube-sealing	3.09b

Means followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test.

In this part of the study, when the hairpencils were excised, the average matings decreased considerably compared with the normal and control groups. This showed that the hairpencils of DBM do play a very important part in mating success. The success of mating of some pairs suggests that either the hairpencils were not pulled out completely or that other scent glands present in other parts of body, such as small scent glands and wing glands which are present in male cabbage looper (Grant 1971), are involved in mating. Further histological studies are necessary to define their involvement.

Mating success of moths in the tube-sealing group did not differ significantly from those without hairpencils. This could be for the following two reasons. Firstly, the quantity of male sex pheromone did not reach the behavior response threshold. Naturally when the hairpencils are displayed before a female moth it secretes a large quantity of male sex pheromone. But when the hairpencils were pulled out, no such action has been involved. Therefore, there is no difference. Secondly, the glue probably cannot completely prevent the escape of volatile sex pheromone chemicals of the male moth.

Both antenna-excision and hairpencil-excision methods proved the presence of a male sex pheromone in DBM. Further studies involving electroantennogram and isolation and identification of the pheromone structure are needed to reach an understanding of the vital function of hairpencils.

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Ecological Approach to Male Diamondback Moth Response to Sex Pheromone

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Abstract

Natural populations of diamondback moth (*Plutella xylostella* L) were collected from five different vegetable fields and the response of males to a synthetic female sex pheromone was monitored using a Y-test in the laboratory throughout the year. Mass trapping of adult males using five blends of the pheromone was also conducted in the field. The antennal esterase activity of diamondback moth was monitored by the use of either 1-naphthylacetate or ^{14}C (Z)-11-hexadecenyl acetate as substrates. In addition, zymograms of antennal esterase were studied by poly-acrylamide gel electrophoresis. Fifth instar larvae of the moth were monitored for malathion resistance. It was found that variations in the pheromone response of adult males to trinary of (Z)-11-hexadecenal, (Z)-11-hexadecenyl acetate, and (Z)-11-hexadecen-1-ol, were age dependent. Assays of antennal esterase activity were positively correlated with the behavior of the male moth. Antennal esterase zymograms revealed 10 bands, each with different characteristics. The pheromone hydrolytic activity of antennal esterase of male adults had a high titer which was coincident with a high rate of malathion degradation activity in the larval stage of the moth. However, this is not interrelated with a strong pheromone response by male adults. Two cycles of male response alternated during the year. Relative humidity was possibly the major factor affecting the male response to the pheromone blends. Temperature may play only a minor role in the response in tropical Taiwan. A pheromone blend of 3:7:0.1 (Ald:OAc:OH) was recommended for use in male trapping in subtropical areas.

Introduction

Organic pesticides are invaluable in suppressing damage to agricultural products. However, the side effects of these chemicals on the environment have become a serious problem over the past decades. In addition, the rapid development of resistance, especially to insecticides, in target insect pests makes control more difficult. This has imposed pressure on scientists to find alternatives that do not depend on toxic agents. This in turn has led scientists to delve into biological and biochemical transformations within the insect system.

Sex pheromones of lepidopterous insects were introduced as biorational chemicals for pest management programs in Taiwan in the early seventies (Chow et al 1973). The female sex pheromone (FSP) of diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), was first isolated by Chow et al (1974). Tamaki et al (1977) then identified the pheromone as a mixture of (Z)-11-hexadecenal (Z-11-16Ald) and (Z)-11-16-hexadecentyl acetate (Z-11-16:OAc). Chow et al (1977) confirmed that the best attractant ratio of the two compounds in the field was from 1:1 to 1:3 at a concentration of 10 μg in Taiwan. Chow et al (1978) announced that when methyl (Z)-11-hexadecenoate was added at low concentrations to the mixture of Z-11-16:Ald

and Z-11-16:OAc in a ratio of 1:1, a synergistic effect was displayed in field screen tests. Later Ando et al (1979) found that attractiveness in the field of the 1:1 mixture of Z-11-16:Ald and Z-11-16:OAc at 10 μg was obviously enhanced by adding 1-10% of (Z)-11-hexadecen-1-ol (Z-11-16:OH). Chisholm et al (1979) in Canada found that a combination of Z-11-16:Ald, Z-11-16:OAc, and Z-11-16:OH in a ratio of 7:3:0.1 in 100 μg achieved the optimum male catch. The catch could be enhanced by the addition of 0.02 part of Z-9-14:OAc (Chisholm et al 1983). In Taiwan, Chow et al (1983) reported that a blend of Z-11-16:Ald, Z-11-16:OAc, and Z-11-16:OH in a ratio of 5:5:0.1 was most attractive to the male adults in the field. Re-evaluation of pheromone blends for achieving high male catch revealed that there was considerable variation in responses to a range of ratios (Maa and Lin 1983). A blend of 3:7:0.1 (Ald:OAc:OH) was found to be the most efficient for mass trapping in the field in Taiwan (Maa et al 1984, 1985d). In Japan, ratios and dosages of the blend varied with the crop growing seasons. Temperature was proposed as the major factor affecting mating behavior and the catch of male adults, as in other lepidopterous insects (Roelofs 1978, Yamada and Koshihara 1980). Variations in the response of male adults to DBM pheromone observed in Taiwan, Japan, and Canada may be due to exogenous factors such as seasonal variations of environmental conditions or to endogenous factors including the genetic differences in the insect itself. This article summarizes the author's work on the variables that were possibly associated with male response to synthetic FSP of DBM in Taiwan.

Materials and Methods

Insects

DBM larvae were reared under a constant temperature of 25 ± 1°C, and photoperiod condition of L:D, 14:10. Larvae were fed on rape seedlings (Koshihara and Yamada 1976) and adults on 20% honey-water (Chow et al 1975). Stocks of newly emerged adults within 12 h period were collected for several days. Male adults of different ages, ranging from 12 h to four days, were bioassayed simultaneously to study the age-dependent variation in pheromone response. For other experiments, male adults aged between 1.5 to 2.5 days were used (Maa et al 1983).

Chemicals

The pheromone components Z-11-16:Ald, Z-11-16:OAc and Z-11-16:OH, used for the bioassay, were synthesized and were of 98% purity as evidenced by GC tests (Lin and Chow 1983b). Blends of the three components in ratios of 1:9:0.1 to 9:1:0.1 (Ald:OAc:OH) were used in both laboratory bioassay and field tests. The doses and blends of the pheromone used depended on the purpose of the individual experiment. The isotope-labeled pheromone Z-11-16:OAc was also synthesized for enzyme assay to monitor the hydrolytic activity of male antennal esterases. All chemicals and reagents were of analytical grade or at the best grade available.

Laboratory bioassay and field test

The pheromone response of male adults to the synthetic FSP was measured according to the procedure of Chang et al (1979). The laboratory bioassay experiments included: (1) assay on age-dependent variations of male response to the pheromone, (2) assay of the optimal blend(s) of the three pheromone components, (3) assay of seasonal variation in male response to the pheromone, and (4) assay of the effect of relative

humidity (RH) and temperature on the pheromone response. For the first and the third experiments, a blend of 5:5:0.1 (Ald:OAc:OH) in 1.0 μg portions dissolved in hexane were used. For the second experiment, pheromone blends of 1:9:0.1 to 9:1:0.1 (Ald:OAc:OH) were used. The blends of the pheromone mixture which achieved a good male catch were used for field tests. For the fourth experiment, pheromone blends of 3:7:0.1, 5:5:0.1, and 7:3:0.1 (Ald:OAc:OH) were used.

The data from the first experiment were analyzed according to Mann and Whitney (1947). Data from the third and the fourth experiments were analyzed according to the equation of the least square and the best linear unbiased estimator according to the theorem of Graus-Markov (Mendenhall 1981). The results of the third experiment were re-evaluated in the field in Hualien and Yeongjing. Blends of 3:7:0.1 to 7:3:0.1 pheromone mixture were further prepared with the addition of 200 μg butylated hydroxytoluene (BHT) for field tests according to the procedure of Lin and Chow (1983). Fifty μg of each pheromone blend with BHT was then injected into plastic microtubes each with one end sealed. The microtubes were fastened under the top of the sticy paper pheromone trap. Experiments were conducted in 100 or 64 sq m vegetable plots using 5 x 5 or 4 x 4 latin square design. The traps in the treatment plots, using a pheromone blend of 8:2:0.1 (Ald:OAc:OH), were hung around the experimental plots. Moth catches were checked every seven days continuously for two to five weeks. The traps and baits were replaced after every check. The experiments were repeated at least twice. The results of the field tests were analyzed according to Duncan's multiple range test.

Daily weather records were transcribed from the daily report of the Central Weather Bureau, Republic of China. Daily temperatures and mean RH were used as the major physical parameters to evaluate the impact of climate on the response of the male adults to the pheromone.

Enzyme preparation and enzyme assay

The appendages of the male insects were excised, homogenized, sonicated, and centrifuged (Maa et al 1985). The supernatant of the preparation was compared with the crude homogenate of the antennae to determine esterase activity. The protein contents of the two different preparations were determined according to Read and Northcote (1981). General esterase assay followed the method of Van Asperen (1962). Eserine, paraoxon, and parahydroxymercuribenzoate were used as inhibitors to characterize the antennal esterases (Bigley and Plapp 1960, Stephen and Cheldelin 1970). Pheromone esterase assay followed the method of Maa et al (1985).

Electrophoresis of antennal esterases

The supernatant of 1000*g* homogenate of insect antennae was examined electrophoretically according to the method of Davis (1964). Inhibitors were also used to characterize biochemically the isozyme bands of the antennal esterase according to the procedure of Maa and Terriere (1983).

Results

Age-dependent variation of pheromone response and antennal esterase activity

Figure 1 shows that the activity of the antennal esterase to naphthylacetate was at its lowest level at adult emergence. Activity increased thereafter, climbing to the highest level during the next 24 h, and staying at the same level for the next two days. On the

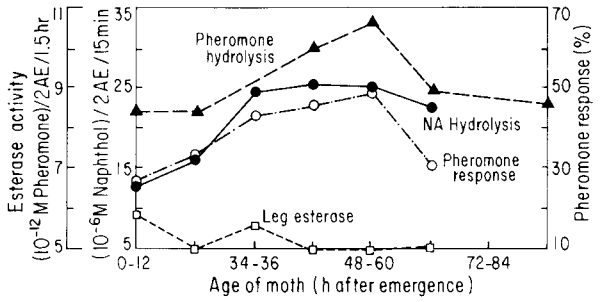

Figure 1.
Variation of antennal and leg esterase activity and pheromone response of male DBM (source: Maa et al 1985a)

other hand, the activity of pheromone esterases was low when the male adults emerged. Activity increased gradually during the next 24 h, peaking at 12th hour and decreased again to the initial level later on. The fluctuations of the pheromone response of male adults and of pheromone hydrolytic activity of male antennal esterase were differentiated in parallel with each other during the ontogenesis of the male adult. The leg esterase activity did not exhibit a parallel relationship with the male pheromone response, nor did with antennal esterase activity, throughout the period of investigation. The leg esterase activity ranged from 4.3 to 5.5 μ mole naphthol produced per two leg equivalent which is about one-third to one-fifth the activity of the antennal esterase.

Comparison of enzyme activity of the five DBM populations

Activity of the general esterase of the antennae of Geoufang, Bamboo Lake, and Kaohsiung males were high, and that of Shehtzu low (Table 1). The pheromone-hydrolytic activity of the male antennal esterases were 13 pico mole/mg protein/1.5 h for Geoufang; 10 for Bamboo Lake, Nankang, and Shehtzu, and 7.6 for Kaohsiung. There is a two fold difference in antennal non-specific esterase activity between the males of Geoufang or Bamboo Lake, and those of Nankang or Shehtzu. However, pheromone hydrolytic activity of antennal esterases of the males of these four populations display similar titer. The differentiation of these two groups of enzymes indicates that these two enzyme systems might be equally associated with pheromone degradation. The high titer of aliesterase found in larvae of the two malathion-resistant strains seems incidental to the high level of antennal esterase activity. The results of enzyme inhibition studies revealed that the major components of the antennal esterase of male adults are of aliesterase type (Table 2).

Table 1. Comparison of antennal esterase activity of the male DBM

Insect population	Esterase activity		Pesticide resistance
	$\times 10^{-6}$M naphthol produced/mg antennal weight/10 min.	$\times 10^{-9}$M pheromone metabolized antennal weight/1.5 h	LD_{50} μg malathion/larve
Geoufang	334.4 ± 18.7[a]	13.1 ± 0.6[b]	45[c]
Bamboo Lake	268.2 ± 11.5	10.4 ± 0.1	—
Nankang	156.2 ± 14.8	10.3 ± 0.6	33
Shehtzu	139.4 ± 17.1	10.2 ± 0.1	84
Kaohsiung	302.1 ± 11.6	7.6 ± 0.1	91

[a] Two assays with triplicate samples; mean ± standard deviation; crude homogenate of eight antennae per assay; incubation at 28°C (source: Maa and Lin 1985). [b] Two assays with two to four replicates each, mean ± standard error; crude homogenate of 100 antennae each at 30°C (Source: Maa and Lin 1985). [c] Mean of four replciates (Source Maa et al 1985a).

Table 2. Effect of inhibitor on antennal esterase activity of the DBM

Insect population	Inhibition (%)		
	Eserine	Paraoxon	PHMB
Geoufang	84[a]	90	74
Nangkang	74	90	77
Bamboo Lake	74	90	71
Kaohsiung	73	90	60
Shehtzu	70	90	57

[a] Average of two experiment, each with three replicates. (Source: Maa et al 1985a)

Comparison of esterase activity of appendages

Table 3 shows that foreleg esterase enzyme activity is one-tenth that of antennal esterase activity when naphthylacetate is used as a substrate. Table 3 also shows that pheromone hydrolytic activity of antennal esterase is about four times as strong as that in the legs, and six times that in the wings. This result strongly suggests that the antennae, organs of pheromone reception and degradation, are appendages equipped with an efficient enzyme system to break down an adhesive molecule like Z-11-16:OAc. The cuticles of the wing and foreleg, with rather larger surface areas exposed to the atmosphere, have only limited pheromone degradative activity.

Table 3. Comparison of esterase activity of appendages of male DBM

	Esterase activity	
	$\times 10^{-6}$M naphthol[a] produced/mg protein/30 min.	$\times 10^{-9}$M Pheromone[b] metabolized/mg protein/1.5 h
Antennal	1417 + 46	9.14 + 0.83
Forelegs	137 + 23	2.36 + 0.01
Wings	—	1.57 + 0.08

[a] Six experiments with triplicates; mean ± standard error. Supernatant of 1,000*g*.
[b] Two experiments with duplicates: mean ± standard error. Crude homogenate.
(Source: Maa et al 1985a)

Polymorphism of antennal esterase

Antennal esterase of male DBM was resolved into isozymes by electrophoresis (Figure 2). Eleven to twelve esterase bands, depending on the age of the adult or origin of the population of the insect, were detected in zymograms. These bands were scattered throughout two zones of the gel, a fast moving upper zone and a slightly slower moving middle one. All the isozymes migrated to the cathode end of the gel. The fast moving zone, composed of one narrow and one wide bands, was detected in all the zymograms examined. The middle zone was composed of nine to ten bands. These bands varied in number, width, and density. Two faint bands in front of the main body of the middle zone were also present in all zymograms. These two faint bands and the two fast moving bands were consistent in appearance, while the other bands varied depending on the males investigated.

The zymograms of the five insect populations could be roughly grouped into four categories according to the patterns of isozymes in the gels. The zymograms of Nankang and Bamboo Lake strains were characterized by a single dense band in the median area; the Kaohsiung strain by two; the Shehtzu strain by three and Geoufang by four. The

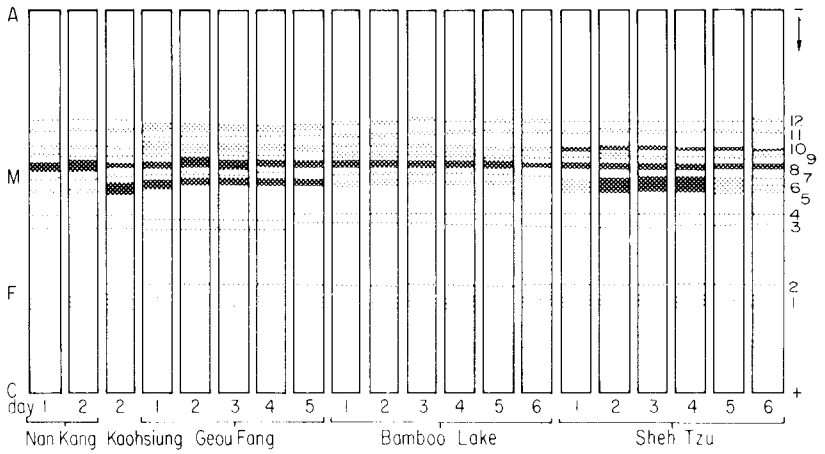

Figure 2. Zymogram patterns of antennal esterases of male DBM adults. Zymogram code: A, anode end; M. medium bands; F, fast moving bands; C, cathode end; and d, age of the moths, days (source: Maa et al 1985a)

variation of these dense bands is believed to be associated with the hydrolytic activity of antennal esterase to the acetate pheromone. The age-dependent variation of esterase isozymes shows that band No. 8 was the most dense and consistent one. This band was at its widest when the male adults were of two days old, the age when insects are most sensitive to the pheromone. On the other hand, the four-band pattern, with No. 8 the widest band, was characteristic of Geoufang male antennal esterase zymograms, which coincidently corresponded to the high hydrolytic activity to both naphthyl acetate and acetate pheromone. These results might explain why Geoufang males were the ones with most active pheromone response to the synthetic material (Table 4). However, this case demonstrates a positive interrelation between naphthylacetate activity and pheromone hydrolytic activity of antennal esterase, and the pheromone response of males to the bait.

Table 4. Variation of pheromone response of male DBM adults of four different local populations collected in Taiwan

Insect populations[a]	U values[b] for male adults of		
	young stage (0-24 h)	mature stage (36-60 h)	aged stage (80-100 h)
BL vs KS	15	82.0	17.0
BL vs NK	3	43.5	6.0
BL vs GF	12	44.5	4.0
NK vs GF	8	34.5[c]	4.0
KS vs GF	28	40.5	9.0
KS vs NK	8	51.0	15.5

[a] BL: Bamboo Lake, KS = Kaohsiung, NK = Nankang, GF = Geoufang. [b] Mann-Whitney U-test: 15-30 males per assay. [c] Significant at $p > 0.05$. Degree of freedom: 0-24 h: KS 7; NK 2; GF 4; BL 3. 36-60 h: KS 12; NK 6; GF 6; BL 10. 80-100 h: KS 7; NK 4; GF 2, and BL 3. Ratio of Ald to OAc in lure, 5:5. (Source: Maa et al 1983)

Insecticide resistance and pheromone response

Bioassay on two insecticide-susceptible strains (Bamboo Lake and Geoufang) and one resistant strain (Kaohsiung) did not show any detectable variation of the pheromone response of male DBM adults to the 5:5:0.1 (Ald:OAc:OH) blend when the temperature was set at 25±2°C, and the RH at 80% (Table 5). It is proposed that variation of male response to the different pheromone blends observed in the field (Table 6) is unlikely to be due to genetic differences between the DBM of individual field populations. Although polymorphism of antennal esterase isozymes was observed (Figure 2), we should not exclude the potential influence of endogenous factors on the male adults. Besides, the level of stimulation by a pheromone to the male adult in the laboratory under controlled conditions does not necessarily correspond to the situation in the field. More work is needed before we can reach a final conclusion on this. The influence on male sexual behavior of other external factors, like temperature and RH, therefore needs to be clarified.

Table 5. Comparison of pheromone response of the male adults of three different malathion-resistant strains

Ratio of Ald to OAc in lure	Insect Population		
	Geoufang (GF)	Bamboo Lake (BL)	Kaohsiung (KS)
	Value of weighted mean		
5:5	7.14	5.50	7.36

Degrees of freedom: GF, 7; BL, 12; KS, 11. The difference is not statistically significant. LD_{50} of malathion to DBM larvae in μg/larva: GF, 45; BL, 25; KS, 85 (Source: Maa and Ying 1985)

Table 6. Effect of humidity on pheromone blend preference of DBM male adults in field tests

Test No.	Ratio of Ald to OAc in lure			
	2:8[a]	3:7	4:6	5:5
	Relative Humidity (%)			
1[b]	74.5[c]	80.0	86.8	86.7
2	68.1	84.9	88.7	—
3	73.0	76.7	—	
4	67.8	81.7		
Mean	71.6	82.7	86.3	86.7

[a] With addition of 0.1 part of alcohol component in the lure. [b] Each test composed of one to two field tests, Latin square design (5×5 treatments), continuously checked for two to five weeks. [c] Average RH of 4 to 7 days interval, transcribed from report of Central Weather Bureau, Taiwan, ROC. (Source Maa and Ying 1985)

The bioassay and the field tests

Bioassay of male response to nine sex pheromone blends revealed (Table 7) that the blends with high aldehyde content attracted comparatively fewer males. The five best choices out of the nine combinations were 3:7:0.1, 4:6:0.1, 5:5:0.1, 6:4:0.1, and

7:3:0.1 (Ald:OAc:OH). For temperature and RH effect studies in the laboratory, a blend of 5:5:0.1 (Ald:OAc:OH) was used.

Table 7. Laboratory evaluation of male adults responding to nine combinations of female sex pheromone[a-b]

Ratio of Ald to OAc	9:1	8:2	7:3	6:4	5:5	4:6	3:7	2:8	1:9
% males attracted	15[c]	11 ± 6	41 ± 22	35 ± 14	30 ± 14	23 ± 16	33 ± 11	29 ± 12	27[c]

[a] Four replicates. [b] 15-30 males per assay. [c] Average of two experiments. (Source: Maa et al 1984).

Effect of temperature and RH on pheromone response

Indoor assay showed that the interaction of monthly RH and adult male orientation response to the pheromone baits was linear, with interception at RH 82.6% (Figure 3). The figure also shows that RH over the interception point of 82.6% would cause a decrease in male response. Temperature and male response also had a linear interrelationship with an interception at 18.4°C on the axis. Temperature over this critical point would have negative impact. Thus bioassay with 5:5:0.1 (Ald:OAc:OH) blend at 18.4°C and 82.6% RH would be ideal. These conditions, however, are not necessarily standard for all blends in respect of optimal male response in the laboratory. In fact, male sexual behavior interaction to three different blends (Table 8) shows that there is a linear interaction of RH and the Ald:OAc ratios of the pheromone. When RH drops below 82.8% a blend of 5:5 (Ald:OAc) is no more effective than above this level.

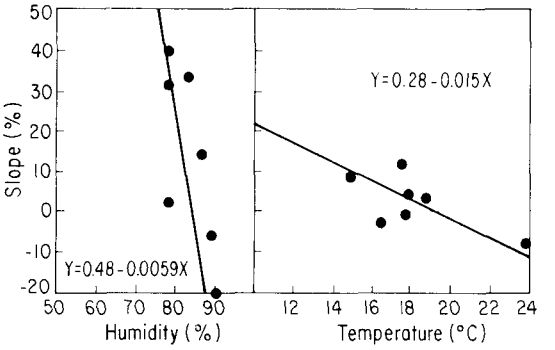

Figure 3.
Influence of relative humidity and temperature on male orientation response

Table 8. Effect of relative humidity on the pheromone blend preference of male DBM in laboratory assay

Ratio of Ald to OAC in lure	Statistical factors			
	slope	confidence interval	degrees of freedom	alpha value
7:3[a]	0.031	81.1-87.2	11	0.1
5:5	−0.055	77.9-83.9	65	0.1
3:7	−0.058	73.0-78.0	19	0.1

[a] Addition of 0.1 part of alcohol component (Source: Maa and Ying 1985)

Effect of physical field conditions on male pheromone response

In order to find out how the RH and Ald:OAc ratio of different blends affect DBM male sexual behavior, these two variables were monitored in relation to the optimal male catch in field. Fifteen tests were carried out around Taiwan. Eleven tests proved valuable for analysis. The other four tests involved males showing preferences for more than one pheromone blend, and were therefore not taken into account for the analysis. As for the 11 tests, in one of them the males preferred the 5:5 blend, and in two others the 4:6 blend, when the RH was above 90%. In four cases the male adults were attracted by a 3:7 blend when the RH was around 78% to 85%. In another two cases the males were ensnared by the lure of a 2:8 blend when the RH ranged from 68% to 75%. Two other cases revealed no significant preferance for any lure of of between 3:7, 4:6, 5:5, and 6:4 (Ald:OAc) blends when the RH was around 68% to 75%.

Seasonal variation of male response to the pheromone

A year-round bioassay with a synthetic sex pheromones of 5:5 blend showed seasonal variation of male response to the lure. Figure 4 shows that the males responded weakly to the synthetic pheromone during winter and summer (Maa et al 1985c), but responded strongly during spring and autumn. Generally, the insect is inactive when it is cold. The pheromone response of the males to the bait gradually increased when the daily temperature and the photoperiod increased during early spring. One out of 14, 18, and 16 bioassays performed respectively during December, January, and February, showed a strong male response to the lure. The frequency of strong response increased to eight out of 16 assays performed during March and 10 out of 23 in April. A few assays conducted during May, June, and July showed distinctly reduced effectiveness of the synthetic material. In August, the DBM were scattered and reduced in number in the vegetable fields of Shehtzu and the Taipei Basine and they were non-responsive to the pheromone (Figure 4). The males became active again in late autumn. Fourteen out of 27 assays showed that the males had a strong response to the lure in September,

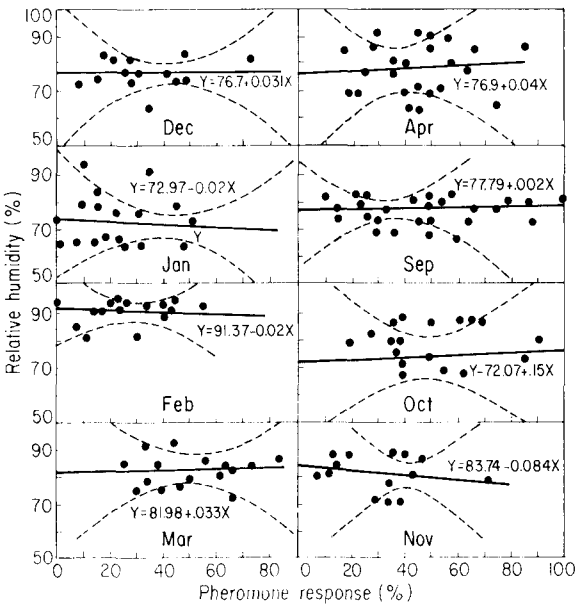

Figure 4.
The interactions of daily relative humidity and orientation response of male adults to synthetic female sex pheromone of DBM (source: Maa et al 1985b)

and nine out of 18 in October. This, however, did not last long. For an unknown reason, the synthetic sex pheromone lost its effectiveness in November.

Temperature, which is generally recognized as a major factor affecting the mating behavior of male adults of many lepidopterous species, nevertheless had a limited influence on the orientation of males to the lure (unpublished data). The pheromone response was low during December, January, and February, when the temperature was low. In September, the monthly average temperature rose to 28°C, and the insect became active. In March, the monthly average temperature declined to 15°C, but the insect was still active to the pheromone. The strong pheromone response of the male adults at either high or low temperature thresholds shows that temperature conditions in this island have a limited regulating effect on the sexual behavior of DBM males.

Discussion

Variations of male adult response to synthetic female sex pheromone of DBM have been reported in Taiwan (Chow et al 1977), Japan (Ando et al 1979), and Canada (Chisholm et al 1979). It was also noticed that the male moths responded to the lure differentially depending on not only the combinations of the trinary components of the pheromone, but also on the concentration of the pheromone used in the bait. In Japan, 100 μg of pheromone was needed for maximum catch in spring and early summer, and 1.0 mg in winter (Yamada and Koshihara 1980a). In Canada, 100 μg proved sufficient for trapping (Chisholm et al 1979). In Taiwan, 50 μg of the pheromone would do the job (Lin and Chow 1983). Koshihara and Yamada (1981) interpreted their findings on the differential response of DBM males in summer and winter to the vapor pressure of the pheromone in the specific atomsphere of these seasons. In Japan it is reported that the mating of DBM mostly depended on ambient temperature (Yamada and Koshihara 1980b).

The weather and the climate of the three countries mentioned above are different from one another. It is reasonable to postulate that these independent variables in the environment of the insect's habitat would eventually affect male sexual behavior elicited by the pheromone. However, certain questions still remained unanswered. For example, how would one explain the variation of male response to different blends of the synthetic sex pheromone observed in areas of the same geographic zone, as well as in different geographic zones? Will the variation prove to be rooted in the genetic diversity of the individual insect populations investigated, as in the case of the European cornborer (Carde et al 1981, Klun and Cooperators 1975), or will it prove to be a result of the moth perceiving the blend at a variety of different thresholds under the influence of different environmental conditions? Another intriguing question concerning the use of synthetic pheromones for mass trapping is to what extent the insecticide resistance will influence the DBM's response to synthetic sex pheromone under variety of environmental conditions since this species has developed degrees of resistance to numerous insecticides (Cheng 1981). As evidence the following facts are offered.

Age-dependent variation and antennal esterases

The profile study of male adult response to the pheromone showed that the response fluctuated in parallel with esterase activity, especially with that of pheromone-degrading esterases of the antennae, when the male adults were between 1.5 and 2.5 days old. Male pheromone response also peaked at this time. The coincidence of pheromone response and antennal pheromone esterase activity of the male DBM indicates that the antenna, as an important olfactory organ, is specific to pheromone reception and

degradation in order to promote normal transmission of the biochemical message through the peripheral nervous system. The leg and the wing, on the other hand, with low titer of esterase activity, are comparatively less specific to the pheromone stimuli. It is known that these organs in the cabbage looper (*Trichoplusia ni*) also have a considerable part to play in hydrolyzing the adhesive pheromone molecule (Ferkovich et al 1982). Nevertheless, the possibility cannot be excluded that esterases of these organs in DBM do not carry on the degradation of the pheromone molecule adhered on the cuticle of these organs.

Another aspect of antennal esterases of DBM is the heterogenous nature of these enzymes. This includes the polymorphism of isozyme patterns and the variation in general and pheromone esterase activity in particular. The activity of pheromone esterase of male adults collected in northern Taiwan is in general of similar titer. This is comparatively higher than in those collected in Kaohsiung in southern Taiwan. The general esterase activities of the male antennae, however, varied between the two regions by a factor of two. Besides, results of general esterase inhibition revealed that the isozymes of the antennae, althrough susceptible to paraoxon inhibition, are more or less heterogeneously responsive to other inhibitors.

From this complexity, it is difficult to clarify the interrelationship between male pheromone response, esterase activity, and/or isozyme pattern of the antennal esterases of the males investigated. It would appear that a potential diversity of genetic intrigue is possessed by males of DBM populations, although it was apparent that the pheromone response of males of malathion-resistant populations were not significantly different from that of the susceptible one.

At the same time it was found that variation in esterase isozymes of different stages of adult males of the same DBM clone is correlated with adult development. For example, two-day old males from Geoufang showed strong response to the bait. The antennal esterase activity of the males of these insects was also greater in degrading acetate pheromone, the substrate. Meanwhile, the zymogram bands of isozymes of antennal esterase of the adults of the same age were also distinctly stained. These facts indicated that zymogram studies would be useful for monitoring the sexual maturation of the male adult, although we were not able to define the so-called 'pheromone esterase' (Taylor et al 1981) in DBM. More detailed work is obviously needed for a fuller understanding of the pheromone perception in DBM.

Seasonally dependent variation and physical conditions

The seasonal variation of pheromone response of male adults to their female sex pheromone is reported for many insect species. Roelofs et al (1972) found that trans-11-14:OAc which is most effective on the male adults of European cornborer of the first brood during June and July, becomes less effective to moths of the second brood during August and September. They suggested that the cornborers present in large numbers in August employ a different communication system. Stech et al (1982) also reported that the synthetic pheromone of W-marked cutworm, *Spaelotics clandestina* (Harris), was unattractive during June and July but became attractive during August and September. Data of bioassay studies presented in previous papers (Maa et al 1985a) reveal that the male adult of DBM responds fairly well to the synthetic pheromone during spring and autumn, but becomes inactive during winter and summer. It is possible that the variation is due to a change in the intraspecies communication system. It is also possible that it could be due to the change in the physical conditions of the habitat of the insect. Results of field test and bioassay (Maa et al 1984, 1985a, 1985d) reveal that variation of male pheromone response due to the change in physical conditions is more

likely the case with DBM. This is supported by three sets of experimental data described in the following paragraphs.

Firstly, male DBM show optimal response to a pheromone blend of 5:5:0.1 (Ald:OAc:OH) under the conditions of 80% RH and 18°C temperature (Maa et al 1985c). RH over this limit has a negative impact. This indicates that a fixed pheromone blend has a limited stimulation threshold under fixed conditions. Secondly, the male preference to the pheromone shifts to the combination of 3:7:0.1 (Ald:OAc:OH) when this blend is available. This is apparent both from laboratory assays and in field tests (Maa et al 1985d). The RH for optimum response to this blend was 82% for laboratory assays and 78% to 85% for field tests. The third piece of evidence comes from the results of field tests (Maa et al 1985b). Of 15 field tests, eleven showed that male adults significantly ($P = 0.01$) preferred certain kinds of pheromone blend. The preference was mostly dependent on the RH. In general, the higher the RH the higher the aldehyde content of the pheromone needed for optimal male catch. The converse is also true. Certainly there are higher and lower threshold limits for the broad range of pheromone component ratios. This ratio range was estimated to be between 2:8:0.1 and 5:5:0.1 (Ald:OAc:OH) for DBM in the field in Taiwan. This range corresponds to an RH from 50% to 90%. In high RH conditions, pheromone blends with higher aldehyde display lower efficacy. Consequently, such a blend would lose its competitiveness to the natural blend released by the ambient population of virgin females in the field.

In Japan the pheromone with aldehyde and acetate in ratios of 1:9:0.1, 2:8:0.1, 3:7:0.1, and 4:6:0.1 lured 6, 31, 30, and 47 male adults respectively (Koshihara and Yamada 1980, Yamada and Koshihara 1980). This indicated that increasing the amount of aldehyde would initiate a positive stimulus to the male adults. On the other hand, aldehyde and acetate in ratios of 5:5:0.1, 6:4:0.1, 7:3:0.1, 8:2:0.1, and 9:1:0.1 attracted on an average, 34, 27, 23, 15, and 5 males respectively. This indicated that the male catch from the pheromone decreased with an increasing amount of aldehyde in the lure. In Canada, the male DBM was found to favor a pheromone combination of 7:3 (Ald:OAc) (Chisholm et al 1979). A combination of 9:1 (Ald:OAc) was able to lure only a few adult males. It seems that an aldehyde content over 80 to 90% of the total amount of pheromone would initiate an inhibitory effect on the sexual behavior of the male adults. It is interesting to note that a blend of high aldehyde content is needed for optimal male catch in Canada, but lower aldehyde content is needed in Taiwan.

In Taiwan, with its humid and warm subtropical weather, the male DBM adults respond to a blend of comparatively high acetate content. When the humidity is nearly 100%, a blend of 4:6:0.1 (Ald:OAc:OH) lures the majority of the males in the field. A blend of 5:5:0.1 (Ald:OAc:OH) is effective if there is no unusual change in temperature at dusk. Blends with ratios of 6:4:0.1 and 7:3:0.1 (Ald:OAc:OH) could not catch great numbers of adult males in the field. These blends are weak lures for male DBM adult in Taiwan. It is not known whether very dry and cold conditions, such as those which exist in Canada, drive the male adults to a pheromone blended with high aldehyde content. How is it possible to interpret this pheromone activity under the 'Hypothesis of Activation Threshold' suggested by Roelofs (1978), when one considers that the active space of sex pheromone of DBM in the field is only about 1.0 meter (Ishii et al 1981)? Could it possibly be another case of geographic variation with sibling species, such as the European cornborer found in North America and Europe (Klun et al 1975; Carde et al 1978)? These and other questions are worth further exploration.

Although no routine check is made on the component ratios for female-released pheromones for each season, the author suspects the possibility of some change in the pheromone secretions of the female adults.

In conclusion, it is interesting to note that the ratio of pheromone blend for optimal male catch varied in Taiwan, Japan, and Canada on a broad range from 3:7:0.1 to 7:3:0.1

(Ald:OAc:OH). The weather and the climate of these three countries are different from one another. Global cooperation on the investigation of DBM pheromone would possibly be helpful in explaining this insect's response to pheromones.

Investigations of the endogenous and exogenous variables encountered by DBM males are of utmost importance both theoretically and practically. Their importance in integrated pest control research will be evident if we consider the utilization of pheromones in the prediction of insect epidemics or in their mass trapping or mating disruption to control DBM.

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Discussion

P. H. LIAO: Have DBM pheromones been used in practice in the program to control DBM in Taiwan?
Y. S. CHOW: No, we have not used the sex pheromone of female DBM alone in the field. But when the monitoring pheromone trap was combined with insecticide use, it did help the farmer to decrease the cost of insecticides. It reduced the number of insecticide sprays in the field.

P. H. LIAO: Have you conducted any field experiment to evaluate the practical value of DBM pheromones?
Y. S. CHOW: As I mentioned above, it is only practical when the sex pheromone is used as a survey tool. We also studied the effective distance of the female sex pheromone, and its effective distance is only one meter.

A. SIVAPRAGASAM: One major problem in the use of pheromone for pest control is that it is not effective as a monitoring tool at high population densitites, when high natural female pheromone release would affect the artificial one from the trap.
Y. S. CHOW: Yes, I agree.

P. A. C. OOI: Are sex pheromones specific to species? I notice that in the traps you used other microlepidoptera were attracted.
Y. S. CHOW: In general, the sex pheromone is rather species specific. However, there are some cases where certain pheromone chemicals attract more than one species. Please refer to Roelofs, W. L. 1978. J. Chem. Ecol. 4:685-699 and Yamada, H. and T. Koshihara. 1980. Kontyu, Tokyo. 48(1):104- 110.

P. A. C. OOI: Can the DBM sex pheromone be used to disorientate the males and contribute to pest control?
Y. S. CHOW: Yes, the DBM sex pheromone could be used to disorientate the males over a short distance. However, we will need higher concentrations of the chemicals to make DBM control more extensive.

R. S. REJESUS: Is there resistance to pheromone in DBM?
C. J. W. MAA: I do not have definite data to make a valid conclusion to this effect.

N. S. TALEKAR: At AVRDC we find two to three shades of color in DBM. They could be different strains of DBM. Is it possible that the differences you are finding could be due to differences in strains or proportions of the strains at a particular location, rather than to insecticide resistance.
C. J. W. MAA: Naturally, a heterozygote gene pool of an insect population is likely to be present in the field. Topical treatment of malathion on larvae of the first generation of two different breeds of I-lan population shows a three to four fold difference in LT_{50}. The variation in shades of color of DBM found at AVRDC could be due to genetic diversity of individual insects in that population. I personally also noticed this phenomenon in DBM at various sites around Taiwan. When I did the Y-test I used several hundred males for it. It is a sizable sampling. I noticed the difference in male response to the pheromone, although the difference was statistically insignificant. There is no evidence yet whether this is due to insecticide resistance. Nevertheless, variation of the

antennal esterase shown in the zymogram and biochemical properties of these enzymes might reflect that there is a potential for variation in pheromone response bestowed on the different insect populations.

Resistance in Crucifers to Diamondback Moth and Other Lepidopterous Pests

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Abstract

A nonreplicated field test in 1972 suggested that PI234599 cauliflower was resistant to larval feeding from a lepidopterous complex including *Plutella xylostella* (L), *Artogeia rapae* (L), and *Trichoplusia ni* (Hubner). Although *P. xylostella* is not usually a serious pest in New York State, plant resistance to it was clarified by supplementing natural infestations with laboratory-reared individuals. We determined that although PI 234599 and related lines were preferred sites for oviposition, they were resistant to establishment by first instar larvae in the field. Resistance was not noted when these lines were grown in the greenhouse.

Introduction

Lepidopterous pests that threaten crucifers in New York State early in the season are the diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae) and the imported cabbageworm, *Artogeia rapae* (L) (Lepidoptera: Pieridae). The cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae), a migrant from the south, arrives later in the season and can become a major threat along with early season species that still are present.

Monitoring moth flights of DBM indicated that crucifers in New York are exposed to oviposition by at least three and possibly five generations of DBM (Baker et al 1982). However, in temperate climates such as in New York and nearby Ontario, Canada, this pest is normally held in check by biotic and abiotic factors (Harcourt 1960). Occasionally large populations cause severe injury on cabbage in New York State (Seymour et al 1979) and on Brussels sprouts in Ontario (Butts 1979), thus necessitating the need for pesticides.

Pesticides are used regularly to suppress various members of the lepidopterous complex. However, even preferred insecticides such as methamidophos and permethrin have provided only mediocre suppression in some situations (Eckenrode et al 1981). Resistant plant material, an attractive alternative or supplement to control with insecticides, has been identified for DBM and other crucifer feeders (Pimentel 1961, Radcliffe and Chapman 1966, Brett and Sullivan 1974, Dickson and Eckenrode 1975), but it has been difficult to isolate resistance to DBM in the field because of simultaneous damage by other crucifer foliage feeders. Radcliffe and Chapman (1966) reported that the relative resistance of cultivars to a specific crucifer feeder was independent of the level of resistance to other crucifer pests. Dickson and Eckenrode (1975) attempted to determine resistance levels to DBM in the field, but could not evaluate this because of feeding by the cabbage looper and the imported cabbageworm. However, reduced feeding damage by this pest complex (including DBM) did occur on field-grown plants of Plant Introduction (PI) 234599, a dark, glossy-leaved cauliflower. In subsequent studies, additional lines and cultivars of crucifers were compared in the laboratory, greenhouse, and field with particular emphasis placed on PI 234599 and related lines. Later stages

of this research focused on resistance to DBM using laboratory-reared insects to supplement natural infestations in the field. These studies are summarized in this report.

Materials and Methods

Discovery of resistance in PI234599

In 1972, selected cultivars and PI lines were planted in the field in single rows (12.2 m) in unreplicated plots. Although pest populations were light until late in the growing season in September, line differences became apparent by 28 August when *P. rapae* egg and larval counts were taken from 15 plants in each row. Minimal *T. ni* activity was observed at that time, although numbers of this pest and also DBM increased slowly for the remainder of the season. On 3 October, we rated entire rows but could not differentiate between feeding by the different species of the lepidopterous complex. A 1 to 5 rating (Chalfant and Brett 1967) was utilized with 1 indicating 'no damage' and 5 representing 'severe damage' (50% or more of the green material destroyed). This type of rating system was used in subsequent tests except that individual plants rated 5 in the greenhouse exhibited 80% or more foliage destruction because of severe feeding pressure. Plants rated as 1 were classified as resistant, 2 to 3 as moderately resistant, while those rated 4 to 5 were termed susceptible.

Resistance to DBM

In a later research phase, colonies of DBM were maintained in the greenhouse in order to ensure the continuous supply needed to clarify resistance to this pest. Moths were released into cages ($76 \times 50 \times 46$ cm) stocked with broccoli plants to provide oviposition sites and subsequent food for larvae, and a honey and water mixture (1:9 ratio) for the adults. Desired larval stages were removed from broccoli foliage and placed on test plants or on plant material using a camel hair brush. First instar larvae quickly mined into broccoli leaves and thus were unavailable for transfer except immediately after hatching, whereas later instars were easy to locate and transfer. Crucifer lines and cultivars were tested for resistance by using whole plants, excised single leaves, or leaf discs (3.8 cm diam) placed on moistened filter paper in covered glass dishes. Feeding damage on whole plants was assessed on the rating scale from 1 to 5 ($1 = < 5\%$; $2 = 5\text{-}20\%$, $3 = 21\text{-}40\%$; $4 = 41\text{-}60\%$; and $5 = > 60\%$ of leaf surface destroyed).

In experiments designed to clarify oviposition behavior, the waxy material present on the leaf surfaces of two cole crops was polished with light strokes of a camel hair bruch or partially removed with one-second dips in ether. After dippng, the leaves were rinsed thoroughly with tap water. Excised leaves from normal-colored light green commercial cultivars were tested in this manner in 1982 using Waltham 29 broccoli and Superdane cabbage in 1983. After removal of the wax, the petioles of the excised leaves were placed in water in a 125 ml flask and the opening was sealed with strips of parafilm. Three leaves (normal, brushed, and ether-dipped) were placed in a cage in the greenhouse for one night with 20 newly-emerged moths. These tests were replicated four times (using four cages) and each replication consisted of three nights of oviposition, with new leaves placed in the cage each night. Eggs were counted in the morning with the aid of 3x magnification.

In the greenhouse in 1982, seeds from 52 lines and cultivars were sown in flats on 18 March, and the resulting seedlings were transplanted approximately one month later into pots filled with Cornell Mix (peat moss, vermiculate, and perlite) (Broodley and Sheldrake 1977). The mix was fertilized with 20-20-20 soluble fertilizer once each

week (three applications). On 5 May, three replications (one plant per replication) were placed at random at 21°C along with 500 moths supplied with honey-water in open petri dishes. Eggs were counted twice weekly for three weeks, starting four days after introduction of moths. Larvae, and later pupae, were counted twice weekly, starting 15 days after moth introduction. During the last reading, larval feeding damage was recorded. Averages were derived from the six counts of eggs and the three counts of larvae and pupae.

In the field, laboratory-reared moths were used to supplement a naturally-occurring infestation at the Robbins Vegetable Research Farm near Geneva, New York, by placing 700 pupae in the field in five dishes fitted with rainproof caps on 10 August. The dishes were positioned on stakes (1 m high), and a stake was placed in each quadrant of the planting and at the center. Additional pupae (500) were collected from nearby fields and placed in the dishes on 18 August. In this experiment, 34 lines and cultivars were replicated four times in a randomized complete block design with 12 plants per treatment per replicate. Each replicate had three rows planted 91 cm apart and a plant spacing of 41 cm. To reduce differences in maturity between the various crops, the following planting dates were used: 18 June (cabbage and cauliflower), 28 June (Chinese cabbage), and 6 July (kale). Before placement of pupae in the field, permethrin (0.06 kg AI/ha) and mevinphos (0.3 kg AI/ha) were applied to the plot on 29 July and 4 August, respectively, to reduce unwanted infestations of foliage pests. All larvae and pupae from post-insecticide treatment infestations on the center two plants in each treatment were counted on 29 August, on 8, 20, and 29 September, and on 7 October. Feeding damage was assessed during the final count.

In 1983, we examined lines and cultivars selected from previous experiments for oviposition and survival of DBM. On 15 June, transplants of resistant lines PI234599 cauliflower and G8329 cabbage (Lin et al 1983), and susceptible commercial cultivars Imperial 10-6 cauliflower and Round-Up cabbage, were planted in single rows in a randomized complete block design with four replications (seven transplants per pedigree per replication). Plants were spaced 93 cm apart with 62 cm between rows. On 14, 15, and 16 September, one plant of each pedigree in each replication was selected randomly and removed from the field. Every leaf was removed and examined at 3x magnification for eggs, larvae, and pupae.

Finally, in 1983, dark green, glossy-leaved lines PI234599 cauliflower and inbred cabbages G8329, G9660, and G9639, plus additional lines and cultivars with normal bloom, were grown in the field on the planting dates and using the methods described previously. Although natural DBM and small numbers of other members of the lepidopterous complex were present, plants were infested manually with three age classes of DBM from greenhouse colonies: eggs, late 1st and early 2nd instar larvae, and late 2nd and early 3rd instar larvae (Lin et al 1983) to determine survival of each class. Manual infestations consisted of either 50 eggs on 25 and 26 July, or 20 larvae on 25 and 30 July. On 7 August, surviving larvae and pupae were counted. Mean numbers counted were converted to percentage of larvae surviving.

Results and Discussion

Discovery of resistance in PI234599

In the unreplicated field test when feeding injury from the entire lepidopterous complex was rated, the most outstanding line (0% damage) was a late-maturing, glossy-leaved cauliflower from Australia (PI234599). The red cabbages, Storage Red, Red Storage 4004, PI246047, and Red Hollander, had a damage score of 2 as did Tall Green

Curled kale. Ruby Ball, PI245000, PI261758, PI246057, PI246071, PI343638, and PI245084 (all reds) had a damage rating of 3, as did the green cabbages Market Prize, Storage Green, PI245098, PI275003, PI288229, PI343500, and PI302985. In addition, eight lines from a cabbage-kale cross had ratings of 3, apparently having inherited low resistance from the kale parent. The rest of the lines in this nonreplicated test were susceptible with ratings of 4 or 5.

The outstanding field performance of PI234599 in this first nonreplicated field test encouraged us to continue testing this line and also to initiate an ongoing breeding program where desirable characteristics were incorporated into more acceptable lines.

Resistance to DBM

Alteration of wax on the leaf surfaces of Waltham 29 broccoli and Superdane cabbage increased oviposition in greenhouse cage experiments (Table 1). The increase may have been due to physical change in condition of the wax because of light polishing or partial removal, or to the noticeable change in color from light to dark green. Alteration of the wax on the leaves may have changed the release rate of mustard oils and this could have influenced oviposition (Gupta and Thorsteinson 1960).

Table 1. Influence of wax alteration of leaf surfaces on DBM oviposition in greenhouse cage

Alteration method	Mean no. eggs/leaf/night[a]	
	Waltham 29 broccoli (1982)	Superdane cabbage (1983)
Ether dips	63.0a	84.3a
Brushing	9.8b	12.8b
Normal leaf	1.0c	2.5c

[a] Means in each vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test.

In the greenhouse test, four cultivars of Chinese cabbage and two of mustard were preferred sites for oviposition and were susceptible to larval feeding (Table 2, Figure 1). Eggs per plant averaged 108 and 84 respectively for these two crucifer types, and feeding damage ratings for both were severe (ca 5). Cabbage and cauliflower types were less preferred. Specific lines and cultivars least preferred were Red Head and Round-Up cabbage, Calabrese broccoli, and Dwarf Blue Vates kale. PI234599 cauliflower, resistant to a complex of crucifer feeders in earlier field tests (Dickson and Eckenrode 1975), was highly preferred for DBM oviposition (93 eggs/plant) in this experiment and was heavily damaged (rating 5). Snowball cauliflower and Savoy cabbage also were heavily damaged (rating 4.0 and 4.8 respectively). Correlations among eggs, and larvae plus pupae, were: $r = 0.755$ ($P = 0.001$) and the damage ratings were: $r = 0.468$ ($P = 0.001$). Although PI234599 had exhibited strong resistance to the lepidopterous complex in earlier field tests, it was susceptible to DBM in this experiment in the greenhouse.

Heavy DBM population pressure from feral and introduced populations was noted in the field planting in 1982 (Table 3). Infestations from other crucifer feeders were minimal because of the permethrin-mevinphos applications before the test. PI234599 cauliflower, G9101 cauliflower, and cabbages G8329 and G9619 were completely free of larvae and damage. Pak choi (*Brassica campestris* ssp *chinensis*), Michihli Chinese cabbage, and Flowering kale were lightly infested and exhibited low amounts of damage. In spite of staggered plantings, Pak choi and Chinese cabbages were very mature compared with other crops in the test. Mature crucifers of this type are resistant to attack by the complex of lepidopterous pests (Dickson and Eckenrode 1975). White Summer

Table 2. Oviposition preference and damage caused by DBM to various crucifer lines and cultivars in the greenhouse

Pedigree[a] or type	Mean no. / plant[b]		
	Eggs	Larvae and pupae	Damage rating[c]
Red Head cabbage	1.7a	11.3a-d	2.6ab
Round-Up cabbage	2.7a-c	17.8a-e	4.3g-i
Calabrese broccoli	3.0a-c	43.3b-e	4.0f-h
Jade Cross hybrid brussels sprouts	6.6a-e	21.7a-e	2.3a
Dwarf Blue Vates kale	8.7a-e	33.3a-e	3.7d-g
Snowball cauliflower	10.0a-f	48.2d-e	4.0f-h
Savoy cabbage	11.7a-e	20.8a-e	4.8ij
Marion Market cabbage	22.0fg	46.3c-e	4.7hi
PI234599 cauliflower	93.2h	90.8fg	5.0j
Southern Giant Curled mustard	141.7i	210.5i	5.0j
PI234601 Chinese cabbage	129.7i	289.9j	5.0j

[a] Selected from 52 lines and cultivars for a range of preference and for different types. [b] Means in each vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test. All 52 pedigrees in this test were included in the analysis. [c] Based on a scale from 1 to 5, where 1 = 5% and 5 = 60% of leaf surfaces destroyed.

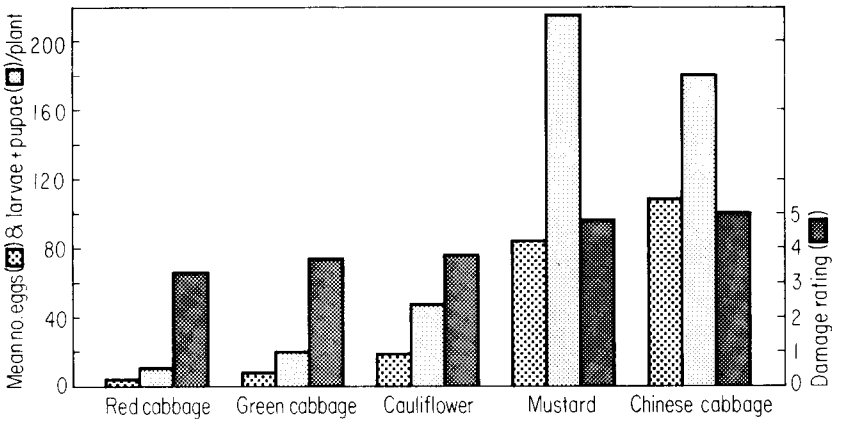

Figure 1. Oviposition preference and damage of DBM to red cabbage (2 lines), green cabbage (33 lines), cauliflower (8 lines), mustard (2 lines), and Chinese cabbage (4 lines) planted in the greenhouse. Geneva, New York, 1982

cauliflower was the most heavily infested, with 28.8 larvae per plant and a mean damage rating of 3.8. Unlike the greenhouse test (Table 2), the crucifer types with dark green foliage and the Chinese cabbages were least damaged by DBM larvae. As a group, cauliflower with normal green coloring was the most preferred, with 21.9 larvae per plant and a mean damage rating of 3.4 (Figure 2).

Continued testing in the field in 1983 with selected lines and cultivars (including PI234599) indicated that DBM adults preferred to oviposit on crucifer types with dark green, glossy leaves of the cauliflower (Table 4). This preference has been noted in earlier greenhouse studies (Lin et al 1983). PI234599 cauliflower averaged 11.5 eggs per plant, while on Round-Up cabbage there was an average of only 0.5 eggs. However, an average

Table 3. Infestations of DBM on various crucifers planted in the field[a].

Pedigree[b] or type	Mean number[c] larvae and pupae / plant	Damage rating[d]
G8329 cabbage	0.0a	1.0a
G9619 cabbage	0.0a	1.0a
PI234599 cauliflower	0.0a	1.0a
G9109 cauliflower	0.0a	1.0a
Pak choi	0.2a	1.0a
Michihli Chinese cabbage	0.8ab	1.2ab
Flowering kale	2.8ab	1.3ab
Round-Up cabbage	11.6ef	2.6cd
White Summer cauliflower	28.8n	3.8g

[a] Geneva, New York. 1982. [b] Selected from 34 lines and cultivars for a range of larval numbers and damage. [c] Mean in each vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test. [d] Based on a scale from 1 to 5, where 1 = < 5% and 5 = > 60% of leaf surface destroyed.

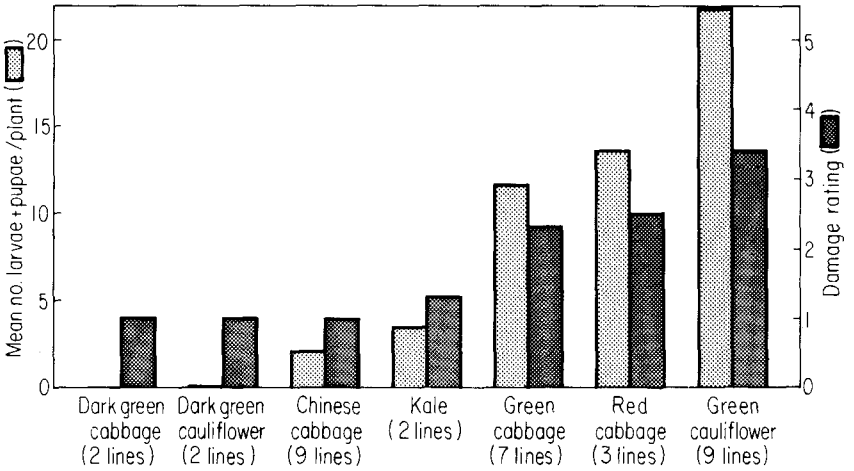

Figure 2. Infestation of DBM of various crucifers planted in the field. Geneva, New York, 1982

Table 4. Oviposition preference and larval survival of DBM on selected pedigrees of crucifer crops in the field[a]

Pedigree	Mean no. / plant[b] Eggs	Larvae and pupae
Round-Up cabbage	0.5a	12.5c
Imperial cauliflower	1.0a	8.5b
G8329 cabbage	3.5a	0.5a
PI234599 cauliflower	11.5b	0.3a

[a] Geneva New York 1983. [b] Means in each vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test.

of only 0.3 larvae and pupae was noted on the dark green cauliflower, while 12.5 occurred on the normal colored cabbage. A dark green glossy cabbage (G8329) supported low numbers of larvae; however oviposition was much lower on plants of this pedigree than on PI234599.

In the final field test in 1983, all larval stages failed to develop in the field on crucifer pedigrees with dark green foliage (Table 5). Low survival rates were noted on maturing plants of Jade Pagoda Chinese cabbage and pak choi. High survival rates occurred on Imperial cauliflower, Round-Up cabbage, and Premium Flat Dutch cabbage. Relatively low survival of DBM (‘27%) was noted in the field plantings in 1983 because of a high incidence of larval and pupal parasitism by *Microplitus* spp and *Diadegma* spp, respectively (Putnam 1968, Andaloro and Baker 1983). This was noted by visual observation but no counts were taken.

Table 5. Development (pupation) of DBM placed at various stages of development on plants of selected pedigrees of *B. oleracea* in the field[a]

Pedigree	DBM pupation (%) from[b]		
	Egg	Larval instars	
		1-2	2-3
PI234599 cauliflower[c]	0.0a	0.0a	0.0a
G8329 cabbage[c]	0.0a	0.0a	0.0a
G9660 cabbage[c]	0.0a	0.0a	0.0a
G9639 cabbage[c]	0.0a	0.0a	0.0a
Jade Pagoda Chinese cabbage	1.1ab	3.3ab	4.2b
Pak-choi	2.5b	2.5a	5.0b
G9150 cauliflower	9.0c	8.3bc	21.6c
Premium Flat Dutch cabbage	10.0c	14.1d	22.5cd
Round-Up cabbage	10.5c	18.3d	27.5e
Imperial 10-6 cauliflower	13.5d	13.3d	25.8de

[a] Geneva, New York, 1983. [b] Means within each vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test. [c] Glossy leaved, inbred lines.

Ongoing breeding studies are in progress at the New York State Agricultural Experiment Station, Geneva, where the resistance factors discussed here and other traits are being incorporated into crucifer lines with commercial appeal. Two cabbage lines discussed here (G8329 and G9602) were released recently (Dickson et al 1984). It must be noted that field observations indicated that dark green glossy foliage is highly preferred by the flea beetles, *Phyllotreta striolata* (F) and *P. cruciferae* (Goeze). The mechanisms that mediate this resistance to the lepidopterous complex are unknown; however, if natural chemicals are involved they probably do not occur in amounts that are toxic to mammals. No differences were determined between sexed weanling rats fed either 10 or 25% semipurified diets incorporated with a standard cauliflower cultivar and PI234599 (Babish and Stoewsand 1975). Unpublished greenhouse and field tests suggested that the resistance to *T. ni* and *A. rapae* is influenced to a strong degree by light intensity and the use of nitrogen fertilizer. Plants exhibiting the dark green glossy characters and grown with liberal amounts of N fertilizer under fluorescent greenhouse lights were extremely susceptible to larval feeding while the same pedigrees grown under high-intensity lights with minimal amounts of soluble fertilizer were less damaged. Field plantings with side-dressings of N also were more heavily damaged than identical plantings with no side-dressings. It is likely that resistance to DBM is influenced similarly.

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Breeding for Diamondback Moth Resistance in *Brassica oleracea*

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Abstract

PI234599, a glossy-leaved cauliflower from Australia was found to be highly resistant in the field to diamondback moth, *Plutella xylostella* L. We have been unable to separate this resistance from the glossy leaf character because the two traits are closely linked. The glossy character is inherited as a simple recessive. Broad sense heritability of resistance to damage by lepidopterous pests based on nonglossy plants from crosses involving PI234599 was 85% and narrow sense resistance was 35%, indicating progeny of a selection will be equal in resistance to the selected parent 25-50% of the time. In a study exclusively on *P. xylostella*, broad sense resistance based on numbers of larvae and pupae per plant was 75 and 88%, respectively. In a diallel study involving lines unrelated to PI234599 resistance was additive and dominant. In no case was resistance in a nonglossy selection as high as that in PI234599, but then selections were much more resistant than unselected lines.

Introduction

Insect resistance in cole crops is well documented (Brett and Sullivan 1974, Chalfant and Brett 1967, Creighton et al 1975, Dickson and Eckenrode 1975, Dunn and Kempton 1976, Pimental 1961, and Radcliffe and Chapman 1966). However, there has been very little breeding of cole crops for lepidopterous pest resistance, or specifically for diamondback moth (DBM) (*Plutella xylostella* L, Lepidoptera: Yponomeutidae) resistance, although damage produced by the DBM larvae is a worldwide phenomenon, especialy in the tropics. Dickson and Eckenrode (1975) reported that Plant Introduction (PI) 234599, a dark green glossy-leaved cauliflower, was highly resistant to the cabbage looper (*Trichoplusia ni* [Hubner]), to imported cabbage worm (*Artogeia rapae* L), and to DBM, and that several other cabbage and cauliflower lines exhibited less feeding injury than standard cultivars. We also reported on screening cultivars and PI lines for resistance in the greenhouse, but this environment appeared to influence the level of resistance (Dickson and Eckenrode 1975, Kim 1979, Lin et al 1984).

These observations have resulted in two approaches to breeding for resistance to lepidopterous pests. The first is to use vertical resistance derived from PI234599, in which the resistance is closely linked or pleiotropic with the glossy-leaf character. This approach has resulted in the release of four glossy-leaved cabbage lines: NYIR 8329, 9602, 9605 (Dickson et al 1983) and NYIR 9909 cauliflower. A second approach using horizontal resistance (resistance due to multiple genes) at a lower level of resistance was reported by Dickson and Eckenrode (1980).

Resistance form PI234599

PI234599, a long-season cauliflower from Australia, was found to be resistant in the field to the lepidopterous complex. Data from screening tests are reported in this

symposium (Eckenrode et al 1985). Since a large population of DBM is unlikely to occur regularly in New York, natural populations were supplemented by placing additional pupae from our laboratory colonies in the field plots. Planting every third row with a susceptible cultivar also appeared to increase the degree of infestation. We attempted to suppress beneficial insects by application of carbaryl and unwanted members of the lepidopterous complex with application of permethrin.

Table 1 presents the results of an experiment to investigate the inheritance of resistance from PI234599. The broad sense heritability, 85%, indicates the percent of total variance caused by genetic influence (Mohammed and Kramer 1951) and the narrow sense heritability, 37%, predicts the effectiveness of selection on progeny performance (Warner 1952) for plants with normal bloom. However, most plants with glossy leaves are resistant and this glossy leaf character is inherited as a simple recessive character. Table 2 indicates that the genetics of resistance of DBM and other members of the complex are similar, although Radcliffe and Chapman (1966) reported that resistance to each pest may differ.

Table 1. Distribution of population from crossess of Snowball A and PI234599 in different damage score classes[a]

Pedigree	Leaf type[b]	No.of plants in damage score[c]							
		1	2	3	4	5	N	x	s^2
Snowball A	N	—	—	3	21	19	43	4.4	0.382
PI234599	G	46	3	—	—	—	49	1.1	0.059
PI234599xSnow F_2	N	1	5	16	12	20	54	3.8	1.20
	G	7	4	6	—	—	17	1.9	0.81
	G+N	8	9	22	12	20	71	3.4	1.73
PI (PIxSnow) BC	N	—	3	10	12	9	34	3.6	0.90
	G	24	5	8	—	—	37	1.5	0.70
	G+N	24	8	18	12	9	71	4.9	2.04
Snow (PIxSnow) BC	N	—	6	8	22	17	53	3.9	0.94
NSH[d] G+N = 28%	BSH, G+N = 87%								
NSH, N = 47%	BSH, N = 82%								

[a] Scored on 15 August in the field at Geneva, New York. [b] N = normal leaf with bloom, G = glossy leaf, [c] Damage score: 1 = 5% and 5 = 60% leaf surface, [d] NSH and BSH = narrow and broad sense heritability, respectively

The glossy leaf character has been associated with susceptibility to flea beetles (*Phyllotetra cruciferae* (Geoze) and *P. strieolata* (F) (Superak 1976). Lines which are less glossy but which still carry the glossy gene and exhibit high levels of caterpillar resistance, could be selected with a corresponding reduced level of susceptibility to flea beetle. The caterpillar resistance associated with the gene for glossy leaves was not influenced by the modifying genes which influence the degree of glossiness of the leaves and corresponding susceptibility to flea beetles.

At the New York State Agricultural Experiment Station, Geneva, selected cabbage and cauliflower lines based on resistance from PI234599, showed a high level of field resistance to DBM and other lepiopterous pests (Table 3, see also Eckenrode et al, this volume). In all of these tests, the plants were at least 50 days old before lepidopterous pest pressure became serious. In Australia, Hamilton and Dickson (1978, unpublished data) observed that young plants were less resistant to DBM than older ones. Similar observations were noted in the Philippines by D. Rasco (unpublished). In both countries significant resistance was observed in older plants (over 50 days from seeding).

In 1982 three cabbage inbreds: NYIR9602, 9605, and 8329; derived from PI234599 as a resistance source (Figure 1) were released by the New York State Agricultural

Experiment Station (Dickson et al 1984). These have subsequently exhibited good insect resistance in England and Holland.

Table 2. Distribution of field resistance to DBM in two populations of *B. oleracea* resulting from crosses of resistant with susceptible parents

Pedigree	Leaf type[a]	No. of plant with no. of larvae and pupae											No.	Mean	s^2
		0	1	2	3	4	5	6	7	8	9	10			
G 9101 cauliflower[b]	G	22	3	—	—	—	—	—	—	—	—	—	25	0.19	0.07
G 7642 cauliflower	N	—	—	1	4	6	2	4	4	3	1		25	5.34	3.89
G 9101 x 7642-2 F_1	N	—	1	2	3	1	1	—	2	2	2	2	16	5.43	9.14
G 9101 x 7642-2 F_2	N	—	1	5	15	11	7	11	13	1	3	2	69	5.04	5.11
	G	15	—	—	—	—	—	—	—	—	—	—	15	0.02	0.01
	N+G	15	1	5	15	11	7	11	13	1	3	2	84	4.13	7.89
		BSH[c] not using $F_1 = 0.75$													
G 9602 cabbage[b]	G	19	6	—	—	—	—	—	—	—	—	—	25	0.20	0.06
G 326R cabbage	N	—	6	10	4	1	1	—	—	—	—	—	22	2.11	1.12
G 9602 x 326R F_1	N	—	1	3	4	8	3	6	—	—	4	—	25	4.13	1.96
G 9602-1 x 326R F_2	N	—	1	9	14	11	8	6	5	4	4	4	66	4.95	6.40
	G	17	—	—	—	—	—	—	—	—	—	—	17	0.40	0.01
	N+G	17	1	9	14	11	8	6	5	4	4	4	83	3.95	9.07
		BSH[c] = 0.88													

[a] G = Glossy (resistant); N = normal color (susceptible). [b] Glossy-leaved resistant parents, [c] BSH broad-sense heritability.

Table 3. Caterpillar counts and damage scores on cultivars and selected glossy resistant cauliflower in 1978 and cabbage lines in 1979

	Number of larvae per 4 plants			Damage score[a]
	T. ni	*P. rapae*	*P. xylostella*	
Snowball	21	18	39	4.5
PI234599	5	4	11	1.5
4160	3	8	2	1.0
4166	3	1	1	1.0
Round Up	5	15	4	4.5
5936	0.5	2.5	0.5	1.0

[a] Damage score: 1 = 5% and 5 = 60% of leaf surface destroyed.

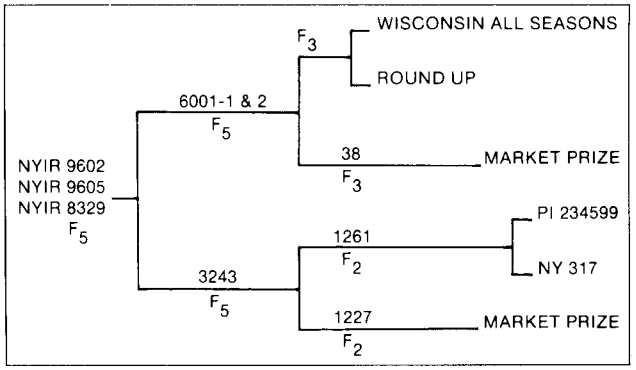

Figure 1. Pedigree of NYIR 9602, NYIR 9605, and NYIR 8329

Horizontal Resistance to Lepidopterous Pests

In glossy leaves the wax platelets on the cuticle lie horizontally rather than standing vertically, as they do in plants with blooms. This arrangement of wax platelets, which is not always considered desirable, is associated with resistance to lepidopterous pests. Hence an effort was made to breed for resistance in cabbage with normal leaf bloom. Several field trials at Geneva and Ithaca, New York, identified several lines less susceptible than most cultivars. A diallel (Hayman 1954) study of this type of tolerance involving five lines was undertaken. G364 was the most susceptible, and BM-15, 1228, 3220 and 3222 were selections which exhibited progressively reduced damage levels. Table 4 gives the results of this study in 1978 and 1979 and Figure 2 shows the regression of Wr (parent-offspring covariance) on Vr (Variance) for resistance to cabbage caterpillars for the five cabbage lines.

Table 4. Mean cabbage looper (CL), imported cabbage worm (ICW), and DBM larvae counts and damage ratings for a 5-parent diallel of cabbage

Pedigree	Mean no. larvae per 4 plants						Damage scores[a]		
	1978			1979			1978	1979	Mean
	CL	ICW	DBM	CL	ICW	DBM			
G364 (P1)	4.5	17.0	18.0	1.7	11.5	2.5	2.8	5.0	3.9
BM-15 (P2)	12.5	13.5	23.0	0.8	10.2	1.2	3.0	2.7	2.9
1228 (P3)	16.0	22.0	23.5	0.8	8.3	2.7	3.0	1.7	2.4
3220 (P4)	2.0	11.0	28.0	—	—	—	2.3	2.7	2.5
3222 (P5)	13.0	25.5	17.5	1.0	10.7	0.8	1.9	1.2	1.6
P1 x P2	20.5	36.0	22.5	1.5	12.5	2.3	3.2	3.5	3.3
P1 x P3	15.0	35.5	32.0	4.2	11.5	1.3	3.4	2.8	3.1
P1 x P4	14.5	25.5	22.0	1.2	17.0	1.3	2.7	2.7	2.2
P1 x P5	19.5	37.5	21.0	1.3	11.3	1.0	2.1	2.6	2.4
P2 x P3	10.0	22.5	14.0	1.0	6.5	0.5	2.5	2.3	2.4
P2 x P4	12.0	24.5	26.5	1.3	9.5	0.3	2.9	3.1	3.0
P2 x P5	9.0	21.0	22.5	1.3	9.5	0.3	2.8	1.7	2.2
P3 x P4	16.5	20.5	16.5	0.7	11.0	1.2	2.6	2.7	2.6
P3 x P5	8.5	13.5	27.0	0.8	8.5	0.3	2.6	2.0	2.3
P4 x P5	4.5	20.5	12.0	0.8	9.8	0.8	2.6	2.0	2.3
Round Up	23.5	45.0	26.0	1.7	29.0	4.3	3.8	4.2	4.0
LSD 5%	5.0	4.9	13.5	0.59	3.30	0.6	0.6	0.8	1.0
1%	6.8	6.7	18.5	0.78	4.37	0.8	0.8	1.1	1.3

[a] Damage score 1 = 5% and 5 = 60% of leaf surface destroyed.

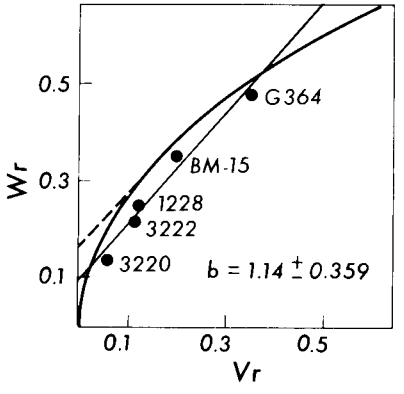

Figure 2.
Regression of Wr on Vr for cabbage caterpillar resistance in a diallel involving five cabbage lines

There was no genetic interaction, since the regression line is not significantly different from one, indicating simple additive dominance for resistance. The susceptible parent (G364) was clearly at the upper end of the regression line, while the most resistant parent (3222) was closest to the ordinate, indicating dominant genes for resistance.

Continued selection has not produced plants with normal leaf bloom with resistance comparable to PI234599, but selections exhibiting considerable reduction in damage were reported by Dickson and Eckenrode (1980) (Table 5). The number of DBM pupae and amount of damage were recorded on 80 lines in 1982 (Table 6). The glossy-leaved lines showed the best levels of resistance, selections with normal leaves were less resistant, but almost all were considerably better than unselected lines.

Table 5. Ratings for damage due to caterpillar[a] feeding on seven cabbage and two cauliflower lines as influenced by plant maturity

Lines	Damage ratings[b]			
	Days from transplanting		Mean	Maturity effect (33-63)
	33	63		
			Cabbage	
Storage Green	4.43	3.20	3.93	1.23*
Round Up	4.00	2.80	3.52	1.20*
King Cole	3.90	2.75	3.44	1.15*
BM15	3.40	1.60	2.68	1.80**
1228	3.77	1.50	2.86	2.27**
3270	2.77	1.90	2.42	0.87
3243[c]	1.70	1.90	1.78	0.20
			Cauliflower	
Snowball A	3.57	2.80	3.26	0.77
PI234599	1.07	1.00	1.04	0.07
Mean	3.18	2.16	2.77	1.02
LSD 5%	0.89	1.04	0.75	0.94
LSD 1%	1.08	1.50	1.01	1.47

[a] Population consisted of *T. ni* and *A. rape*. [b] Rating: 1 = no damage to 5 = severely damaged (50% or more of foliage destroyed). [c] 3243 has resistance from PI234599

Table 6. Effects of selection for resistance to DBM and age of plant

Plant type	Date	No. of larvae per plant			
		Mean	Max.	Min.	st. dev.
Glossy[a]	7/23	0.25	2.35	0.0	0.36
Normal[b]	8/24	2.69	5.83	0.0	1.73
Glossy	7/23	0.02	0.25	0.0	0.01
Normal	8/24	2.63	6.25	0.0	2.30
Unselected[c]	7/23	4.12	9.00	0.0	7.26
Unselected	8/24	6.16	11.08	2.76	8.48
			Damage rating[d]		
Glossy	7/23	2.14	3.00	1.00	0.53
Normal	8/24	2.02	3.00	1.00	0.42
Glossy	7/23	1.51	2.67	1.00	0.41
Normal	8/24	2.03	3.00	1.00	0.31
Unselected	7/23	2.55	3.00	1.33	0.31
Unselected	8/24	2.62	3.00	2.00	0.21

[a] Populations = 41 lines, [b] population = 27 lines, [c] Population = 20 lines, [d] Scale 0 = no damage, 3 = severely damaged.

Crossing the best lines with normal leaves with the glossy-leaved lines produced F_1s with normal leaves, with lower levels of resistance than in the parent with normal leaves. This was probably because minor genes for susceptibility in the glossy-leaved lines were masked, resulting in hybrids with lower resistance than in parents with normal leaves.

Conclusions

It appears that there are at least two approaches for selection for resistance to DBM. The first approach has produced cabbage and cauliflower lines with glossy leaves and which are highly resistant. Acceptable inbreds of both cabbage and cauliflower are available at the present time from the senior author. However, further breeding will be necessary to develop cultivars adapted to the many locations where DBM is a problem. This should be relatively simple, due to the very close linkage of the glossy leaf character and resistance.

The second approach would utilize recurrent selection to develop cultivars with normal waxy bloom which exhibit tolerance, but perhaps not with as strong a resistance to lepidopterous pests. However, wider diversity of parental material would increase the chances of improving the levels of resistance.

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Intercropping and Modification of Irrigation Method for the Control of Diamondback Moth

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Abstract

Monitoring of diamondback moth (*Plutella xylostella* L) population on cabbage and Chinese cabbage over the past eight years has indicated that heavy rains from June to September limit the population of the insect. Therefore, during the dry period when diamondback moth is a serious pest, water was applied by sprinkler system placed 1.5 m over the cabbage crop rather than by traditional furrow irrigation. Sprinkler irrigation applied for five minutes at dusk on alternate days over the first three to four weeks, and every day thereafter, significantly reduced the diamondback moth infestation and increased the yield over drip irrigation check plots which received an equal amount of water. The physical disruption of flying activity, oviposition, and to some extent wash-off of larvae and adults were presumably the major causes of the observed effects. In an intercropping study, cabbage was planted between two rows of each of 54 selected crops. Intercropping with tomato, dill, garlic, safflower, oat, and barley reduced diamondback moth damage to cabbage. Laboratory study indicated that application of tomato leaf extract to cabbage significantly reduced diamondback moth oviposition on treated surfaces.

Introduction

Diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), is a serious pest of cruciferous vegetables in Taiwan and several other countries of southeast Asia, especially around large cities and in specialized vegetable growing areas that supply vegetables to cities throughout the year. This insect is cosmopolitan and reproduces under extremely varied climatic conditions (Paramonov 1953). Although a temperature range of 17°C to 25°C is considered optimum for the pest (Atwal 1955), it is one of the most serious pests of cabbage even in Polar regions of the USSR (Kutsenin 1977). It breeds all year round in warm humid tropical regions. In Taiwan, it breeds throughout the year and can have up to 20 generations per year with considerable overlapping of generations in the field.

At present, farmers in Taiwan and elsewhere in Asia use large quantities of insecticides to control this pest. The insecticide use is intensive, as a result of which the insect has become resistant to several insecticides belonging to all classes of commercially available chemicals. Indiscriminate insecticide use has eliminated many parasites and predators and some previously minor pests, such as *Spodoptera exigua* in Thailand, have become major ones. This has necessitated the use of alternative control measures which can be used alone or integrated with certain other methods.

At the Asian Vegetable Research and Development Center (AVRDC) our initial research efforts involved finding the sources of resistance with the aim of breeding of Chinese cabbage cultivars resistant to this pest. However, despite intensive efforts, we

did not find any source in *Brassica campestris* germplasm with a high enough level of resistance to initiate a resistance breeding program. We therefore switched our research efforts to identifying suitable cultural practices such as irrigation and intercropping which, when coupled with our on-going pest population monitoring designed to help in forecasting pest infestations, will help in integrated management of DBM.

DBM Monitoring

Accurate information on the seasonality of the pest, and of the crop growth stage at which insect populations will most damage a crop, is critical to the implementation of control measures. Such information, coupled with meteorological data, also helps in forecasting insect pest epidemics. With this purpose in mind we initiated a detailed insect pest monitoring program for Chinese cabbage and cabbage in 1976. Once every month, from January 1976, four-week old seedlings of Chinese cabbage and cabbage were transplanted onto the top of four 30 x 1 m beds, two adjacent beds for each crop. The crops were raised according to standard cultural practices, except that no insecticide was applied. At harvest the land was rototilled, and used again for planting in an identical manner. Infestations of DBM and other insects were recorded from a 30-plant sample once every two weeks starting four weeks after transplanting. The number of DBM larvae and pupae were recorded from each of the 30 plants. Records of daily maximum and minimum temperatures, relative humidity, rainfall and solar radiation were maintained (Talekar and Lee 1985).

DBM infested Chinese cabbage and cabbage from October to May but was practically absent from June through September (Figure 1). In 1980, when rainfall was less than one third of normal during the traditional May through September rainy season, the DBM population was high almost throughout the year. The cool dry winter is a crucifer season in Taiwan, and host plants, including wild crucifers, are readily available. The absence of DBM during the summer months, despite the availability of host plants, in our study appears to be due more to frequent rains than to high temperatures. Certain studies (Chen and Su 1978, Chin 1973, Hsu and Wang 1971, Schmutterer 1977) indicate that DBM is capable of multiplying and causing damage at temperatures approaching those of the Taiwan summer. Besides, in Indonesia, the Philippines, and Thailand, where summer temperatures are as high as those in Taiwan but where these temperatures are coupled with dry (rainless) weather, DBM is a particularly serious pest in this season. Therefore, it seems that frequent rains limit incidence of DBM. The larva of this pest is a surface feeder and is frequently washed away or drowned in the cavity created as a result of its peculiar feeding habit. Rain can also disrupt the flying of the adults and thus hamper their movement, including possibly oviposition, and this may also limit infestation. This hypothesis is further supported by the fact that in 1980, when Taiwan experienced severe drought, DBM was present throughout the year. Harcourt (1963) in Canada has also reported rainfall as a major mortality factor in the population dynamics of DBM.

Modification of Irrigation for DBM Control

The study of the possibility of modification of irrigation method to control DBM was the direct consequence of our DBM population monitoring, which indicated that frequent rains during summer adversely affect the DBM infestation of cabbage and Chinese cabbage (Talekar and Lee 1985). Two experiments were conducted during 1983-84 in which the method of irrigation was modified. In the first experiment, we

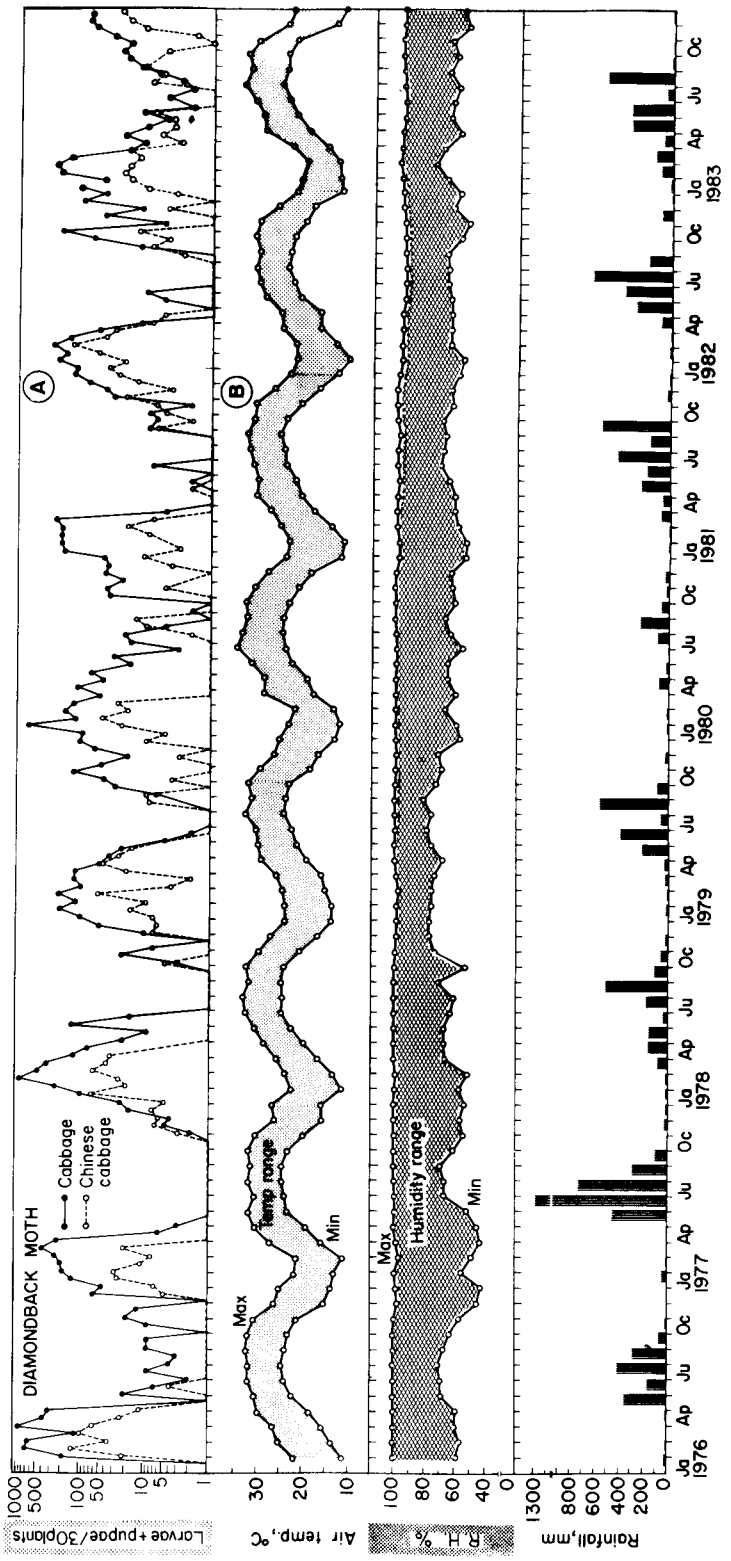

Figure 1. Seasonality of DBM on Chinese cabbage and cabbage (A) and temperature, relative humidity, and rainfall during 1976 to 1983 (B)

used three irrigation methods: 1. Furrow irrigation check where water was confined in furrows on both sides of raised beds on the top of which cabbage was transplanted; 2. Sprinkler irrigation where water was sprinkled over the plot from one central point where a Rainbird-type sprinkler was established; and 3. Sprinkler irrigation where the water source, a perforated plastic pipe, was fixed 1.5 m above cabbage plants in such a way that when filled with pressurized water, tiny water jets sprinkled over the plants.

Six weeks prior to transplanting, two rows of cabbage were transplanted all around the field and infested with a large number of DBM adults. This infestation later acted as the infestation source for the experimental plots.

In the furrow irrigation system, the plots were irrigated when necessary as judged by the dryness of the soil. In both sprinkler irrigation treatments the plots were irrigated for five minutes each at dusk once every two days for the first three to four weeks and every day thereafter. All other cultural practices such as weeding, fertilizer application, profilactic disease control measures and so on were observed but no insecticide was applied.

The crop was evaluated for DBM infestation twice when the insect population in the furrow irrigation plot was high. The numbers of DBM larvae and pupae were recorded on 20 randomly selected plants from each plot. At harvest, yield was determined by weighing the cabbage heads after removal of non-wrapper leaves.

The results (Table 1) indicated that both sprinkler systems of irrigation significantly reduced the insect infestation and increased the crop yield.

Besides insect infestation, the irrigation system probably played a significant role in other ways in increasing the yield. The frequent sprinkler irrigation kept the soil moist most of the time providing adequate moisture all the time, as against furrow irrigation where water was applied, based on visual observation, only when judged necessary. This probably induces water stress at certain periods, and perhaps adversely affects yields.

In the second experiment, therefore, instead of furrow irrigation we used a drip irrigation check. In this case, the frequency of application and the amount of water received by the sprinkler and drip irrigation plots were maintained equal. The sprinkler irrigation was modified slightly so that water was delivered from above the plants by a perforated rotating pipe instead of a fixed one. All other management practices, irrigation timing and frequency, insect infestation, and observation methods, remained the same as in the first experiment.

Table 1. Effect of various irrigation methods on DBM infestation and cabbage yield[a-e]

Irrigation methods	No.DBM larvae + pupae/20 plants		Marketable yield t/ha
	6 Jan 1984	19 Jan 1984	
Furrow irrigaiton	13.2a	84.9a	67.5b
Sprinkler, central	9.6b	51.6c	73.6ab
Sprinkler, overhead	7.9b	60.7b	77.8a

[a] Cultivar: KK cross. [b] Transplanting date: 27 October 1983. [c] Harvest date: 19 January 1984. [d] Data are means of four replicates. Means in each vertical column followed by thesame letter are not significantly different at 5% level according to Duncan's Multiple Range Test. [e] Plot size: 10 × 9 m.

The results of this experiment are summarized in Table 2. The numbers of DBM larvae and pupae were consistently lower in the sprinkler plots than in the drip irrigation plots during each observation. The numbers of marketable heads and total yield in the sprinkler plots were significantly greater than in the drip irrigation plots. On average, cabbage heads in the sprinkler irrigation plots weighed 738 g as against only 421 g in the drip irrigation plots. Since the amount and frequency of water received was equal

Table 2. Influence of method of irrigation on infestation and yield of cabbage[a]

Irrigation method	No.diamondback moth larvae + pupae/20 plant			Marketable heads %	Yield t/ha
	24 Feb	6 Mar	15 Mar		
Sprinkler	305b	506b	609b	88b	20.0b
Drip	381a	820a	1061a	59a	8.3a

[a] Transplanting date: 30 January 1984. Data are means of six replicates. Means in each vertical column followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test. Plot size: 10 × 9m.

in both treatments, the greater yield from sprinkler plots must have been due to lower DBM infestation.

Sprinkler irrigation presumably drowns and washes away DBM larvae feeding on the leaf surface. It also disturbs the adult moths and forces them to fly upon which the water droplets wash them away. Since sprinkler irrigation was carried out close to dusk, when the DBM mate and start laying eggs (Harcourt 1957), there seems a distinct possibility that this treatment disturbs mating and/or oviposition.

Intercropping for DBM Control

The use of modern high yielding crop cultivars creates monocultures with a narrow genetic base which are subject to increasing losses to pests. This is because monoculture reduces the diversity of pest species, which tend to explode in numbers because they have a greater potential for building up their numbers under conditions of reduced competition. In many specialized vegetable producing areas in Asia, crucifers are grown year-round, and this provides a year-round source of food for DBM and other crucifer pests. This factor, along with DBM's development of resistance to insecticides, has played a significant role in DBM becoming an important pest.

On the other hand, intercropping is a common practice with other crops in many parts of Asia. Under certain combinations, intercropping has beneficial effect in reducing insect pest damage (Nickel 1973, IRRI 1974, Buranday and Raros 1973, Karel et al 1982). However, such intercropping is rarely practised with crucifers, especially in specialized vegetable production areas where DBM is a menace.

The purpose of this experiment, therefore, was to explore the possibility of intercropping cabbage with other crops to reduce DBM damage to cabbage.

Seeds of 54 crops were planted one crop/plot, in two lines, 40 cm apart, on the top and along the length of 10 m long and 1.5 m wide plots. Each crop was planted in three randomly arranged beds, each bed representing one replicate. One month after sowing of intercrops, four-week old cabbage seedlings were transplanted in a single row at the center along the length of each plot. The crop was raised by customary cultural practices except that no insecticide was applied. At 40, 60, and 80 days after transplanting, DBM infestation of cabbage was recorded by counting the number of larvae and pupae/10 plants in each plot.

The 54 crops that were planted along with cabbage were as follows: amaranthus (*Amaranthus blitum*), barley (*Hordeum vulgare*), barnyard millet (*Echinochloa frumentacea*), barseem (*Trifolium alexandrinum*), broccoli (*Brassica oleracea* var *italica*), Brussels sprouts (*Brassica oleracea* var *gemmifera*), buckwheat (*Fagopyrum esculentum*), carrot (*Daucus carota*), cassava (*Manihot esculenta*), cauliflower (*Brassica oleracea* var *capitata*), celery (*Apium graveolens*), cabbage (*Brassica oleracea* var *capitata*), chilli pepper (*Capsicum annum*), Chinese cabbage (*Brassica campestris* ssp *pekinensis*),

coriander (*Coriandrum sativum*), corn (*Zea mays*), cosmos (*Cosmos sulphureus*), cucumber (*Cucumis sativus*), daisy (*Bellis perennis*), dill (*Anethum graveolens*), eggplant (*Solanum nigrum*), four o'clock (*Mirabilis jalapa*), garlic (*Allium sativum*), hollyhock (*Althaea rosea*), kale (*Brassica acephala*), kodo millet (*Paspalum scrobiculatum*), Leek (*Allium porrum*), marigold (*Tagetes erecta*), mesta (*Hibiscus cannabinus*), methi (*Trigonella foenumgraecum*), mustard (*Brassica juncea*), oat (*Avena sativa*), pai tsai (*Brassica campestris* ssp *chinensis*), parsley (*Petroselinum hortense*), pea (*Pisum sativum*), portulaca (*Portulaca grandiflora*), pumpkin (*Cucumis pepo*), radish (*Raphanus sativus*), rape (*Brassica napus*), ridge gourd (*Luffa aculangula*), rutabaga (*Brassia napobrassica*), safflower (*Carthamus tinctorius*), shallot (*Allium ascalonicum*), smooth gourd (*Luffa cylindrica*), sorghum (*Sorghum bicolor*), soybean (*Glycine max*), spinach (*Spinacia oleracea*), sugarcane (*Saccharum officinarum*), sweet pepper (*Capsicum frutescens*), sweet potato (*Ipomoea batatas*), tobacco (*Nicotiana tabacum*), tomato (*Lycopersicon esculentum*), white potato (*Solanum tuberasum*), and wild tomato (*Lycopersicon hirsutum* f *glabratum*).

Among the intercrops, cabbage planted between barley, dill, garlic, oat, safflower, or tomato had relatively less DBM larvae and pupae, especially during the third observation when insect population was especially high (Table 3). It must be pointed out that due to wide variation among replicates, the results were not statistically significant. Crops like safflower, oat, and barley grew tall and such crops act as a barrier against DBM which is carried by winds over long distances (French and White 1960). Such crops also by their shadowing effect, adversely affect growth of cabbage plants and hence have limited utility. On the other hand dill, garlic, and tomato do not grow tall and their influence in reducing DBM damage to cabbage appears to be a characteristic repellent odor that each of them possesses. Some studies have indicated the useful effect of tomato intercropping in reducing infestation of crucifers, mainly cabbage, by insect pests (Buranday and Raros 1973, Vostrikov 1915, Srinivasan 1984). Studies have also shown that certain principles in tomato leaf extract adversely affect oviposition of DBM on cabbage and Chinese cabbage (Gupta and Thorsteinson 1960, AVRDC 1985). It is possible that similar principles in dill and garlic repel the DBM infestation. Studies with large plot size are under way to modify the cultural practices so that both main crop and intercrop can be grown more profitably with reduced DBM damage to cabbage.

Table 3. Population of DBM on cabbage intercropped with selected crops

Intercrop	No. larvae + pupae/10 plants at days after transplanting		
	40	60	80
Barley	39	12	64
Dill	44	25	62
Garlic	42	20	69
Oat	36	12	83
Safflower	19	11	0
Tomato	15	10	166
Control	37	33	330

Cabbage transplanting date: 12 December 1983.

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Discussion

A. SAVAPRAGASAM: Do you know the reason why, although there is high oviposition on PI234599 cauliflower compared to the other varieties, the number of larvae tends to be low? Is this due to poor egg viability?
C. J. ECKENRODE: No, the egg viability was good on all varieties in these tests. The reason that few larvae are found on PI234599 cauliflower grown in the field is that the larvae either leave the plants because they are unacceptable or are killed shortly after they hatch.

R. S. REJESUS: You observed that light and N influenced resistance inside the greenhouse as opposed to outside. Any possibility that either light or nitrogen is an immediate mediator for the loss or enhancement of resistance?
C. J. ECKENRODE: This has not been determined with certainty, but Dickson and I believe that antibiosis is present in the glossy lines when grown in the field. It is quite possible that light and/or nitrogen influence this.

T. H. CHUA: Could you comment on the taste and quality of the resistant varieties?
C. J. ECKENRODE: The taste is perfectly normal, the quality of the cabbage is quite good, but the color may be foreign to some consumers. I do not see any problems with cauliflower.

T. H. CHUA: Why do you think the female DBM prefers to lay eggs on the resistant varieties?
C. J. ECKENRODE: Because of the tactile feel of the smooth leaf or because of some difference in the chemical composition. We are trying to get information on differences in its chemical make-up.

N. WILDING: Speakers have spoken about longevity of different stages in the lifecycle of DBM and about its fecundity. I assume that this work has been done with one or more local strains of the pest. Has any of the speakers studied these factors in strains from elsewhere? How genetically homogeneous in this insect?
C. J. ECKENRODE: It is most probable that such differences do exist.

T. H. CHUA: Do you anticipate the development of biotypes in DBM similar to those of brown planthopper which broke down the resistant rice varieties?
M. H. DICKSON: It is possible, but that is why we also have a breeding program based on multiple gene resistance which would be harder for a biotype to overcome. The breeding program is also more complicated.

G. S. LIM: Your work shows potential for the use of resistant cultivars to suppress DBM population. Are you aware of any case where crucifers resistant to DBM are cultivated on a fairly large scale?
M. H. DICKSON: No. We intend to test these materials in large plots in 1986.

J. HOFFMANN: Did you obtain glossiness in leaves of DBM resistant cabbage by genetic manipulation or by selection?
M. H. DICKSON: The PI 234599 which had resistance to DBM has glossy leaves. Not all lines with glossy leaves are resistant, only those with the gene for glossy leaves from PI 234599. There are a number of other genes which confer glossy leaves.

B. ROWELL: We grew a cabbage cultivar, Cornell line from Peto Seed Co, which has glossy leaves. But the damage to this line was not less than others. Could it be due to much higher insect population pressure?
M. H. DICKSON: Young plants appear to be quite susceptible, but develop resistance as they mature. This was observed in trials in the Philippines and Australia. There is also some difference in levels of resistance in lines with the glossy leaves, we observe this regularly and it was also apparent in the Philippines. I do not know which of these lines I released was tested by Peto, but I know one was not very resistant to DBM. The lines were released as resistant to lepidopterous pest, more specifically to *Pieris rapae* and *Trichoplusia ni* at the time of release. Since then we have done more selection for tolerane to DBM.

G. S. LIM (COMMENT): We also have done some studies on the effect of tomato extract on DBM and would like to share our findings here. We found that tomato extract (1 g ground up leaves in 1000 ml water) will cause reduction in oviposition by DBM adults but has no significant effect on the development and survival of DBM larvae that may be already present on the plants.

T. R. OMOY: You showed the beneficial effect of tomato intercropping on DBM control. Is there any specific cultivar requirement for tomato to be effective? Would tropical tomato do?
N. S. TALEKAR: There is no specific cultivar requirement for tomato to be effective. We used heat-tolerant, heat-sensitive and even wild tomato (*Lycopersicon hirsutum* f *glabratum*) and all gave equally beneficial effect as far as deterring the DBM adults from layings eggs is concerned.

M. P. FERINO: Would a lower plant population of the intercrop have the same effect on the DBM as the normal plant population?
N. S. TALEKAR: We have not yet studied this aspect. It would be the aim of a future study to lower the intercrop population to the bare minimum required for DBM control since some of the intercrop species are not economically important and we do not want to waste land under such crops.

T. H. CHUA: What would be the cost of installing the sprinkler system. I think the cost of US$1000 per 0.2 ha is too high for small farmers to adopt.
N. S. TALEKAR: Yes, the initial cost is definitely too high for small farmers to utilize this system. However, this system can be used over several cropping seasons. This, combined with the savings on insecticide cost and labor cost, will make the system economical. In the meantime we are trying to modify the system to make it less costly as well as more effective.

E. D. MAGALLONA: Usually, with high moisture, such as under sprinkler irrigation, development of diseases is encouraged. Was there any noticeable difference in disease incidence between your check and sprinkler irrigation treatments?
N. S. TALEKAR: No, we did not observe any unusually high incidence of disease with cabbage. I am, however, afraid that the disease problem will be important if we use cauliflower or broccoli.

L. C. CHANG: What is the present situation in the use of parasites for DBM control in Taiwan?
N. S. TALEKAR: Certain parasites were introduced in Taiwan specifically to control DBM about 10 years ago but the parasites did not get established, possibly due to

excessive use of insecticides. Nothing was done after that. At the moment AVRDC has imported *Diadegma eucerophaga* from Indonesia and we are mass rearing it for release on farmers' fields starting autumn 1985.

T. MIYATA: Your overhead sprinkler system shows promising results as far as DBM control is concerned. Does this method also control other insects such as cabbage looper and cabbage butterfly?
N. S. TALEKAR: During the experimental period we did not get cabbage looper infestation at all and cabbage butterfly population was too low and too unevenly distributed to get any realistic information on its control. However, sprinkler irrigation significantly reduced aphid population. But aphid infestation was rather low and came during late growing stage and its reduction could not have contributed to increased yield.

A. SIVAPRAGASAM: Did you observe any direct effect of overhead sprinkler irrigation on larval mortality, egg mortality, and adult behavior in the field?
N. S. TALEKAR: No, we merely recorded the number of DBM larvae and pupae and yield in both control and overhead irrigation treatments. We did find though that during application of sprinkler irrigation DBM adults flew around and some of them were caught under the water jets and washed away.

B. ROWELL: Do you see crucifer tomato intercropping in Taiwan?
N. S. TALEKAR: It is not common. Crucifers are grown in specialized vegetable production areas for domestic fresh market use and export, whereas tomato is mainly grown for processing in different areas. The farmers who grow these crops are different. I have, however, observed crucifer- tomato intercropping in North Sumatra where both crops are grown for the fresh market.

Biological Control of Diamondback Moth

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Abstract

The diamondback moth, *Plutella xylostella* (L), is recognized as a widely distributed and serious pest of crucifers in many countries. In some countries, however, it is effectively suppressed by parasites. These are critically examined as are the various attempts to import parasites and to release them. The appraisal reveals that the parasites of *P. xylostella* are a valuable control component and resource. Though numerous parasite species exist, not all are found to be effective. On the contrary, the key ones are restricted to only a few species and these belong largely to the genera *Diadegma, Apanteles*, and *Microplitis*. Except for *Diadegma eucerophaga* and possibly *Diadegma fenestralis*, none appears capable of exerting full control by itself. Many countries are still continuously plagued by *P. xylostella* and there is strong evidence that this is due to the lack of crucially important parasites. Unless the relevant key species are made a part of the host-parasite complex, these problems are likely to persist. On the other hand, abandoning them will condemn crucifer cultivation to continued drenching in ever-increasing amounts of insecticides. These conclusions seem inescapable as all known cases of successful *P. xylostella* control have been obtained only when the basic control component constitutes either parasites or chemical insecticides.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), has been recorded as long ago as 1746 (Harcourt 1962). Since then there have been many accounts of its importance throughout literature on economic entomology. In some countries, such as Argentina, Australia, New Zealand, and South Africa, its depredations were the cause of serious economic losses to cruciferous crops well before 1930 (Muggeridge 1930). Since then and until 1939, Robertson (1939) noted that although little detailed work appeared to have been done, the moth was recorded as a pest of crucifers in many other parts of the world: Tanganyika, Morocco, Chile, the Bahamas, British Columbia, Jamaica, Montana, Vancouver, Cyprus, Kona, Northern Caucasus, Lower Volga, Pulawy and Lubin, Latvia, Poland, Finland, Denmark and Britain. Many more localities were added in later years, *viz* Brazil (Becker M. 1981, personal communication), Bulgaria (Khristova 1957), Egypt (Hassanein 1958), Hong Kong (Lee 1968), India (Abraham and Padamanabhan 1968), Indonesia (Ankersmit 1953, Vos 1953), Malaysia (Henderson 1957, Ho 1965), the Philippines (Capco 1959), Singapore (Chuo 1973) and Taiwan (Hsu and Wang 1971, Chin 1974). Altogether, up to 1972 at least 128 countries or territories had reported the occurrence of this pest (CIE 1967, Salinas 1972).

In general, the level of DBM infestation varies considerably according to the locality. For example, it is particularly serious in most of the countries in south and southeast Asia while only moderately so in several other Asian regions. On the other hand, in many parts of Canada, Europe and the United States (Muggeridge 1930, Hardy

1938, Sutherland 1966, Oatman and Platner 1969) it is generally of minor concern. In England, only very occasionally were large economic losses involved, resulting from mass immigration (Hardy 1938, French and White 1960, French 1965). In Germany, France and Italy, this insect is not present in sufficient numbers to be a serious pest, and in the last-named country it is comparatively rare (Muggeridge 1930). Nevertheless, it is very widely distributed, and the true distribution is undoubtedly greater than indicated by CIE (1967). Hardy (1938) believed that it could survive wherever crucifers are cultivated.

In spite of the wide adaptability of DBM, the insect appears to be held in check in some regions. Marsh (1917), in outlining the situation in the United States, pointed out that DBM was a striking example of a potentially serious pest normally held in repression naturally by parasites. The occurrence of such natural control of DBM is, however, also recorded in many other places where the moth has remained relatively scarce (Muggeridge 1930, Hardy 1938, Robertson 1939, Ullyett 1947, Kopvillem 1960). Such records suggest that DBM may have become a serious pest only in those countries in which natural enemies are absent or ineffective. Whether this is true requires critical examination.

To date, investigations into the importance of natural enemies have been limited. This was clearly revealed in an analysis by Salinas (1972), wherein most of the published work on DBM between 1947-71 was found to be related to chemical control while studies on its general biology (life history, population dynamics, distribution and host plant records) ranked second. In contrast, papers mentioning natural enemies comprised barely 23% of the total literature, with those containing detailed studies on their biology, ecology and actual utilization even scarer. To a large extent this reflects how little importance has been attached to the biological control of DBM. Whether this is justified can only be gauged from an overview consideration and assessment of the status of the biological agents involved. Evidently, in such an appraisal it is recognized that not all the species of natural enemies are of equal significance and importance. Their contributions vary considerably, depending on the kinds of natural enemy agents, their interrelations and also their relationships with the environment. In view of this, it is essential to examine and estimate closely the real potential and/or limitations of these agents individually. Such knowledge is deemed necessary not only for formulating sound biological control programs but also for ensuring a better chance of success in their eventual utilization. Considering the agents individually or in small distinct groups is essential since biological systems are often complex. Besides, broad generalization would be difficult without running the risk of overlooking any specific and vital features that may exist. Such an analysis is thus attempted for all the known parasites of DBM in this paper. Other natural enemies, such as predators, are not considered as investigations into these have been scanty and incomplete. It is hoped that this appraisal will contribute to the attempts to realize the potential of some of these parasites in the control of DBM.

Attempts at Parasite Importation and Release

Biological control, which involves principally the introduction, augmentation, and conservation of natural enemies, has already proven itself to be a valuable weapon in pest control on a number of crops. Substantial numbers of successes have been achieved to date (DeBach 1964, Huffaker 1971, Pemberton 1948, Sweetman 1958). However, against DBM, it has been attempted only on a few occasions and the effort concerned largely the use of parasites, both indigenous and introduced. One of the earliest attempts was in New Zealand. Initially, work on biological control was undertaken to ascertain what natural enemies were present (Muggeridge 1930). From 1768 hosts collected 1582

moths and 120 parasites were reared, revealing a very low degree (about 7%) of parasitic control. This was effected by the only larval parasite, *Angitia laterallis* Grav (Hymenoptera: Ichneumonidae). However, follow-up studies in 1935-37 by Robertson (1939) recorded three parasitic species. Among these, only one species (*Angitia* sp) was confirmed as a primary larval parasite, the second (*Eupteromalus* sp.) a hyperparasite, while in the case of the third (*Diadromus* sp) researchers were uncertain as to whether it was a parasite or a hyperparasite. In any case, none was able to provide effective control of DBM. Introductions were subsequently made (Muggeridge 1939) with effective suppression achieved by *Diadegma eucerophaga* Horstm (*Angitia cerohaga*) (Hymenoptera: Ichneumonidae) and *Thyraeella* (*Diadromus*) *collaris* (Grav) (Hymenoptera: Ichneumonidae).

In Australia a somewhat similar situation existed. Here, DBM was a major pest of crucifers throughout Australia until many parasitic species were introduced (Wilson 1960). Among these the more important ones were *D.* (*Horogenes*) *eucerophaga, Diadegma* (*Hymenobosmina*) *rapi* (Cam), *T. collaris*, *Apanteles ippeux* Nixon (Hymenop tera: Braconidae), and *Apanteles plutellae* Kurdj (Hymenoptera: Braconidae) (Wilson 1960, Hamilton 1978a, Goodwin 1979). *D. eucerophaga* was widely established both on the mainland of Australia and in Tasmania, and was extremely abundant in many areas. However, *T. collaris* was established mainly in Queensland, New South Wales (NSW), Victoria, and Tasmania, and *A. plutellae* in the Australian Capital Territory, New South Wales, and Queensland. Following the introductions there were subsequent reports of heavy parasitism with marked reduction in the abundance of DBM (Wilson 1960, Hamilton 1978b, Goodwin 1979). For example, in Richmond (NSW) in 1971-74 *Diadegma* spp, *T. collaris* and *A. ippeus* were responsible for parasitizing an average of 72% of DBM pupae collected, while in Victoria *D. eucerophaga, T. collaris* and *D. rapi* effected an average of 93% from 1972 to 1974.

A highly successful introduction was also observed in Indonesia (Vos 1953). Efforts at biological control of DBM by parasite introductions had been initiated in 1928 (Eveleens and Vermeulen 1976). But these did not result in success until the early 1950s with the importation and release of *D. eucerophaga* from New Zealand. From a detailed evaluation involving analysis of population trends of host and parasite before and after introduction of the parasite, the effectiveness of the latter in suppressing DBM was convincingly shown (Vos 1953).

In Zambia it was claimed (Yaseen 1978) that a combination of the newly established *A. plutellae* and *T. collaris*, along with the endemic *Tetrastichus sokolowskii* Kurdj (Hymenoptera: Eulophidae) have recently provided an 80% reduction in damage by DBM.

However, elsewhere, as in the Lesser Antilles, such control successes through parasite introducitons have not been obtained. In this case *A. plutellae* stocks were obtained from India in 1970 and subsequently mass-reared in Trinidad for shipping to Grenada, St Vincent, St Lucia, Dominica, Antigua, Montserrat, St Kitts and Nevis, and British Honduras. Small releases were also made in Trinidad, Barbados and Jamaica. In some of these release sites the parasite has been recovered but full biological control was never achieved (Bennett and Yaseen 1972, Yaseen 1974, Bennett 1974).

During 1971 the parasite *Apanteles vestalis* Haliday (Hymenoptera: Braconidae) was obtained from the Netherlands. Following laboratory production it was widely disseminated. However, there was no recovery (Bennett and Yaseen 1972, Yaseen 1974). Similarly, *T. collaris* failed to become established.

In Trinidad, both *A. plutellae* and *T. sokolowskii* were introduced and are now well established. But to date they have not given adequate control (Yaseen 1978).

The most important cabbage pest in Cape Verde Islands until 1981 was DBM. In biological control of DBM, three parasites; *A. plutellae, T. sokolowskii,* and *Microptilis*

plutellae (Hymenoptera: Braconidae); imported from Pakistan were liberated in 1981 and 1982. To date the first two species are successfully established and DBM is reported to be extremely scarce in areas where it was previously very common (Cock 1983). It was also apparent that the encouraging results were assisted by the use, where necessary, of *Bacillus thuringiensis* Berl.

Attempts at introducing exotic parasites were also made in Malaysia in the 1970s to supplement those occurring locally, i.e. *A. plutellae* (Lim and Ko 1975) and *Tetrastichus ayyari* Rohw (Hymenoptera: Eulophidae) (Ooi and Kelderman 1977). The species introduced from Australia, India, Indonesia, and New Zealand were *D. eucerophaga, T. collaris, T. sokolowskii* and *Macromalon orientale* Kerr (Hymenoptera: Ichneumonidae). Among these, both *D. eucerophaga* and *T. collaris* have successfully become established in the Cameron Highlands. For *T. sokolowskii* there was only initial recovery. *M. orientale* failed to breed in the laboratory and no release was made. In total, the numbers of adult *D. eucerophaga, T. collaris* and *T. sokolowskii* released between 1976-1978 were 1202, 1981 and 21225, respectively.

To date, the parasite complex has yet to provide a full biological control of DBM locally. This has been attributed to excessive use of insecticides (Lim 1982, Ooi and Lim 1983) and hyperparasitic activity (Lim 1982).

More recently there have also been attempts made to introduce *A. plutellae* from Hawaii and Malaysia into Papua New Guinea (Thistleton B.M., personal communication 1983). Although it has become established, the parasitism rates are however quite low and the degree of control inadequate.

In general, from the few attempts at parasite introduction for DBM control, the proportion of successful cases can been considered to be relatively high. Where natural enemies failed to establish or provided only temporary control, this has been attributed to the attempts being short term and of unsustained effort. However, as a result of these failures and the limited control achieved in some cases there have been created in some quarters doubts, apprehension, and pessimism as to the real value of biological control for DBM. Some researchers, basing their opinions on this alone, have even completely disregarded the natural enemy component in control programs. However, it would appear that such decisions based essentially on overall successes/failure rates may not be sufficiently justified. This is especially so since some of the attempts, conducted mainly on an empirical basis, were not of sustained effort and have had neither sufficient nor concerted manpower support. Furthermore, some were launched haphazardly and with little consideration given to the ecological requirements. It is not unexpected, therefore, that these did not show positive results. In contrast, however, the effect has been remarkable for those few cases of success, clearly indicating the potential and practical feasibility of biological control for DBM.

DBM Parasites and Their Potential

Evidently, the parasites of DBM do constitute a valuable control component and resource if properly managed. However, effective exploitation is generally not simple. Knowing the relative potential of the individual species and how they should be utilized is particularly important and could prove crucial in determining the outcome. An attempt is made here to deal critically with this aspect.

Relative importance of the egg, larval, and pupal parasites

To date, many parasite species have been recorded on DBM. Forty-eight species were catalogued by Thompson (1946) while Goodwin (1979) stated that there are more

than 90. However, not all the natural enemies are effective. Frequently, only a few predominate. Even among these, most appear to be unable to exert full control over their host individually under natural conditions, besides differing in their degree of control. Thus, their potential as biological control agents varies, often depending not only on their direct relationships with their host(s) but also on the interrelationships between themselves and the environment. In view of this, it is often difficult to assess accurately the potential of each individual agent. Notwithstanding this limitation, a useful assessment can still be made of the relative potential of the different parasite species. Moreover, an approximation of the potential of the agents and to what extent they may be exploited, if at all, is essential for a control program aiming at the optimum utilization of such agents. Table 1 lists some common egg, larval, and pupal parasites of DBM reported in the literature.

Table 1. Parasites attacking various stages of DBM

Egg parasites
Trichogramma brasiliensis (Ashm), *T. minutum* Riley, *T. pretiosum* Riley, *Trichogrammatoidea armigera* Nagaraja
Larval parasites
Antrocephalus sp, *Apanteles aciculatus* (Ashm), *A. albipennis* Nees, *A. fuliginosus* Wetm, *A. halfordi* Ullyett, *A. ippeus* Nixon, *A. laevigatus* group, *A. limbatus* Marsh, *A. plutellae* Kurdj, *A. ruficrus* Hal, *A. sicarius* Marsh, *A. vestalis* Hal, *Apanteles* sp (*ater* group), *Apanteles* sp (*glomeratus* group), *Brachymeria phyta* (Walk), *B. sidnica* Hlgr, *Compoletis* sp, *Chelonus ritchiei* Wlksn, *Diadegma armillata* Grav, *D. eucerophaga* Horstm, *D. fenestralis* Holmgren, *D. insularis* (Cresson), *d. neocerophaga* Horstm, *D. plutellae* Viereck, *D. rapi* (Cambridge), *D. varuna* Gupta, *Diadegma* sp (near *lateralis* Grav), *Diadromus erythrostomus* (Cameron), *Habrocytus* sp, *Itoplectis* sp, *Macrobracon hebetor* Say, *Macromalon orientale* Kerrich, *Microplitis plutellae* (Meus), *Spilochalcis hirtifemora* (Ashmead), *Spinolia* sp, *Stictopisthus* sp, *Cadurcia plutellae* van Emden, *Tetrastichus* sp
Pupal parasites
Diadromus plutellae (Ashmead), *D. subtilicornis* Grav, *Dibrachys cavus* (Walkr), *Euptromalus viridescens* (Walsh), *Celis tenellus* (Say), *Habrocytus* sp (near *phycidis* Ashm), *Itoplectis maculator* Fab, *Phaeogenes* sp, *Spilochalcis albifrons* (Walsh), *Stomatoceras* sp, *Tetrastichus ayyari* Rohw, *Tetrastichus sokolowskii* Kurdj, *Thyraeella collaris* Grav

From the review, it is evident that most of the recorded parasite species are of limited use or of no potential use in the control of DBM. These include numerous species which are only rarely recorded, as well as species which, although widespread, can never rise to dominate the parasite complex and whose abundance is consistently low.

In general, the egg parasites seem to contribute little, with species being restricted to the genera *Trichogramma* and *Trichogrammatoidea*. Since chemical ovicides are largely unavailable, these egg parasites may however be exploited to increase the overall host mortality accumulated over the different developmental stages.

Larval parasites have the greatest control potential. Among these, the major ones, in order of decreasing importance, belong largely to the genera *Diadegma, Apanteles* and *Microplitis*. It seems that, except for *D. eucerophaga* and possibly *Diadegma fenestralis* (Hymenoptera: Ichneumonidae) none appears capable of exerting full control by itself. Utilization of even the more promising ones; *Apanteles halfordi* Ullyett, *A. ippeus, A. plutellae, Apanteles ruficrus, Apanteles sicarius* Marsh, *Diadegma armillata* Grav, *D. insularis, Diadegma neocerophaga* Horstm, and *M. plutellae*; would thus be restricted to making their contributions only in combination with others. This is also true for the more important pupal parasites which, although effecting only moderate

levels of parasitism, are nevertheless considered beneficial and desirable. Among these however, only the following would appear to be potentially useful: *Diadromus plutellae* (Ashmead), *Diadromus subtilicornis* Grav, *T. sokolowskii*, and *T. collaris*.

From the above it is evident that much scope still exists for increasing overall parasitic activity in many countries through further introductions, because a number of potentially useful species have still not been exploited.

Extent of parasitism, diversity, and quality of parasite species

When closely compared, many countries which are continuously plagued with difficult problems of DBM control are observed to share some common features. Of relevance are situations in most southeast Asian countries, in the Carribean islands, and in South America. Except for South Africa (Wahl 1916, Gunn 1917, Ullyett 1943, 1947), many African countries, like Egypt (Hassanein 1958), Ghana (Gupta 1971), Kenya (Anderson 1922, Ghesquiere 1939, van Emden 1942, dePury 1968), Malawi (Smee 1942), Tanzania (Morstatt 1913a, b, 1914, Ritchie 1932, Harris 1934, dePury 1968, Eberhard 1978), Uganda (Hargreaves 1924, dePury 1968), Zimbabwe (Jack 1936, 1942), and Zaire (Ghesquiere 1939) may also share similar conditions although the situation here is not so fully known because of scanty and limited published information. In particular, the associated parasitic species are revealed to be absent or scarce. Furthermore, the total level of parasitism is generally low, usually not exceeding 36%.

In general, from available records for parasitic activity on DBM in different parts of the world, it is evident that as the total parasitism rises the mean host density tends to decrease, finally becoming negligible under situations of complete biological control when parasitism rates of more than 70% are normal while levels exceeding 80% are not uncommon. In parallel, there is an increase in species diversity; situations with higher total parasitism frequently having a greater number of parasite species. In view of this and also because many of the parasites by themselves are limited in ability to check the host population, biological control objectives and efforts against DBM should aim at combining effects to attain high overall parasitism. However, this should be viewed with some reservation since it is not relevant and applicable to all parasites but likely to be meaningful in practice only for the crucially important ones, as will be made clearer below. Except within each parasite's limit potential (which unfortunately is still not known for many) the attempt to achieve very high parasitism by any one particular species should not be looked upon as feasible. A great abundance of various parasites at the same time is unnecessary as each is eventually limited by its own capacity for host finding. Moreover, a great diversity of the natural enemy complex is not necessarily desirable in pest management (Way 1977) and in some instances can be harmful (Taylor 1937, Varley 1959, Turnbull and Chant 1961, Watt 1968, Zwolfer 1963, Way 1976, Pimentel 1980, May et al 1981).

For practical management, various parasite species may be encouraged to act concurrently or in sequence; the latter, however, is considered more effective since high parasitism by different species usually occurs at different times over the crop and at different stages of the pest. A good knowledge of the sequence or pattern of parasite succession is thus essential. Efforts should therefore be devoted to this, especially to identify periods of natural enemy 'vacuum' or scarcity, and where possible to introduce or encourage appropriate parasites to fill or supplement such 'vacuum'.

In general the abundance of DBM is lower when its parasite diversity is higher, the few exceptional situations, however, have notable implications. Specifically, in the Leeward Islands (Lesser Antilles) five parasite species were unable to provide any significant DBM suppression (Bennett and Yaseen 1972, Yaseen 1974) while full control was achieved in Java (Indonesia) by *D. eucerophaga* alone (Vos 1953). Evidently, such

a situation does not bear out the dogma that increasing diversity increases stability and in general lessens pest outbreaks and damage (Elton 1958, Pimentel 1961, Rudd 1964, Odum 1971). This view was seriously queried in the mid-1960s (Way 1966) and it was subsequently pointed out that diversity and stability may not necessarily be causally related (van Emden and Williams 1974, Murdoch 1975). Also, in practice increasing diversity can sometimes increase rather than decrease pest problems (Southwood and Way 1970, Way 1977). In DBM an increase in pest problems is unlikely to result from increased parasite diversity, but rather from the absence of some crucially important parasite species. This is suggested by the consistent involvement, together or separately, of the same few species (specifically *D. eucerophaga* and *D. fenestralis*) in all but one of the cases where full biological control has been achieved. With the exception in Columbia (USA) where the DBM is held in check by *Diadegma plutellae, M. plutellae* and *T. sokolowskii* (Parker 1971), the insect still poses some problems where *D. eucerophaga* or *D. fenestralis* is absent. However, the situation is most serious, with the pest continuously requiring regular and heavy insecticidal control, when other *Diadegma* spp (except *D.* sp (near *lateralis*) and perhaps *D. plutellae*) are also absent. Otherwise, partial control may still be obtainable, with limited supplements of chemical insecticides. From such evidence, it thus appears that effective control of DBM by parasites may only depend on a few important agents. This parallels most successes in biological control (DeBach 1974) where a single or only a very few natural enemy species have usually proved to be overwhelmingly important (Huffaker and Kennett 1966). The essence, as summed up by Way (1976) is: success in biological control is not associated with simple increase in diversity but it depends primarily on a few crucially important functional links. It is the quality of diversity and not the amount that really matters, the right kind being fundamental to insect pest control (Way 1979). For some pests, however, very small amounts of the right diversity may be adequate. The failure to recognize this is perhaps largely responsible for most of the unsuccessful control of DBM where attempts at introductions have been only with relatively less important parasites and have not included the crucial species (largely *Diadegma* spp, particularly *D. eucerophaga* and *D. fenestralis*) (Wilson 1960, Bennett and Yaseen 1972, Yaseen 1974, 1978, Nagarkatti 1975). In some instances, the poor parasite choice is also unfortunately governed by mere convenience (Nagarkatti 1975, Ooi 1979) which, considering the quality of parasite species, should not have taken priority. In particular, recognizing and ensuring the involvement of these key species is crucial, for failing to do so could lead to much effort and expense being devoted to other biological agents that inherently are unable to effect satisfactory control.

Discussion

From the present review it is evident that the DBM parasites do play a dominant role in the population dynamics of the moth. Nevertheless, Harcourt (1963), on the basis of his life tables from studies at Merivale (Canada), suggested that the value of the biological control method for DBM must seriously be questioned. His conclusion that parasites are relatively unimportant was inevitable since the parasite complex involved in his studies in Canada did not include the more important species. Although *D. insularis* was present, it cannot effect full control except when consistently in combination with other appropriate species. If *D. eucerophaga* or *D. fenestralis* had been present, a very different conclusion could have resulted. Too high expectation of the parasites' role is, however, unrealistic, as both biotic and abiotic factors sometimes may disturb the population balance needing occasional insecticidal applications to combat the pest. While full population suppression through biological control is the prime objective, a partial biological control to be used in conjunction with integrated pest control (IPC) program

with attendant reduction of chemical usage is also considered important (Ooi 1979, Ooi and Lim 1983).

To date, many areas are still plagued by DBM and emerging out of the present studies is strong evidence that this is due to the lack of crucially important parasites. Unless the relevant key species are made a part of the host-parasite complex these problems are likely to persist, largely because such species constitute the few key links that are usually present in the food-web interactions of a pest (Way 1976). Learning how to exploit fully these key links in ways which are compatible with local farm practice (Way 1966) is the answer to the DBM problem. In this regard the detailed investigations with *A. plutellae* by Lim (1982) have provided much of the required information for some of these links. For the other parasites, the links for a few species have been made clearer in this review, nevertheless, additional information is still needed to help define more precise methods of exploitation.

Other important key links are adult food sources in flowers (Kopvillem 1960, Garnaga 1975), the staggering of crop planting, and the cruciferous host weeds to maintain host-parasite equilibrium (Ullyett 1947). Those which are potentially promising have included appropriate multiple cropping systems, in which the right choice and sequence of crops is particularly crucial (van Emden 1976). Beyond these, except in a few cases, the links with the wide array of microbial agents and conventional chemical insecticides are still less clearly defined, largely because of inadequate investigations into the former (Burges and Hussey 1971) and conflicting reports on the latter (Ullyett 1947, Vos 1953, Todd 1959, Kopvillem 1960, Adashkevich 1966, Bennett 1974, Kumar 1974, Yaseen 1974, Sudarwohadi et al 1974, Hamilton and Attia 1977, Hamilton 1978a, 1978b, Ooi and Sudderuddin 1978, Lim 1982). However, since chemical insecticides are in general detrimental to parasitic arthropods, their use should only be considered when absolutely necessary. Biological control of DBM, and of other insect pests in the vegetable ecosystem, should be considered as one technique to be integrated with other mehods as part of an IPC programme. In nature we are rarely faced with a single pest problem, but instead must deal with a complex of pest species within the crop ecosystem. Integration becomes a necessity if the range of pests is to be suppressed and this control be sustained continuously for over a good length of time. Prime consideration must be given to the natural enemies as they have been, in most instances, the cornerstones in developing sound programs in integrated control. They should be given high priority because not only do they constitute the main factor that is capable of regulating pests, but also a naturally-occurring resource that is usually self-perpetuating.

Those parasites which potentially can provide full control, however, are restricted to a few crucially important species. Using these as basic control components is imperative for it is only on such a basis that an improved and more rational program of DBM management can be developed. Although inclusion of the key parasite species may not guarantee complete biological control, marked improvements in the overall pest situation can invariably be expected. On the other hand, in most known situations, abandoning these crucial parasites will mean that cruciferous vegetables will continue to be drenched in ever-increasing amounts of chemicals. Probably, when use of such chemicals become uneconomical, crucifer cultivation would then cease altogether in many areas. These conclusions seem inevitable as all known cases of successful DBM control have been obtained only when the basic control component constitutes either parasites or chemical insecticides. All other potentially useful approaches have yet to be demonstrated as being practically effective in large scale farm situations.

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Evaluation of three Parasites in the Biological Control of Diamondback Moth in the Cameron Highlands, Malaysia

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Abstract

The evaluation of *Apanteles plutellae* Kurdj and two introduced parasites, *Diadegma eucerophaga* Grav and *Thyraeella collaris* Horstn of *Plutella xylostella* was carried out by first measuring the searching efficiency (in terms of area of discovery (a), the killing power (K), and other biological attributes in the laboratory, and then in the field. The laboratory results indicated that *D. eucerophaga* was the most intrinsically superior parasite ($a = 0.87$, standardised $a_s = 10.36$), followed by *A. plutellae* ($a = 0.18$, $a_s = 5.14$) and then *Th. collaris* ($a = 0.11$, $a_s = 3.85$). However, the field performance gave a different ranking. The mean percentage parasitism for 1977-78 was 11.7%, 8.9%, 3.0% and 0.03% respectively for *A. plutellae, Th. collaris, D. eucerophaga* and *Tetrastichus sokolowskii*, another introduced species. In 1984, a similar pattern of dominance was observed at the same sampling site, the values being 4.8%, 0.07%, 0.04% and 0% respectively. The reasons for the dominance of *A. plutellae* over *D. eucerophaga* in the field are the former parasite's possible development of resistance to chemicals, and the high female ratio in its progeny, and the inability of *D. eucerophaga* to adapt to local conditions. The future of biological control of diamondback moth in Malaysia is discussed and integrated pest management incorporating mainly *A. plutellae* is suggested.

Introduction

Diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), a non-native pest of cruciferous crops in Malaysia, was first collected in 1925 (Ho 1965). By 1941 however, it had already become an important pest of cabbages in the Cameron Highlands (Corbett and Pagden 1941). The Highlands, approximately 915-1525 m above sea level and surrounded by jungle, form the main vegetable growing area in Malaysia. The vegetables cultivated here include cabbage, Chinese cabbage, tomatoes, lettuce, watercress, sugar peas, and chillies. Cultivation, however, is confined to seven main areas: Kampung Raja, Kampung Kuala Terla, Kea Farm, Mensum Valley, Ringlet, and Bertam Valley.

All vegetable farmers practise chemical control to combat DBM. In a survey involving 114 farmers (representing 23.3% of all farmers) in the Cameron Highlands, Ooi and Sudderuddin (1978) found the three most commonly used insecticides were fenvalerate, methamidophos, and prothiophos. These chemicals were reported to be used in 'cocktail' formulations of two or more insecticides combined together. The dosages used were often in excess of what is recommended. Forty percent of the farmers interviewed used twice the recommended dosage of fenvalerate while another 26% used

even more. The frequency of spray was also high: 12% sprayed three times per week, 39% twice weekly and 49% once weekly. In fact, the use of insecticides was so heavy that it amounted to about 30% of the cost of production for common cabbage (Lim 1972).

Given the scenario of improper, excessive, and frequent use of insecticides, it is not surprising that resistance to chemicals has developed in DBM over the years. For example, in 1957 malathion was reported to give good control (Henderson 1957). However, some twenty years later Sudderuddin and Kok (1978) found that the resistance factor for malathion was 2096, which explains why the farmers have stopped using malathion in the Cameron Highlands. The resistance factors for methamidophos and fenvalerate were reported to be 6.2 and 4.5 respectively. These values could be even higher now.

A possible alternative to chemical control is biological control. In New Zealand, for example, it was reported that DBM was effectively controlled by *Diadegma* (*Angitia*) *eucerophaga* Grav. and *Thyraeella* (*Diadromus*) *collaris* Grav, especially by the former (Todd 1959). Similarly, in Australia four introduced parasites have become established and have contributed a certain measure of control (Wilson 1960). The introduction of *D. eucerophaga* into Indonesia has led to an average parasitism of over 80%, resulting in a decline of DBM populations (Vos 1953). In Canada, Putnam (1973) reported that the combined parasitism of *D. insularis* (Cress) and *Microplitis plutellae* Mues could reach a mean level of 68% for the first generation of DBM.

In Malaysia, *Apanteles plutellae* Kurdj., first recorded in 1975 (Lim and Ko 1975), does not appear to exert sufficient control of DBM. So in an attempt to enhance control exerted by biocontrol agents, three other parasites, *D. eucerophaga, Th. collaris* and *Tetrastichus sokolowskii* Kurdj. were released by Ooi (Ooi 1979, Ooi and Lim 1983). A total of 1201 *D. eucerophaga*, 1981 *Th. collaris* and 20975 *T. sokolowskii* were released (Table 1). The percentage parasitism by these parasities and *A. plutellae* were then monitored in the field. The overall recovery rates for the three species were 5.7%, 15.2%, and 1.6% respectively.

This paper concentrates on three species only *viz A. plutellae, D. eucerophaga* and *Th. collaris*. The host selection of these three species has already been documented quite some time ago by Lloyd (1940). The aim of this study and the approach adopted here differ somewhat. These species were first evaluated in the laboratory in terms of their searching efficiency, killing power and other basic biological attributes. Then, as a follow-up to Ooi's work (Ooi 1979), their performance in the field was assessed again and then correlated with the laboratory findings.

Materials and Methods

The DBM culture was maintained in the laboratory using Choy-sum (*Brassica rapa*) leaves as the food plant. Culture of *A. plutellae* was started from field-collected specimens, that of *D. eucerophaga* from specimens imported from Indonesia, and that of *Th. collaris* from Australian specimens.

In the study on the searching efficiency of the parasites, the required number of females were kept together with a specific number of healthy hosts in an experimental cage for 24 h. After this both the parasites and hosts were removed, the latter (if larvae) further reared to the pupal stage. Pupae were then kept until the emergence of the adult parasites. Wooden cages of cuboidal shape, the dimensions of which and other details are given in Table 2, were used. The experiments were conducted with female parasite densities of 1, 2, 4 and either 8 (for *Th. collaris* and *D. eucerophaga*) or 16 (for *A. plutellae*). Each set was replicated three to six times.

Table 1. Record of releases and recovery of *Diadegma eucerophaga, Thyraeella collaris* and *Tetrastichus sokolowskii* in the Cameron Highlands, Feb 1976-April 1978[a]

Site[b]		*Diadegma*			*Thyraeella*		*Tetrastichus*	
MRS	RL[c]	Mar '77-Jan '78 (8)	345 F[e]	467 M[f]	Nov '76-Nov '77 (9)	343 F 243 M	Nov '76-Dec '76 (2)	3045 adults
	RC[d]	Jun '77-Apr '78 (20)	206/3437	6.0%	Oct '77-Apr '78 (9)	49/215 22.8%	Nov '76-Jul '77 (6)	7/1005 0.7%
BV	RL	Sep '77-Nov '77 (2)	73 F	58 M	Nov '77-Dec '77 (2)	131 F 112 M	Jan '77 (1)	250 adults
	RC	Dec '77-Feb '78 (3)	39/726	5.4%	Dec '77-Feb '78 (3)	7/153 (4.6%)	—	—
KR	RL	—	—		Apr '76-Sep '76	582 F 189 M	Feb '76-Sep '76 (8)	16930 adults
	RC	—	—		—	—	Aug '76-Oct '76 (4)	14/321 4.4%
TR(1)	RL	Aug '77-Sep '77 (3)	58 F	25 M	Sep '77 (2)	9 F 20 M	—	—
	RC	Sep '77 (1)	6/224	2.7%	—	—	—	—
MV	RL	Sep '77-Jan '78 (2)	36 F	53 M	Jul '77-Mar '78 (3)	131 F 141 M	Apr '77-May '77 (2)	1000 adults
	RC	—	—		—	—	—	—
KF	RL	Feb '78 (1)	46 F	40 M	Feb '78 (1)	40 F 40 M	—	—
	RC	—	—		—	—	—	—
Total	RL		558 F	643 M		1236 F 745 M		20975 adults
	RC		251/4387	5.7%		56/368 15.2%		21/1326 1.6%

[a] The number of releases of number of sampling occasions is indicated within parentheses following the date. For the recovery data, the number of hosts parasitized over the total number hosts collected, and the percentage parasitism are given. Dash (–) indicates no parasites were released or no samples were taken. [b] MRS = MARDI research station, BV = Bertam Valley, K.R. = Kampung Raja, TR(1) = Tanah Rata (1), MV = Mensum Valley, KF = Kea Farm. [c] RL: Record of release and [d] RC: Recovery. [e] F = Female. [f] M = Male.

Table 2. Details of cage dimensions and host number used in experiments on the area of discovery for *Apanteles plutellae, Diadegma eucerophaga* and *Thyraeella collaris*

Species	*Apanteles*	*Diadegma*	*Thyraeella*
Cage dimensions (cm)	45 × 45 × 45	31 × 31 × 36	22 × 13 × 31
Cage Vol. (m^3)	0.0911	0.0346	0.0089
Internal surface area (m^2)	1.2150	0.6386	0.2742
No. hosts used	255 larvae[a]	170-210 larvae[b]	30-35 pupae
Host plant	choy-sum	cabbage	none[c]
Surface area (m^2) with hosts	0.0350	0.0840	0.0286

[a] 2nd and 3rd instar. [b] 3rd instar. [c] Only pupae were pasted on paper at the bottom of the cage.

Fecundity was studied by offering daily a fixed number of hosts to a female parasite until the latter died. The number of host individuals used was for *A. plutellae* (n = 5) 20 larvae; for *Th. collaris* (n = 45) 5-20 pupae, and for *D. eucerophaga* (n = 48) 15-20 larvae. The hosts were removed after 24 h and kept until the parasite larvae pupated and adults emerged.

Diluted honey streaked on the sides of the experimental cages was offered as food to the parasites. All experiments were conducted at room temperature of 25-27°C.

The area of discovery, which is a measure of searching efficiency, is calculated using the formula (Hassell 1971):

$$a = \frac{1}{p} \log_e \frac{N_i}{N_f}$$

where N_i, N_f are the initial and the final (unparasitized) host densities respectively and P the parasite density. The relationship between a and the density of parasites searching for hosts can be described by the formula (Hassell and Varley 1969):

$$a = QP^{-m}$$

where Q is the quest constant or the level of efficiency of one parasite, and m the interference constant between searching parasites. Expressed in logarithms, the equation becomes linear:

$$\log a = \log Q - m \log P$$

The killing power of the parasite, K, is calculated by using formula:

$$K = \log \frac{N_i}{N_f}$$

To investigate the performance of these three parasites under field conditions, samples were taken at Tanah Rata, the Cameron Highlands at intervals of about two weeks in 1977-78 (during and after the parasite release); and again six years later in May-June 1984. During 1977-78, destructive sampling was adopted in which 20 cabbage plants were uprooted and examined in the laboratory. All DBM larvae, pupae, and *A. plutellae* cocoons were collected, their numbers recorded and reared.

In 1984, the samples were collected from the experimental plots of the Malaysian Agricultural Research and Development Institute (MARDI) Station, Tanah Rata (as in 1977-78), and in addition from several farmers' fields in Brincang. At each site, a total of 25 cabbage plants were examined, leaf by leaf, for DBM larvae, pupae, and *A. plutellae* cocoons. These were collected and brought back to the laboratory for rearing to determine the parasitism level.

Results

From a comparison of the basic biological attributes observed in this study (Table 3), and by Delucchi (1954) (Table 4), it would appear that *D. eucerophaga* is a superior parasite, being able to parasitize a greater number of hosts (117), even though its mean life span is only intermediate (22 days). This amounts to 5.3 hosts parasitized per day, slightly less than the figure for *Apanteles* (6/day). *D. eucerophaga* has the highest area of discovery (a), and the highest killing power (K) per parasite, 0.87 and 0.38 respectively.

Table 3. A comparative summary of the biological attributes of *Apanteles plutellae, Thyraeella collaris* and *Diadegma eucerophaga*

Species	Host stage attacked	Developmental duration (egg, larva, pupa)	Female adult longevity (days)	No. hosts attacked per female in life time	Sex ratio progeny F : M	Searching characteristics using one of female in expt		
						K	a	standardized a
Apanteles plutellae	2nd to 4th instar larvae	11-14	14 (Range 6-21)	85[a]	1 : 1.2	0.09	0.18	1.98[e] 0.15[f] 5.14[g]
Thyraeella collaris	pupae	18[b]	36 (Range 11-85)	45[c] (Range 4-134)	1 : 2.4	0.05	0.11	12.41[e] 0.40[f] 3.85[g]
Diadegma eucerophaga	all larval stages	12.5-19	22 (Range 10-65)	117[d] (Range 6-362)	1 : 3.1	0.38	0.87	25.15[e] 1.36[f] 10.36[g]

[a] 20 hosts offered/day. [b] Delucchi et al (1954). [c] 5-20 hosts offered/day. [d] 15-20 hosts offered/day. [e] Per cage volume. [f] Per cage internal surface area. [g] Per unit area containing hosts.

Table 4. Biological attributes of DBM parasites[a]

Species	Longevity[b] (days)	No. hosts killed in life time	Sex ratio[c] of progeny F : M	Life cycle (days)
A. plutellae	14 (6-21)	85	1:1.2	11-14
T. collaris	36 (11-85)	45 (4-134)	1:2.4	18
D. eucerophaga	22 (10-65)	117 (6-362)	1:3.1	12.5-19

[a] Delucchi et al (1954). [b] Female. [c] F = Female, M = Male.

However the proportion of female progeny for *Diadegma* is the lowest (20%) and the lifecycle the longest. On the basis of searching efficiency alone, *A. plutellae* may be considered the least effective parasite, while *Th. collaris* is intermediate.

Since cages of different size were used for different species, values of a were also standardized to per cage volume, per cage internal surface area, and finally to per unit surface area where hosts were located (Table 3). It is clear that *D. eucerophaga* still has the highest standardized a, followed by either *Th. collaris* (for cage volume and internal surface area) or by *A. plutellae* (for area containing the hosts). If it is assumed that the area containing the hosts is the area where the parasites would actively search for hosts, it is likely then that the values of a per area with hosts would be more useful for comparison purposes. These are 10.36, 5.14 and 3.85 for *D. eucerophaga, A. plutellae* and *Th. collaris* respectively.

The K value increases with the parasite density for all species (Figure 1), although the rate of increase may differ. Again, *D. eucerophaga* stands out as being the species which has the highest K and the highest rate of increase with a change in parasite density. However, *A. plutellae* and *Th. collaris* do not differ very much from each other.

Plotting log a against log parasite density, it is clear that the value of log a decreases with parasite density (Figure 2). The values of a for *D. eucerophaga* are always much higher than for both *Th. collaris* and *A. plutellae*. The values of Q for the species are 0.72, 0.17 and 0.17 respectively; while the interference constants are 0.30, 0.47 and 0.63 respectively.

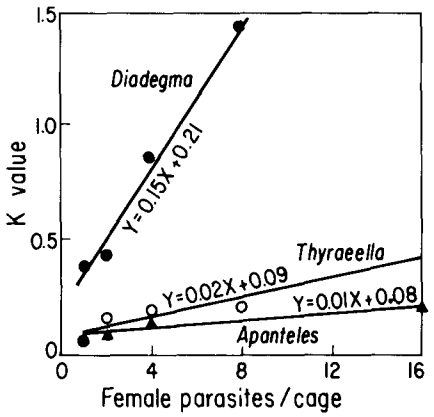

Figure 1.
The relationship between the proportion of hosts parasitised (expressed as K-values) and the number of female parasites per experimental cage

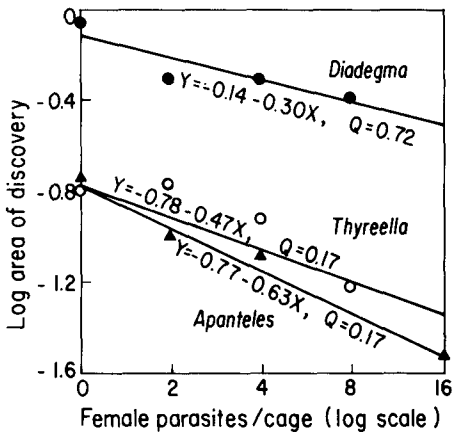

Figure 2.
The relationship between searching efficiency and log number of female parasites per experimental cage

In 1977-78 season the mean percentage parasitism for *A. plutellae, D. eucerophaga, Th. collaris* and *T. sokolowskii* were 11.7%, 3.0%, 8.9% and 0.03% respectively (Table 5). *D. eucerophaga* was first recorded three months after the first release, while *Th. collaris* only two months after the second release (that is ignoring the first release in November 1976 which obviously failed). *T. sokolowskii* was recorded only twice. The percentage samples containing these parasites were respectively 96%, 74%, 33% and 7%.

In 1984, the DBM population was rather low compared to 1977-78 (Ooi 1979). A total of only 209 larvae (2nd-4th instar) and 74 pupae were collected from 200 cabbage plants, giving an average of one larva and 0.4 pupa per plant (Table 6). *A. plutellae* was the main parasite recorded, scoring a mean percentage parasitism of 12.9% (for May) and 17.1% (for June) with a combined range of 0 to 33.3%. Only one specimen of *D. eucerophaga* two of *Th. collaris* and none of *T. sokolowskii* were recorded at the MARDI station.

Table 5. Parasitism of DBM by *Apanteles plutellae, Diadegma eucerophaga, Thyraeella collaris* and *Tetrastichus sokolowskii* at MARDI Research Station, Tanah Rata, the Cameron Highlands for April 1977-April 1978[a]

Date	*Apanteles*		*Diadegma*[b]		*Thyraeella*[c]		*Tetrastichus*[d]	
	No.	parasitism %	No.	parasitism %	No.	parasitism %	No.	parasitism %
6 April 77	59	6.4	—	—	—	—	—	—
18 April	59	15.4	—	—	—	—	—	—
5 May	30	7.4	—	—	—	—	—	—
17 May	6	35.3	—	—	—	—	—	—
2 June	34	40.0	10	11.8	—	—	—	—
14 June	16	12.8	8	6.2	—	—	—	—
30 June	24	13.6	11	4.5	—	—	1	0.4
13 july	20	9.9	1	0.4	—	—	1	0.4
26 July	90	12.9	2	0.3	—	—	—	—
12 August	10	7.0	4	2.6	—	—	—	—
23 August	9	8.6	5	4.6	—	—	—	—
9 Sept.	6	4.8	1	0.7	—	—	—	—
21 Sept.	86	16.4	12	2.3	—	—	—	—
4 Oct.	4	2.1	—	—	3	18.8	—	—
19 Oct.	10	10.2	—	—	—	—	—	—
2 Nov.	8	8.4	1	0.9	1	8.3	—	—
14 Nov.	2	1.1	—	—	—	—	—	—
28 Nov.	7	6.7	2	1.3	8	17.0	—	—
15 Dec.	42	23.9	18	10.2	—	—	—	—
27 Dec.	7	6.7	1	1.0	1	100.0	—	—
11 Jan. 78	9	11.7	3	3.8	1	50.0	—	—
26 Jan	1	2.2	2	3.1	9	47.4	—	—
9 Feb.	52	44.4	19	15.7	—	—	—	—
22 Feb.	5	6.9	23	23.0	—	—	—	—
8 March	61	17.3	43	9.6	22	23.7	—	—
21 March	—	—	3	9.1	3	42.9	—	—
5 April	4	5.7	16	18.2	1	5.6	—	—
Total	661	11.7	185	3.0	49	8.9	2	0.03
Sample with parasites	26	96.3	20	I74.1	9	33.3	2	7.4

[a] A sample of 20 cabbage plants was taken at each occasion and all DBM larvae and pupae collected. The denominator for calculation of percentage parasitism is total larvae (for *Apanteles*), total pupae (for *Thyraeella*) and total larvae plus pupae (for *Diadegma* and *Tetrastichus*). *Apanteles* cocoons collected from the field are excluded from calculations. [b] Releases Mar 1977-Jan 1978. [c] Nov 1976, Jul 1977-Nov 1977. [d] Nov 1976-Dec 1976.

Table 6. Parasitism of DBM collected in 1984 in the Cameron Highlands[a]

Date	Sites	Stage of crop	DBM larvae		DBM pupae			*A. plutellae* cocoons collected
			No. Collected	Parasitised by *A. plutellae* (%)	No. Collected	Parasitised by *D. eucerophaga* (%)	*Th. collaris* (%)	
20 May 84	MARDI Station, Tanah Rata							
	(a) Ecological plot	Harvesting	24	1 (4.2)	17	1 (5.9)	1 (5.9)	2
	(b) Plot sprayed with juvenile hormone	Harvesting	38	2 (5.3)	11	1 (0.09)	—	2
	Farmer's field I, Brincang							
	i) Sample 1	Harvesting	22	4 (18.2)	25	—	—	5
	ii) Sample 2	Harvesting	55	11 (20.0)	19	—	—	1
	Total		139	18 (12.9)	72	1 (1.4)	2 (2.8)	10
9 June 84	(a) Farmer's field I, Brincang	end of harvest	6	2 (33.3)	2	—	—	2
	(b) Farmer's field II, Brincang							
	i) sample 1	2 weeks old	16	4 (25.0)	—	—	—	—
	ii) sample 2		30	6 (21.4)	—	—	—	—
	(c) Farmer's field III, Brincang	4 weeks old	18	—	—	—	—	—
	Total		70	12 (17.1)	2	—	—	2
	Grand total		209	30 (14.4)	74	1 (1.4)	2 (2.7)	12

[a] A total of 25 cabbage plants were sampled at each site.

Discussion

Although there is no predetermined set of criteria agreeable to all for the choice of a parasite to be used in a biocontrol program, nevertheless certain basic characteristics could be proposed to define a good, reliable and efficient regulating parasite. These are: (a) the parasite should have a reprocical density-dependent relationship with its host, (b) it should have a high searching efficiency, low handling time, high aggregational behavior and a sigmoid functional response, (c) it must be able to adapt to the varying physical conditions of the environment, (d) it should have a high power of increase relative to that of the host and relative to its power of host parasitism, and (e) it must have other 'good' intrinsic properties such as synchronization with its host, host specificity, discriminatory power, ability to survive host-free periods, and so on.

In the light of characteristic (b) listed above, the results of our laboratory evaluation would single out *D. eucerophaga* as the superior parasite, surpassing *A. plutellae* and *Th. collaris* in terms of area of discovery and killing power, both of which are also reflected in the number of hosts parasitized by a female in its life time. On the same basis, *A. plutellae* would be a poor parasite. Incidentally Vos (1953) also speculated that *D. eucerophaga* had a well developed searching abilities when he tried to explain its success in Indonesia.

However, if the field results of 1984 could be taken as indicative of the situation (since they are similar to the 1977-78 findings with respect to the relative dominance of the parasites), then it is reasonable to think that the field performance of the parasites contradicts the laboratory results. *A. plutellae* was, with one exception (farmer's field III, Brincang, Table 6) always reared from DBM larvae, giving an overall mean percentage parasitism of 14.4% (range 0-33.3%). Both *D. eucerophaga* and *Th. collaris* were only occasionally recorded (only one *D. eucerophaga* and two *Th. collaris* at MARDI station, Tanah Rata). In the 1977-78 results (Table 5) *Th. collaris* appeared to have achieved a higher parasitism rate. However, this could be an artifact due to the smaller number of pupae collected, as a result of DBM adults emerging earlier from the unparasitized ones. In Queensland, *Th. collaris* was reported to have achieved a lower level of parasitism than *D. eucerophaga* (*nythobia*), the values being 2.4% and 29.0% respectively (Yarrow 1970). On the other hand it was not surprising that *T. sokolowskii* was not recorded in 1984, considering that it did very poorly even in 1976-78, being recovered only six times with a maximum parasitism of only 2% (Ooi 1979). In Bangalore, India, *T. sokolowskii* was reported to achieve a parasitism of 13-14% (Nagarkatti and Jayanth 1982).

It is not easy to explain for certain why *A. plutellae*, the least effective parasite according to the laboratory tests, could end up as relatively dominant parasite in the field, in contrast to the *D. eucerophaga*. One important factor could be that *A. plutellae* having been associated with insecticide-resistant DBM in the Cameron Highlands for a reasonably long period of time, and having been exposed to insecticides as much as DBM, has also developed some degree of resistance. In other words, *A. plutellae* and DBM may have somehow co-evolved with respect to resistance to insecticides. Further work along this line is being carried out at the moment. Another factor could be that *A. plutellae* has a much higher female proportion in its progeny, thus conferring an advantage over *D. eucerophaga*. A third factor is that *D. eucerophaga* has yet to adapt itself to the environmental and climatic variations of the Cameron Highlands. Temperature has been shown to play an important part in the performance of a parasite. Putnam (1968) found that increasing constant temperature from 20°C to 30°C favored *D. insularis* but reduced the effectiveness of *Microplitis plutellae*. The apparently high percentage parasitism by *D. eucerophaga* in New Zealand (Todd 1959) could be an artifact of the sampling size, since the maximum number of larvae collected in a sample was 69, of

which 44.9% were parasitized, while samples with one to five larvae constituted 74% of all samples with DBM larvae. Although multiparasitism was not investigated here, it is unlikely to occur as observed by Lloyd (1940) who also showed that the three species do exhibit some degree of discrimination between parasitised and unparasitised hosts. Interestingly enough, Lloyd found that when *A. plutellae* and *D. eucerophaga* occurred together in a host in the laboratory, neither appeared to be intrinsically superior.

What is the future of biologial control of *Plutella* in the Cameron Highlands? The present results appear to indicate that of the three species of parasites released by Ooi (1979), only *D. eucerophaga* and *Th. collaris* have been recovered but in very low numbers. This could mean that, despite the earlier small success recorded in 1977-78, these two species have yet to fully establish themselves. However it is still possible that the role of these three introduced parasites (that is, including *T. sokolowskii*) might become more important in the future, as was the case for the Hessian fly parasite, *Pleurotropis metallicus* which was introduced in 1894 into the United States. That parasite was recovered only after 21 years, yet it subsequently became one of the dominant parasites of the Hessian fly (Lloyd 1940).

Previous results seem to indicate that there is a ceiling to the level of parasitism that can be achieved by *A. plutellae*. Ooi's work (1979), covering a time span of two years and sampling four ecological sites, indicated that the mean parasitism was only 12.3-19.1% (Table 7). This has mainly been attributed to hyperparasitism, which is in contrast to other parasites of DBM. For example, Robertson (1939) claimed that hyperparasitism was of little significance in the reduction of the New Zealand *Diadegma* (*Angitia*) sp. Ooi (1979) has reported eight different species of hyperparasites of *A. plutellae*, the more common being *Hemiteles* sp (Ichneumonidae), *Tetrastichus* sp (Eulophidae), *Mesocorus* sp and *Ceraphon* sp, roughly in that order of importance. In the lowlands, however, *Ceraphon* sp was the only hyperparasite recorded (Chua and Lim 1979). The hyperparasitism rate could be so high that 26.6% of the *A. plutellae* cocoons collected were parasitised (Table 7). Whether the level of parasitism of DBM by *A. plutellae* could be increased substantially, for example by inundating the field with laboratory-reared adults as advocated by Chiu et al (1974), remains to be seen, although the possibility of mass-rearing and releasing this already-adapted parasite should not be overlooked. For the moment however, it appears unlikely that *A. plutellae* alone could achieve the desired level of control of DBM. In Trinidad too, Yaseen (1974) concluded that *A. plutellae* could not provide adequate control of DBM.

Table 7. Rate of parasitism (by *Apanteles plutellae*) and hyperparasitism of DBM in Cameron Highlands[a]

Site	Date	No. of crops	Parasitism Range	(%) Mean	Hyperparasitism (%)
Kampung Raja	Jan '76 - Oct '76 (19)	4	4.0-50.0	12.3	16.9
Tanah Rata (1)	Feb '76 - Nov '76 Jan '77 - Dec '77 (46)	8	3.8-78.8	18.5	23.3
Bertam Valley	Apr '76 - Apr '78 (43)	8	0-57.0	19.1	11.7
MARDI Research Station (TR2)	Aug '76 - Apr '78 (43)	9	2.0-66.5	18.2	26.6

[a] Samples of either 10 (first three sites) or 20 cabbage plants (last site) were taken fortnightly from the ecological plots at each site. The total number of samples is given within parentheses following the date.

The value of biological control of DBM has been questioned before by Harcourt (1963) after a detailed study on the major mortality factors, including parasitism by three parasites viz *Diadegma* (*Horogenes*) *insularis, Th. collaris* and *Microplitis plutellae*. Our

results also indicate that the sole use of biocontrol agents would be unlikely to succeed in controlling DBM. Perhaps another approach is required. The use of *A. plutellae* in integrated pest management (IPM) programs has recently attracted some attention locally, for example in the work of Lim (1982) and Sivapragasam et al (1984). The findings of Lim (1984) in particular indicate that the potential of *A. plutellae* in the integrated management of DBM has yet to be tapped.

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Status of Biological Control of Diamondback Moth by Introduction of Parasitoid *Diadegma eucerophaga* in Indonesia

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Abstract

The present distribution and effectiveness of the parasitoid *Diadegma eucerophaga* Horstm, introduced in 1950 for biological control of *Plutella xylostella* L. on cabbage in Indonesia, were investigated. The parasitoid is well established in the highland cabbage growing areas in Java, Bali, and West Sumatra. In 1976, the parasitoid was successfully introduced and established in North Sumatra. This parasitoid has also been introduced in South Sulawesi in 1984. The parasitoid also occurs in the highlands where it has never been released, such as in some cabbage growing areas in West Java and North Sumatra. Despite a level of parasitization of over 80%, diamondback moth is still a very important pest on cabbage in some crucifer growing areas. Since at present *D. eucerophaga* is well established almost all over Indonesia and plays an important role as a biological control agent of *P. xylostella*, efforts are being made to conserve and further augument its population. Improvement of control may be achieved by the use of the selective insecticide, *Bacillus thuringiensis* Berliner when diamondback moth population pass an action threshold of about 0.3 larvae/plant.

Introduction

Crucifers in Indonesia are attacked by several insect pests, such as the black cutworm (*Agrotis ipsilon* Hufn) diamondback moth (DBM) (*Plutella xylostella* L, Lepidoptera: Yponomeutidae), cabbagehead caterpillar (*Crocidolomia binotalis* Zell) and in some cases cabbage looper (*Chrysodeixis orichalcea* L) (Sastrosiswojo 1982). Among these insect pests, DBM and *C. binotalis* are the most destructive. If no control measures are undertaken, feeding injury caused by these caterpillars may reduce crop production to zero, particularly during the dry season (Sudarwohadi 1975). As early as 1916, serious damage by these leaf eating caterpillars was reported from Java, Bali, Sumatra, North Sulawesi and certain other parts of Indonesia (Vos 1953).

Efforts to achieve biological control of DBM by introduction of parasitoids from abroad were initiated in the 1920s. In 1928, Leefman introduced the ichneumonid parasitoid *Diadegma* (=*Angitia*) *fenestralis* Hlmgr from the Netherlands, but failed to get a laboratory culture established (Vos 1953). In 1950, Vos introduced an ichneumonid parasitoid, *Diadegma eucerophaga* Horstm (=*Angitia cerophaga* Grav), closely related to *D. fenestralis*, from New Zealand to Indonesia. This effort was more successful. Vos (1953) reported that the importation and release of *D. eucerophaga* in the cabbage growing area around Pacet, West Java (Figure 1), led to its establishment there as an effective biological control agent. Following the success in this original release area, attempts were made to introduce the parasitoid into other cabbage growing areas. However, these efforts were successful at only two locations, in Central Java and West

Sumatra (Figure 1). The commonly used practice of growing cabbage in situ from seed entailed heavier use of insecticides, and this thwarted efforts to get *D. eucerophaga* established.

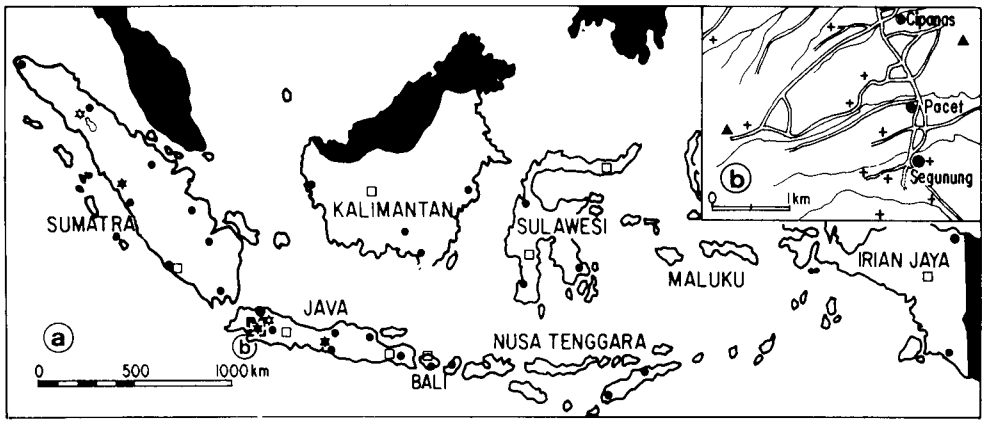

Figure 1. a. Map of Indonesia showing the distribution of *D. eucerophaga* in 1952. ★Parasitoid released and established. ☆Parasitoid released but not established. □Parasitoid not released. b. Map of Pacet showing release and establishment sites (+) of *D. eucerophaga* in 1952

Progress in Biological Control of DBM

We will discuss four stages of progress in the biological control of DBM by *D. eucerophaga* in Indonesia: (1) 1953 to 1970, (2) 1971 to 1975, (3) 1976 to 1981; and (4) 1982 to 1984.

1953 to 1970

No investigations were carried out on the status and further spread of *D. eucerophaga* during the 15-year period following Vos' publication in 1953. Although several releases of *D. eucerophaga* have been made in Lembang, Vos (1953) reported that the parasitoid failed to establish there. This was assumed to be due to heavy applications of insecticides in this region. However, in 1974 the presence of *D. eucerophaga* in the vegetable growing area of Lembang, West Java (Figure 2), was reported by Sastrodihardjo (1974). He conducted an intensive study from November 1968 up to mid-1969 and from January to July 1970. He found that less than 60% of the DBM population was parasitized by *D. eucerophaga*. Apparently the parasitoid has spread in Lembang area, in spite of the reported failure of the first release due to excessive insecticide usage, although the level of parasitism was not adequate to suppress the DBM population.

1971 to 1975

During this period, two different studies were carried out (Sudarwohadi and Eveleens 1977) with the objectives of determining: (1) Current distribution in Indonesia of *D. eucerophaga* as a DBM parasitoid. (2) Rates of parasitization in two selected vegetable centers (Pacet and Lembang) in West Java.

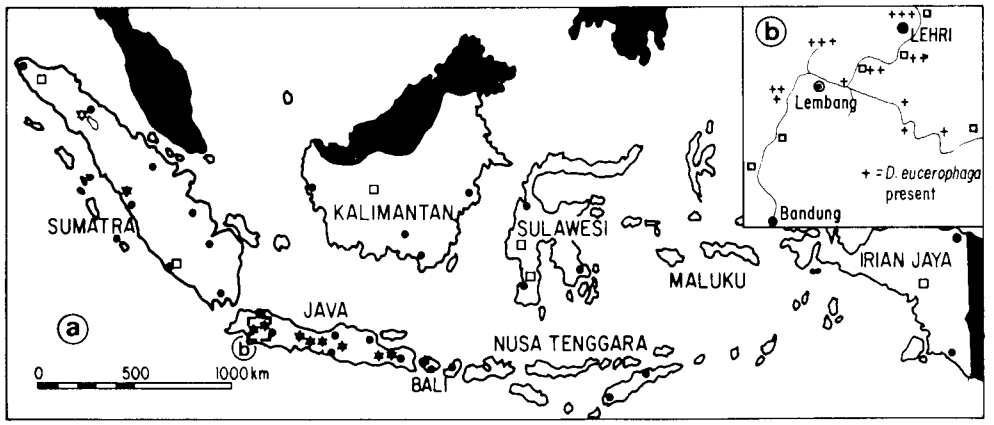

Figure 2. a. Map of Indonesia showing the distribution of *D. eucerophaga* in 1975. ★ Parasitoid released and estabished. ☆ Parasitoid released but failed to estabish. □ No release made. b. Distribution of *D. eucerophaga* at Lembang in 1970

1. Distribution of *D. eucerophaga* in Indonesia Surveys were carried out in those provinces where highland vegetables are mainly grown. Practically all the principal cabbage cultivation districts in each province were visited. At least two municipalities in each district were surveyed, and observations in each case covered a minimum of two plantings. Presence of *D. eucerophaga* was determined in field-collected 3rd and 4th instar DBM larvae and pupae. The larvae were either reared, or, if sufficiently large, dissected to determine the presence of parasitoid larvae inside.

The results of this extensive survey (Table 1, Figure 2a) indicated that the parasite is well established in Java and Bali, and in parts of Sumatra but not in Sulawesi. Some observations on the level of parasitism in three larger islands: Java, Bali, Sumatra, and Sulawesi are as follows:

Table 1. Results of a country-wide survey on the current distribution of *D. eucerophaga* in Indonesia[a]

Province	District	No.of plantings surveyed	No.of plantings with *D. eucerophaga*
West Java	Bandung	2	2
	Cianjur	3	3
Central Java	Semarang	3	3
	Wonosobo	3	3
	Karanganyar	2	2
East Java	Malang	6	3
Bali	Tabanan	2	1
	Badung	1	1
West Sumatra	Agam	4	1
	Solok	2	1
North Sumatra	Simalungun	3	0
	Tanah Karo	4	0
	Tapanuli Utara	3	0
South Sulawesi	BantaEng	1	0
	Jeneponto	2	0
	Gowa	3	0

[a] Source: Sudarwohadi and Eveleens (1977).

A. Java and Bali *D. eucerohaga* is widely distributed in all three provinces of Java and in Bali (Figure 2). Despite the widespread occurrence of the parasitoid, DBM is relatively a more serious pest in the cabbage growing areas in the central and eastern parts of Java than in the western part. This difference may result from the marked west-east gradient of decreasing precipitation on Java (Oldeman 1975). It has been found elsewhere that rainfall constitutes a major mortality factor of newly hatched DBM larvae (Ullyett 1947, Harcourt 1963).

B. Sumatra In West Sumatra province, high rates of parasitization were found on the slopes of Mount Singgalang near Bukittinggi which was one of the original release areas (Figure 2). We did not find *D. eucerophaga* in the districts of Agam and Solok, except in an isolated area near the village of Allahan Panjang, more than 100 km southeast of the original release site. In this field, DBM was scarce and heavily parasitized by *D. eucerophaga*. These findings indicate that the parasitoid has spread over the highland vegetable region of West Sumatra, but is of limited effectiveness.

In North Sumatra (Figure 2), no *D. eucerophaga* was found. Vos (1953) had already reported failure of release efforts at Brastagi and Tarutung due to excessive use of insecticides. During our visit in September 1975, we observed severe DBM infestation of crucifers. Although cabbage plants were heavily treated with a variety of insecticides (up to three times per week) DBM control was disappointing due to development of insecticide resistance.

C. Sulawesi Only a portion of the province of South Sulawesi was surveyed in 1976. We did not visit the district of Enrekang, which is one of the centers of cabbage growing in the highlands. In the areas visited (Table 1 and Figure 2), infestations of cabbage by DBM were moderate to high and no *D. eucerophaga* was found. In these areas, the parasitoid was not released.

2. Rates of parasitization of DBM in West Java Rates of parasitization of DBM in Pacet and Lembang areas were determined in a bi-weekly sampling program from February to August 1975. Third and 4th instar caterpillars were collected and reared on cabbage leaves in the laboratory. The parasitoid cocoons were then counted to determine the rate of parasitization. Most of this sampling was carried out in farmers' fields which were routinely sprayed with insecticides.

The parasitism rates in West Java (Table 2) were about as high as those reported by Vos (1953) in the Pacet area following the establishment of the parasitoid in 1951. The levels of parasitization ranged from 54 to 82%, with an average of 70%. Since Vos (1953) also showed that at these rates of parasitization the parasitoid effectively suppressed its host, it is to be assumed that *D. eucerophaga* acts as an important mortality factor. Moreover, it appears that the parasitoid is well established in the Lembang area as well, parasitizing DBM at rates similar to those found in Pacet. The rate of parasitization in these areas ranged from 37 to 81% with an average of 70.4%, a little higher than that reported by Sastrodihardjo (1974).

1976 to 1981

Although *D. eucerophaga* had been introduced to North Sumatra in 1951/1952 (Vos 1953), we found that the parasitoid had failed to establish and was not found even in the areas where it was first released. This was presumably due to excessive use of insecticides by the farmers in North Sumatra. To overcome this problem, efforts were made to re-introduce *D. eucerophaga* from Segunung (Pacet, West Java) to Brastagi, North Sumatra, in March 1976. Following mass rearing at Kutagadung (Brastagi), the

Table 2. Rates of DBM parasitization by *D. eucerophaga* in various fields around Pacet and Lembang, West Java, 1975[a]

Month	Pacet[a]			Lembang[b]		
	Larvae		Parisitized	Larvae		Parisitized
	collected	parasitized	(%)	collected	parasitized	(%)
February	5	3	60	30	11	37
March	330	179	54	257	175	68
April	238	138	58	78	59	76
May	263	206	78	188	152	81
June	168	131	78	181	138	76
July	195	160	82	167	129	77
August	69	55	80	82	64	78

[a] Locations sampled: Segunung, Gunung Putri and Pasir Cina. [b] Locations sampled: Margahayu and Cikidang. Source: Sudarwohadi and Eveleens (1977).

parasitoid was again released in the vicinity of Brastagi which is a center of cabbage growing areas in North Sumatra (Gurning 1979). These efforts were combined with a selective spraying regime of *Bacillus thuringiensis* Berliner (Bactospeine, Dipel, Thuricide). According to our studies, *D. thuringiensis* is effective against DBM and cabbage-head caterpillar and does not have any detrimental effects on the parasitoid (Sudarwohadi et al 1977).

In October 1981, an intensive survey was made in the cabbage growing areas in North Sumatra to evaluate the status of biological control of DBM by *D. eucerophaga* (Sastrosiswojo 1981). The same methods as described earlier were used. Surprisingly, we found that the parasitoid was widely distributed and has established by itself very well in all of the vegetable growing areas (Figure 3). The rate of parasitization ranged from 64 to 100%, with an average of 82% (Table 3). The parasitoid was also well distributed in other cabbage growing areas where it has never been released, such as in Lintong ni Huta, North Tapanuli, approximately 200 km from the original release area, Brastagi. The rate of DBM parasitism in that location was 82%. Significant progress has been made also in North Sumatra in regulating insecticide applications. The types of insecticide used, dosages, and frequency of sprays have all been reduced. We conclude that the parasitoid is well established and is effective in suppression of DBM population in North Sumatra.

Table 3. Rates of parasitization of DBM by *D. eucerophaga* in various cabbage fields in North Sumatra (October 1981)[a]

District and municipality	Village	Diadegma released/ not released	Rate of parasitization (%)
Tanah Karo:			
Kabanjahe	Raja Payung	released	80.6
	Kutagadung	released	77.8
	Cinta Rakyat	released	100.0
	Merdeka	not released	b
	Tongkoh	released	64.0
Simalungun:			
Silima Kuta	Seribudolok	released	87.5
Tapanuli Utara:			
Lintong ni-Huta	Simanampang	not released	82.0

[a] Source: Sastrosiswojo (1981). [b] No. of larvae sampled were too small, but all were parasitized by *D. eucerophaga*.

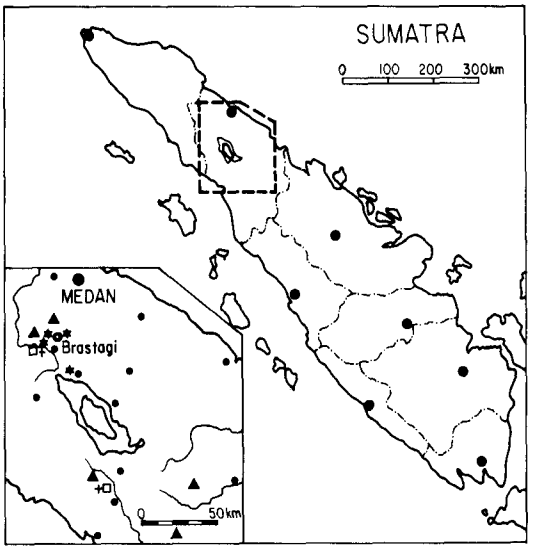

Figure 3.
Distribution of *D. eucerophaga* in North Sumatra (October 1981). ★Released and established. □ + Not released but present.

1982 to 1984

An intensive survey was carried out in October 1983 with the object of determining the current distribution and effectiveness of *D. eucerophaga* as a biological control agent of DBM in West Java (Sastrosiswojo 1984c). Similar research methods to those described earlier were used. During the present study, we visited all cabbage growing areas in the highlands of West Java. The results of a country-wide survey of the present distribution and rates of parasitism by *D. eucerophaga* are summarized in Table 4. Current spread of the parasitoid in relation to earlier releases is indicated in Figure 4.

Results of the extensive survey indicate that *D. eucerophaga* is well established in West Java (Figure 4). The parasitoid also occurs in the highlands, such as in Kuningan and Sukabumi, where it has never been liberated. Both of these vegetable growing areas are relatively newly established as compared with other areas in West Java.

D. eucerophaga has probably a well developed searching ability, for even if the DBM larvae are scarce, the level of parasitism is high (Vos 1953). No information was

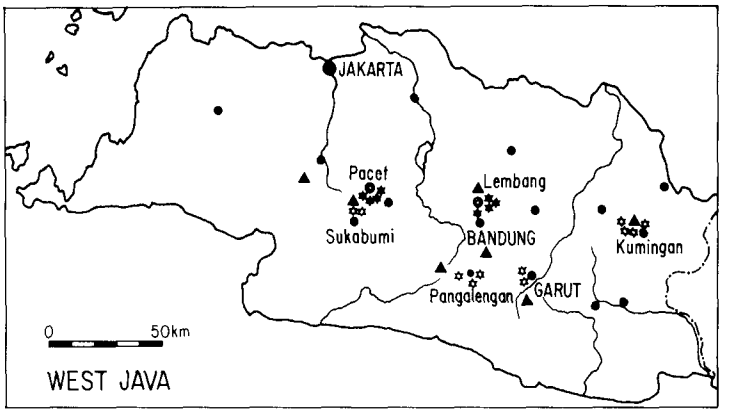

Figure 4. Distribution of *D. eucerophaga* in West Java (October 1983). ★Released, established. ☆Not released but found

Table 4. Rates of parasitization of DBM by *D. eucerophaga* in various cabbage fields in West Java (October 1983)[a]

District and municipality	Village	Diadegma released/ not released	Rate of parasitization (%)
Bandung:			
Lembang	Cibodas	released	76.3
	Langensari	released	33.3[b]
Pangalengan	Warnasari	not released	5.7[c]
	Sukamanah	not released	61.2
Cianjur:			
Pacet	Cipanas	released	88.9
	Cipendawa	released	82.8
Garut:			
Samarang	Samarang	not released	0[c]
	Sukarasa	not released	10.0[c]
Cikajang	Girijaya	not released	16.7
Kuningan:			
Kuningan	Cisantana	not released	77.0
Sukabumi:			
Sukabumi-Utara	Selabintana	not released	50.0
Utara			

[a] Source: Sastrosiswojo (1984). [b] Population of DBM was very low, due to *B. thuringiensis* spray. [c] Population of DBM moderate to very high, ranging from 3.5 to 24.1 caterpillars/plant. DBM problem was very severe.

available in the literature on the migration of the parasitoid. However, we assume that the parasitoid cannot migrate long distances. From our studies, we recorded that *D. eucerophaga* is well established in areas such as in Kuningan and Sukabumi where it has never been released. Presumably cocoons of *D. eucerophaga* or parasitized larvae of DBM were carried on cabbage harvests or cabbage seedlings from one place to another.

The rate of parasitized DBM found in the intensive sampling program in West Java varied considerably, ranging from 0 to 90% (Table 4). It appears that differences in the surrounding vegetation may have contributed to the uneven distribution of the parasitoid. In most places where cabbages were not treated heavily with insecticides, *D. eucerophaga* played an important role in the control of DBM. On the other hand, in some other locations, *D. eucerophaga* did not effectively suppress the DBM population. In these locations, DBM is still a very important pest of cabbage, and may create a serious problem. It is assumed that the reason was the excessive and improper use of insecticides, especially in the Pangalengan and Garut areas.

Following the success in North Sumatra, attempts were made to introduce *D. eucerophaga* into South Sulawesi (Figure 2). During the past ten years or less this province has become a very important cabbage growing area. Farmers in this province are also faced with the insecticide resistance problem. To overcome this problem, *D. eucerophaga* was shipped in 1984 to South Sulawesi from Lembang, West Java. Since work along these lines is still underway, evaluation has not yet been undertaken.

Problems and Prospects for Biological Control of DBM

From the foregoing information it is evident that *D. eucerophaga* is an important biological control agent of DBM in Indonesia, especially in areas where it is well established. As indicated earlier, *D. eucerophaga* could effectively suppress the DBM population in cabbage growing areas. Levels of DBM parasitism were relatively high,

in some places amounting to more than 80%. Although the rate of parasitism cannot always be correlated directly with the success or failure of control of DBM, this component of biological control nevertheless has great potential for developing integrated control programs (van den Bosch and Messenger 1973).

Besides the success of biological control of DBM, results of our surveys have indicated that *D. eucerophaga* is unable to suppress the DBM population to low and non-injurious levels, in some cabbage growing areas. Some possible reasons are discussed here briefly.

Firstly in some areas cabbage fields are rather sparsely distributed (Sudarwohadi and Eveleens 1977). The crop is grown in isolated single plantings, in rotation with other crops like paddy rice. This results in a lack of continuity of host and parasitoid habitat both in space and time. Under these conditions, the demands made on the dispersal capacities of the parasitoid may be too heavy for effective biological control.

Secondly farmers tend to spray a variety of insecticides in a calendar system to protect their crops. Spraying are made at least twice a week, often with disappointing results due to the development of resistance in the target species. Increasing pesticide usage not only increases production costs, but is also a prime cause of biological control failure as most of the insecticides used are toxic to *D. eucerophaga*.

Thirdly most of the growers are not aware that *D. eucerophaga* has already been established in their area and is playing an important role in regulating the population of DBM. Instead of supporting our efforts to conserve and augment the population of the parasitoid, most farmers rely solely on chemical control. It is true, as Stehr (1975) stated, that grower understanding and education is essential not only for any biological control program, but also for an entire pest management program.

At present *D. eucerophaga* has established itself very well in most highland vegetable growing areas of Indonesia, except for South Sulawesi, Irian Jaya, and may be in some newly cultivated areas (Figure 5). This fact encourages us to include this parasitoid as a key component of integrated pest control programs on cabbage. Work along these lines is still under way.

DBM is a notorious pest for its ability to develop resistance against insecticides. Since the early 1950s this insect had already been developing resistance to DDT (Ankersmit 1953) and to other organochlorine insecticides (Tjoa 1959) at Lembang. There are also strong indications that organophosphorus, carbamate, and synthetic pyrethroid

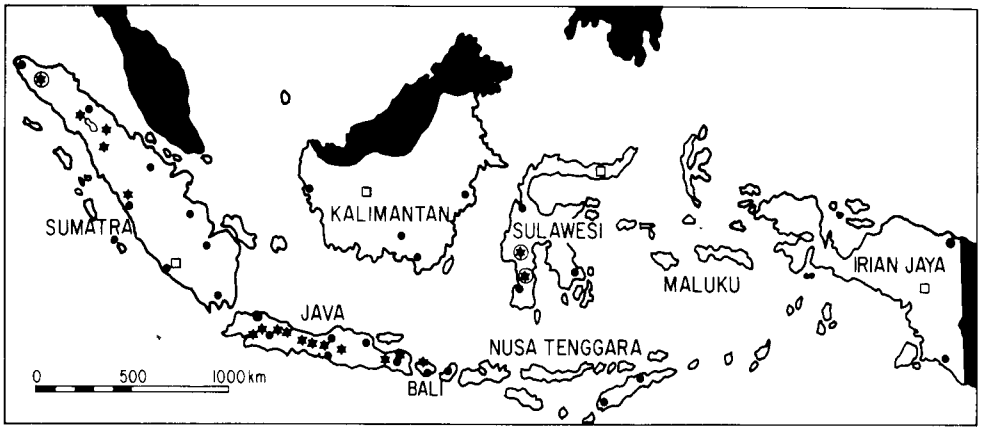

Figure 5. The current distribution of *D. eucerophaga* in Indonesia. ★Parasitoid released and established. ★Parasitoid introduced no evaluation made: □Parasitoid not yet released

insecticides have lost their efficacy against DBM in Indonesia (Soekarna et al 1982, Adiputra 1984). For this reason, we need to put less emphasis on chemical methods. If we must use insecticides they should give satisfactory control of cabbage caterpillars, and be less toxic or non-toxic to *D. eucerophaga*. Results of our studies indicate that a microbial insecticide, *B. thuringiensis*, effectively suppresses the population of DBM and *C. binotalis*, and does not harm *D. eucerophaga* (Sudarwohadi et al 1977, Sastrosiswojo 1984a). A combination of *B. thuringiensis* and cypermethrin for DBM control would have the advantage of 'economic synergism' (Sastrosiswojo 1984b).

The accepted theory of pest management dictates that insecticides should be applied when insect pest populations approach or exceed an economic threshold (Metcalf 1975). In our view an action threshold is more practicable. Insecticides should be applied when pest populations per plant exceed a predetermined level. This approach can be applied over limited areas with similar climatic conditions (Lincoln 1974). Results of our preliminary study indicate that the action threshold for DBM on cabbage in Lembang and Pacet is approximately 0.3 caterpillar/plant (Sastrosiswojo 1983). Selective use of insecticides based on the population of insect pests might be ideal for developing integrated control programs. In this way, *D. eucerophaga* is conserved by applying insecticides to cabbage only if the DBM population reaches the action threshold level. Another benefit of using an action threshold is that the amount of insecticide usage is reduced and the problem of resistance is delayed.

Chiang (1980) stated that the enrichment of natural enemy fauna and flora would be a very useful strategy in integrated pest management. Therefore efforts for conservation and further augmentation of *D. eucerophaga* are being undertaken, such as the use of selective insecticides, estimation of action thresholds and manipulation of cabbage cultivation through intercropping systems. We hope that by implementing these control tactics in a more balanced pest management system we will solve the DBM problem in Indonesia.

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Impact Assessment of *Apanteles plutellae* on Diamondback Moth Using an Insecticide-check Method

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Abstract

Field surveys of parasitoids of diamondback moth, *Plutella xylostella* (L), have indicated that *Apanteles plutellae* Kurdj may have a suppressing effect on the population of this insect. How important the parasitoid really is and to what extent it is beneficial is, however, not exactly known. This was, therefore, evaluated using an insecticide-check method whereby four treatments, each having different selective effects, were compared, viz: Dipel (*Bacillus thuringiensis* Berl, selectively toxic to diamondback moth but not the parasitoid); Sevithion (carbaryl + malathion, which is toxic to the parasitoid but not to DBM); cartap (highly toxic to both host and parasitoid); and an untreated control. Cartap and Dipel treatments had significantly higher yields than either the Sevithion treatment or the control. Sevithion treatment had less yield than the control. Both the control and Dipel treatment had significantly higher *A. plutellae* parasitism. The parasitism rate was least in the cartap treatment while Sevithion had a moderate level of parasitism. Based on these results and on the number of parasitoid cocoons collected from the crop, there was distinct evidence of differential survival and abundance of the parasitoid as well as the diamondback moth adults between different treatments. In caparison with cartap treatment, the diamondback moth adult ratios were 1.9, 8.0 and 47.9 for Dipel, control, and Sevithion respectively. Correspondingly, the parasitoid:host ratios were 3.22, 0.64 and 0.05. These findings, in particular the high adult ratio (47.9) and the extremely low parasitoid:host ratio (0.05) for Sevithion, showed that *A. plutellae* is important and can contribute substantially to the suppression of diamondback moth. That this is so, and that resurgence was not due to hormoligosis or altered physiology of the host plant by Sevithion, was further confirmed in follow-up laboratory investigations.

Introduction

In the Cameron Highlands, control of the diamondback moth (DBM) *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae) by conventional chemical insecticides has so far been the only practice. This unilateral approach and over-reliance on chemicals have resulted in development of insecticide resistance, pesticide poisoning of the farmers, the presence of insecticidal residues in marketable produce, and hazards to beneficial organisms (Henderson 1957, Balasubramaniam 1974, Sudderuddin and Kok 1978, Ooi 1979, Lim 1982). For the foreseeable future, insecticides will continue to remain a powerful and essential tool in DBM management. However, it is necessary that their use be minimized so as to prevent the present trend from reaching a 'disaster phase' (Smith 1969). A prime strategy is to build a broader ecological base that would make

possible the integration of various pest management techniques. Largely because biological control is a natural ecological phenomenon and can potentially provide a relatively harmonious, economical and permanent solution, the consideration of DBM's natural enemies has in recent years been given priority. In consequence, initial surveys in 1973 revealed the presence of a primary endo-larval parasitoid, *Apanteles plutellae* Kurdj (Hymenoptera: Braconidae) (Lim and Ko 1975).

From extensive surveys, *A. plutellae* has been found to be widespread and fairly abundant (Lim 1982). There are indications that it may have a suppressing effect on the population of DBM. However, how important the parasitoid really is and to what extent it is beneficial is not exactly known. There is a need to evaluate this so that priorities may be assessed in attempts to exploit its beneficial role. This seems all the more important since other parasitoid species were observed to be rare (Ooi and Kelderman 1977, Ooi 1979).

In this assessment, the importance and effect of the parasitoid were evaluated by the insecticide-check method. This compares host development and survival in both the presence and the absence of the parasitoid, the latter situation being effected through the selective use of chemical insecticides.

Materials and Methods

The insecticide check method adopted in the present studies compared three chemical treatments (Dipel, cartap, Sevithion) and an untreated control. Dipel, (*Bacillus thuringiensis* Berl was selectively toxic to DBM but not to the parasitoid (Lim 1982). In the case of Sevithion (carbaryl + malathion) the reverse situation was true, while cartap was highly toxic to both the host and parasitoid. Except for Dipel, which was applied at 2.5 g/4.5 l, both cartap and Sevithion were sprayed at 0.1% AI. A total of eight sprays were made beginning two weeks after transplanting and at weekly intervals thereafter. The field design was randomized complete block with three replications. For each treatment, the plot size was 14.3 m x 12.2 m consisting of 23 beds including two outer guard rows. The beds were spaced 0.6 m apart with each bed having 27 plants including two guard row plants at the end. A 0.5 m planting distance was used resulting in a total of 525 plants/plot. Cabbage (cv Constanta F1 Danish) was planted while fertilizer practices closely followed those of the farmers.

Damage was assessed weekly on 10 random plants/replicate. For assessment of injury by the pest, the following damage index (Seaman et al 1963, Williams 1966) was employed:

$$\text{Damage index } (\%) = \frac{(N_0 \times 5) + (N_1 \times 20) + (N_2 \times 60) + (N_3 \times 100)}{N_{0+1+2+3}}$$

where, N_0 = number of plants with score '0' (damage 5% and less), N_1 = number of plants with score '1' (5 to 20% damage), N_2 = number of plants with score '2' (20 to 60% damage), N_3 = number of plants with score '3' (60 to 100% damage), and $N_{0+1+2+3}$ = total number of plants (Figure 1). Following such scoring under normal field conditions, a 10% damage index would correspond approximately to yield loss of 20%, which is unacceptable, while a 20% damage index may result in about 50% yield reduction.

The populations of the larvae and pupae of DBM and cocoons of *A. plutellae* were also recorded weekly from 10 plants/replicate.

For the assessment of host larval survival, 20 larvae/collection/replicate were randomly obtained over a total of nine samplings spread throughout the cropping period.

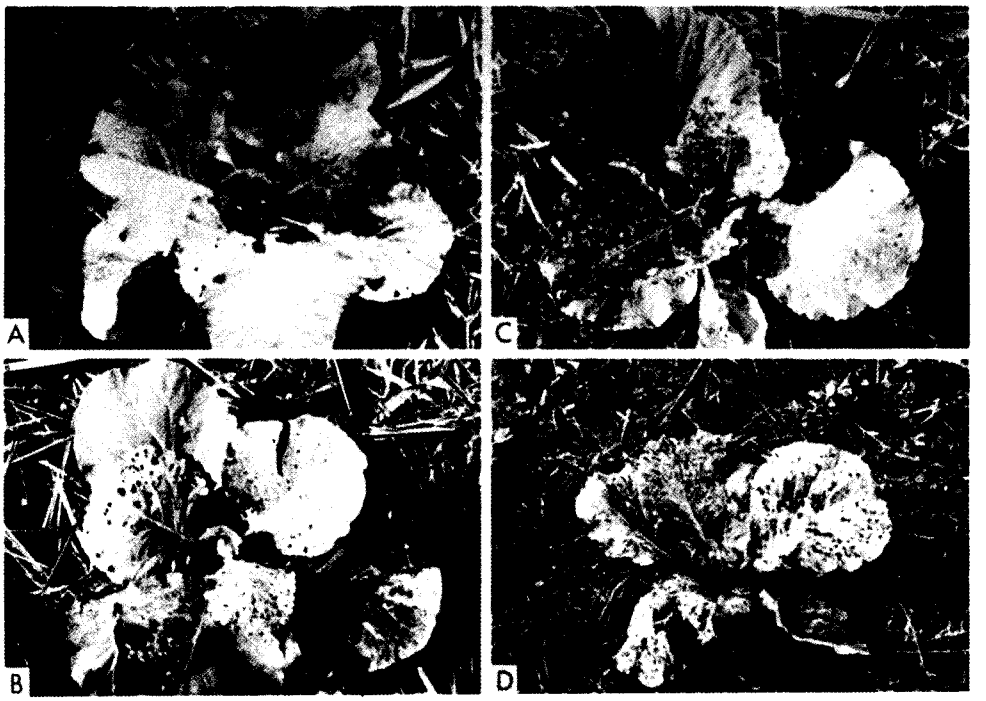

Figure 1. Damage scores of feeding injuries by DBM on cabbages. A = Score '0', damage 5% or less; B = Score '1', damage between 6 and 20%, C = Score '2', damage between 20 and 60%, D = Score '3', damage between 61 and 100%

The larvae collected were maintained in breeding jars until adult host or parasitoid emergence. Survival of the parasitoid cocoons was also similarly examined. This examination was based on 15 cocoons/collection/replicate, and was repeated over nine samplings.

A study was conducted into Sevithion-induced DBM resurgence, using one-month old potted cabbage plants. One group was sprayed with 0.1% AI Sevithion for four consecutive weeks while another, acting as a control was treated only with water. Following the treatment, each plant was enclosed in a net cage (51 cm × 51 cm × 51 cm). For the determination of oviposition rate, three newly emerged and mated DBM females were released into the cage 10 days after the last spray treatment. Every 24 hours for the next five days, the plant was replaced by another which was similarly treated. All eggs deposited on each plant were counted. Throughout the study, a water and 30% honey mixture was provided as food to the adult insects. The experiment was replicated five times.

In the determination of developmental period, 20 freshly-laid (deposited within the first 24 h) eggs from each replicate were isolated. These were transferred to breeding jars, and on hatching were individually reared to the adult stage. The length of each developmental stage was recorded, while the sex of the emerging adults determined. Studies on fecundity and longevity of the first generation adults were made by isolating 10 freshly emerged females from each replicate of the treatment group, as well as from control. These were provided daily with a 30% honey-water solution fed through a wick as well as fresh *Brassica rapa* leaves of similar size for oviposition. All eggs deposited daily were recorded until the females died.

As distinct from the above study, which attempted to explore possible effects of Sevithion indirectly through treatment of the host plants, a parallel and separate experiment was also conducted to determine the effect via direct treatment of the insect. The overall procedure was in general similar to that of the previous study, except that instead of the plants 2nd-instar larvae of DBM were exposed to the insecticide. Only those surviving the treatment and completing the life cycle were considered. For the control, larvae were sprayed with water only.

Results

Field assessment

Results of the field trial of the insecticide-check method (Table 1) showed that the cartap and Dipel treatments gave significantly higher yields than either Sevithion treatment or the untreated control. Between cartap and Dipel, although the former gave a slightly higher yield, the difference was not significant. In the Sevithion treatment the yield was significantly less than in the control, suggesting that insecticidal applications need not necessarily increase crop yields. Our study showed that in some cases insecticidal applications not only involved additional cost, but failed to provide protection of the crop from DBM.

Table 1. DBM damage and cabbage yield as affected by various insecticidal treatments in the Cameron Highlands

Treatment	Head formation		Mean damage index (%) to heads			Mean weight	Yield/plot
	Mean No.	%	Marketable	Non-marketable*	Total	(kg)	(kg)[a]
Dipel	439	83.6	9.43	20.77	14.65	1.49	415.6a
Cartap	429	81.7	6.80	13.33	9.75	1.59	431.6a
Sevithion	330	62.9	13.90	24.43	19.90	1.32	290.6c
Control	368	70:1	11.27	25.73	16.72	1.39	356.2b
LSD (0.05)						ns	48.2

[a] Means in vertical column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test

The yield differences for the various treatments were apparently related largely to successful head formation as well as individual head weight. For the latter, although no significant difference existed among the different treatments the ranking in magnitude of the mean head weight closely paralleled that of the overall crop yields, thus the cartap treatment had the highest, followed by Dipel, the control, and Sevithion (Table 1). In terms of head formation, the Dipel treatment had the highest number of heads formed per unit area. Although the head weight was less than that for cartap the higher number of head formed apparently compensated to some extent in raising the overall yield in the Dipel treatment (Table 1). In the Sevithion treatment and the control, significantly fewer heads were formed, thus depressing further the overall yields.

Assessment of damage by DBM clearly showed that the damage inflicted was higher on non-marketable heads, suggesting that reduced crop yields are both closely associated with and dependent on the extent of DBM infestations. Within both categories of marketable and non-marketable heads, much lower damage occurred in the cartap and Dipel treatments. This trend was observed in assessments throughout the cropping period (Figure 2) as well as at harvest (Table 1). Also, in both cartap and Dipel treatments, the number of plants showing high damage scores was distinctly lower.

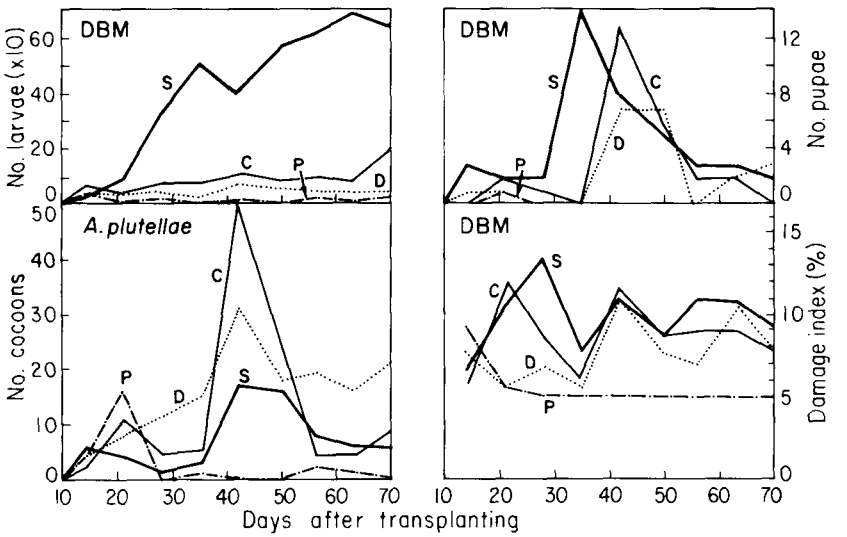

Figure 2. Development of DBM, its parasitoid (*Apanteles plutellae* Kurdj), and crop damage as influenced by insecticidal treatments, D = Dipel, P = cartap, S = Sevithion, and C = untreated control

Cartap and Dipel treatments had much lower levels of DBM infestation while Sevithion and the control exhibited extremely high damage (Table 2). Of the larvae that escaped *A. plutellae* parasitism, the numbers entering the pupal stage were highest in the control, followed by Sevithion, cartap and Dipel treatments. This trend was also noted for the rate of adult emergence from the surviving pupae. From these results and the relative abundance of the larvae in the field (Table 2), it is evident that a much higher number of larvae reached the adult stage in the Sevithion treatment and the control than in the cartap or Dipel treatments. These were respectively 47.9 and 8.0 times that of cartap. With Dipel, the number was nearly double that of cartap, although very much less than that of the Sevithion and the control.

In general, pupal population in the field showed a similar trend to that of the larvae. This was clearly evident from the population development observed in the periodic samplings as well as from the overall total (Figure 2).

Both the control and Dipel treatments had significantly higher levels of parasitoid attack. The parasitism rate was least in the cartap treatment, while the Sevithion treatment resulted in a moderate level of parasitism (Table 3). Higher numbers of parasitoid cocoons could be collected from the untreated control and the cabbage sprayed with Dipel; the number from the Dipel treatment was approximately six times higher than that from the cartap treatment (Figure 3). Such differential survival and abundance of the parasitoid among the different treatments not only strongly indicates the adverse effects of both cartap and Sevithion, but also the selectivity of Dipel for the parasitoid. These differential effects were also clearly reflected in the rate of parasitoid emergence from field-collected cocoons, for which rates of 69.4%, 67.2%, 55.6% and 45.6% were recorded for the control, Dipel, Sevithion, and cartap treatments, respectively. This order of parasitoid emergence was also observed for cocoons which developed from field-collected host larvae (Table 3). From these figures, and from the relative abundance of parasitoid cocoons in the field, it was concluded that a very much higher number of adult parasitoids occurred and survived in the fields sprayed with Dipel and in the

Table 2. Survival and relative abundance of the DBM as affected by various insecticidal treatments on cabbages in the Cameron Highlands

Treatment	No. of DBM			Surviving larvae becoming pupae		Surviving pupae becoming adults		Larvae initially collected becoming adults (%)	Field larval Population			Adult ratio (over cartap treatment)
	Initially collected[a]	Suriving parasitism							No. per 270 plants	Adult equivalent		
		No.	%	No.	%	No.	%			per 270 plants	per ha[b]	
Dipel	540	255	47.22	71	27.84	55	77.46	10.19	400	41	5,448	1.9
Cartap	289	188	65.05	66	35.11	59	89.39	20.42	109	22	2,924	1.0
Sevithion	540	320	59.26	156	48.75	147	94.23	27.22	3869	1053	139,932	47.9
Control	540	268	49.63	132	49.25	119	90.15	22.04	797	176	23,388	8.0

[a] From nine samplings of 20 larvae/sampling/replicate between 19 February and 16 April, 1975. In the cartap treatment, the data were based only on 289 larvae as there were hardly any larvae after 12 March 1975. [b] Potentially, one hectare would contain 35,880 cabbage plants.

Table 3. Survival and relative abundance of the DBM parasitoid, *A. plutellae* as affected by various insecticidal treatments on cabbages in the Cameron Highands

Treatment	No.of DBM larvae			No. (%) of parasitoid adults emerging	Parasitoid population in the field			Adult ratio (over cartap treatment)	Parasitoid: host ratio
	Initially collected[a]	Parasitized			Cocoons per 270 plants	Adult equivalent			
		No.	%			Per 270 plants	ha[b]		
Dipel	540	285	52.78	262 (91.93)	143	132	17,541	7.8	3.22
Cartap	289	101	34.95	73 (72.28)	24	17	2,259	1.0	0.77
Sevithion	540	220	40.74	180 (81.82)	66	54	7,176	3.2	0.05
Control	540	272	50.37	261 (95.96)	118	113	15,016	0.7	0.64

[a] From nine samplings of 20 larvae/sampling/replicate between 19 February and 16 April 1975. In the cartap treatment, the data were based only on 289 larvae as there were hardly any larvae after 12 March 1975. [b]Potentially, one hectare would contain 35,880 cabbage plants.

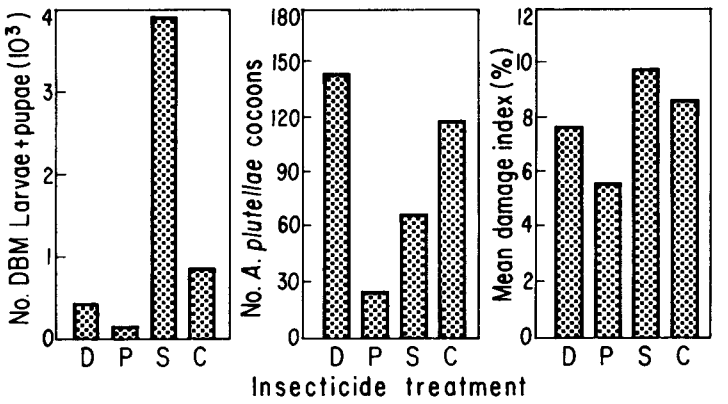

Figure 3. Total DBM and *Apanteles plutellae* count and crop damage as influenced by insecticidal treatments, D = Dipel, P = cartap, S = Sevithion, C = untreated control

untreated control. These numbers were respectively 7.8 and 6.7 times higher than those recorded for cartap-treated fields (Table 3). The figure for the Sevithion treatment was only about 3.2 times high.

Sevithion effects on development and reproduction in DBM

Indirect exposure through the host plant Sevithion had no significant effect on DBM oviposition. Nevertheless, the number of eggs laid by the moths reared on treated plants was higher in several cases when compared to the control. Several other parameters were unaffected; these included the developmental period, the sex ratio, as well as the longevity and fecundity of the first generation females. The mean fecundities of the control and Sevithion-exposed females were 304 ± 17.6 eggs and 254 ± 21.3 eggs respectively, and their mean longevities 13.8 ± 1.0 days and 14.0 ± 1.4 days. Both differences were statistically non-significant.

Direct exposure to sub-lethal dose There were no statistical differences between fecundity of the Sevithion-exposed and unexposed DBM females in both first and second generations. For the first generation the mean fecundities were 96.8 ± 11.6 eggs and 97.7 ± 17.3 eggs/female for treated and control respectively, while for the second generation the number of eggs was 48.0 ± 17.3 and 54.7 ± 7.8/female respectively. Although the mean fecundity was much lower in the first generation, comparisons made for first and second generations in treated adults showed no statistically significant difference. For the controls the difference was, however, significant.

Studies on mean longevity also revealed little difference between the treated females and those in the control. For first generation females, mean longevity was 21.0 ± 1.2 days for the treated and 14.1 ± 1.3 days for the control. For second generation, longevity was 14.3 ± 1.1 days in the treated and 15.0 ± 1.2 days in the control. Similarly, there was little difference in the mean longevity of males in both first and second generation.

Discussion

Previous field observation as well as experimental studies have pointed to *A. plutellae* as one of the more important parasitoids of DBM. In general, a somewhat

similar conclusion was also obtained and confirmed by findings from the present chemical exclusion studies, wherein a much poorer crop yield resulted from higher infestations of DBM due to the selective destruction of *A. plutellae* by Sevithion. Because of Sevithion's selective toxicity to the parasitoid, a shift to an extremely small parasitoid-host ratio (0.05) resulted, leading to a rapid upsurge of DBM (Table 3). On the other hand, the ratio greatly increased to 3.22 in favor of the parasitoid when Dipel was applied. In the case of the cartap treatment there was hardly any significant change in the parasitoid:host ratio of 0.77 from that of untreated control (0.64). These findings clearly revealed that in a host-parasitoid system, the ratio of their respective numbers may be altered in various ways by the use of different insecticides, and depending on direction and degree these changes can either be favorable to the parasitoid or pose a greater hazard to it. Such findings evidently suggest that the correct choice of chemical to be used could be crucial for any effective pest management of DBM, and that the choice should be made very carefully.

In the field trial, the accelerated increase in DBM population in the Sevithion treatment may well also be due to an altered plant physiology. This could result from improved nutrition as in the case of phytophagous mites (Chaboussou 1965). Alternatively, it may be due to hormoligosis (Locher 1958, Luckey 1968, Dittrich et al 1974), wherein Luckey (1968) conceptualized that subharmful quantities of any stressing agent will be stimulatory to an organism by providing it (with) increased sensitivity to respond to changes in its environment and increased efficiency to develop new or better systems to fit a suboptimum environment. In the present studies, no significant differences were observed for all the parameters considered (developmental period, fecundity, adult longevity and sex ratio), showing conclusively that neither hormoligosis nor an improved nutritional basis via an altered physiology of the host plant were responsible for the observed effects. With these factors ruled out, it thus follows that the resurgence of DBM following Sevithion treatment could only logically be attributed to the selective removal of *A. plutellae*. The vast increase in DBM population following the Sevithion treatment furnishes proof of the parasitoid's controlling power and potential. However, the control exerted remained only partial. This is suggested by the fairly high infestations in the untreated control, where the parasitoid's activity was undisturbed, as well as by the results of the Dipel and cartap treatments where these chemicals assisted as supplementary measures to provide effective control.

From investigations into the adverse effects of Sevithion on *A. plutellae*, it was noted that these effects, although substantial, could not exterminate completely the parasitoid population. Thus the total extent of host increase was not fully expressed in the chemical exclusion studies because the parasitoid was not completely eliminated, and so may have continued to produce some effect in limiting DBM. In this instance *A. plutellae* was probably responsible for the observed lower host level. What population level the host might achieve in the complete absence of the parasitoid remains unknown.

The effectiveness of *A. plutellae* was clearly discernible even though the insecticidal-check treatment was carried through only one crop season. Although quite evident, the resurgence effect was not as spectacular as in other parallel studies, such as in the biological control exerted by the parasitoid *Aphytis maculicornis* (Masi) on the infestation of olive scale insect (*Parlatoria oleae* Colvee). In that case, the infestation occurring under conditions of undisturbed parasitoid activity, when compared with the exploded infestations characteristic of DDT-caused suppression of natural enemy activity, had ratios of initial to final densities of 100-fold and 1000-fold (DeBach and Huffaker 1971). Similar studies involved the purple scale insect *Lepidosaphes beckii* (Newm) which is parasitized by *Aphytis lepidosaphes* Compere. Here the selective check-insecticide, endrin, gave an increase in host population over a three-year period from an initial density of 174 to one of 20,615 (DeBach and Huffaker 1971). Such an impressive difference

is probably also obtainable with Sevithion should the period of exposure be greatly extended. That this may be so is strongly suggested by the experience of DeBach and Huffaker (1971) who noted that the biological control potential from established enemies cannot be accurately evaluated in study plots which have not gone without major chemical pesticide treatments for significant periods.

It is recognized that the insecticide-check method employed in the present study may have shortcomings. Nevertheless, the findings clearly demonstrate that the parasitoid can contribute significantly to the control of DBM. This is now firmly established, and should convince critics and sceptics who still have doubts about the beneficial role of the parasitoid.

Although *A. plutellae* has a definite role in the management of DBM, it is important to recognize that its full impact is often affected by several factors, both physical and biological. Among the latter are the parasitoid's behavior (foraging, migration tendency for example), its hyperparasitoids (Lim 1982), the diseases of the host, and the presence of other competitive parasitoids. All these factors merit serious and full consideration in determining the contributory potential of *A. plutellae*, and for its successful exploitation in the control of DBM.

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Pathology and Morphogenesis of a Granulosis Virus of the Diamondback Moth

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Abstract

In 1970 a granulosis virus (GV) was found to infest diamondback moth (*Plutella xylostella* (L) larvae in Aichi Prefecture in Japan. GV infection initially causes swelling of each segment and a series of changes in color from the green of healthy larvae to a dark discoloration at the time of GV-induced death. Body weight increases as the disease progresses. The disease occurs in early summer and is practically absent in winter. The incubation period varies from 2 to 16 days depending upon rearing temperature, the higher the temperature the lower the incubation period. GV of diamondback moth was not infectious to several other important lepidopterous pests. The author describes various pathological changes in host cells, the morphology of the virus, and cytopathological details. Multiplication of GV takes place in the cytoplasm of the cells of fat body, Malpighian tubules, brain, and epidermis.

Introduction

Infestation of crucifers by larvae of the diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae) is a serious problem in Japan. During a survey of infectious disease agents of DBM, larvae infected with granulosis virus (GV) were found in a cabbage field in Aichi Prefecture (Asayama and Osaki 1970). This was the first record of a virus disease of DBM occurring in nature. This paper deals with the progress of studies of GV in DBM.

Symptoms of Granulosis Virus Infection

The first symptom of GV infection is swelling of each larval segment (Figure 1). At an advanced stage of infection, the larval body color changes to pale green, pale yellow green, or pale yellow, in contrast to the dull green of a healthy larva. During this process, the diseased larva appears larger and body weight increases to 1.5-2.0 times that of a healthy larva (Figure 2).

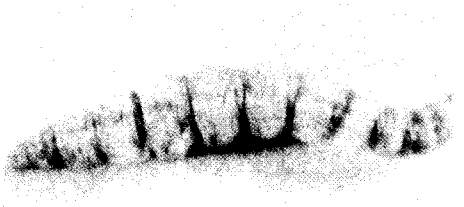


Figure 1.
External symptoms of granulosis virus infection of DBM

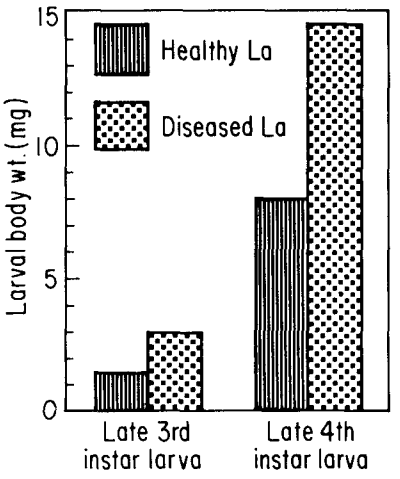


Figure 2.
Comparison of larval body weights between granulosis virus-infected larvae and healthy larvae

The integument of the moribund larva ruptures quite easily and a turbid fluid flows out from the disintegrated integument. Dead larvae become flaccid and the body color is dark.

Pathological Properties

GV-infected larvae often migrate to the top of the cabbage plant, where they attach themselves to the cabbage leaf and die in a hanging position (Figure 3). Under natural conditions GV infection increases in early summer but decreases in the winter.

Pathological changes in GV-infected larval cells show the following process. In the early stage of GV infection, the nuclei of fat body cells swell and clump of the GV capsules appear in the cytoplasm. In the later stages of infection, fat body cells become highly hypertrophic and many vacuoles occur in the cytoplasm. Finally, the boundary of the nuclear membrane becomes obscure, the cytoplasmic constituents disintegrate, and the infected cells become loosely connected with each other by the cell membranes.

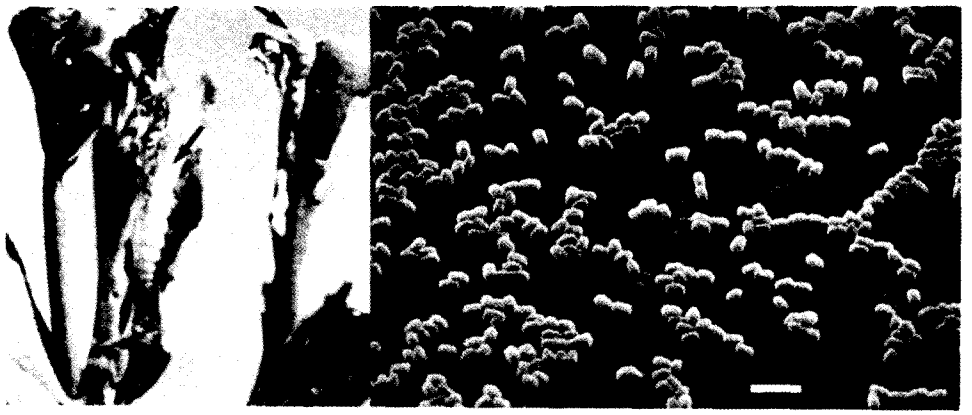


Figure 3. (left). Granulosis virus-infected larvae hanging from the top of cabbage plant

Figure 4. (right). Scanning electron micrograph showing normal shape of capsules isolated from the diseased larvae. Bar = 1 μm

The length of incubation period is influenced by the rearing temperature. Third instar larvae showed typical symptoms of the granulosis 9-16 days after inoculation at 14°C, 6-7 days at 18°C, 3-6 days at 22°C, 2-6 days at 26°C and 2-4 days at 30°C. Granulosis may also be induced by dipping the larvae in 0.2-0.8 μg/ml endrin solution for few minutes.

In peroral infection experiments, the DBM GV was not infectious to common cabbageworm, *Pieris rapae crucivora*; beet worm, *Plusia nigrisigna;* mulberry caterpillar, *Mamestra illoba*; tobacco cutworm, *Spodoptera litura*; common cutworm, *Agrotis fucosa*; or silkworm, *Bombyx mori.*

Virus Morphology

The normal inclusion body (capsule) was ovocylindrical, 411 ± 17 nm long and 240 ± 13 nm wide (Figure 4). The virion (enveloped nucleocapsid) was 260-280 nm long and 70-100 nm wide. Matured capsules were surrounded by an epicapsular layer.

Abnormally shaped capsules were classified under the following categories (Asayama 1976a): (1) Capsule shape abnormal but inner structure of virion normal. Cubic capsules (Figure 5) and agglomerated capsules (Figure 6) belong to this group. (2) Outer form of capsule is normal, but no nucleocapsid is occluded in the capsule (Figure 7 d). (3) Elongate capsules. There are four types of elongate capsules occluding; (a) no nucleocapsid (Figure 7 e), (b) long nucleocapsid (Figure 7 f), (c) excessively encapsulated virion but of normal size (Figure 7 g), and (d) two capsules connected to each other (Figure 7 h,i).

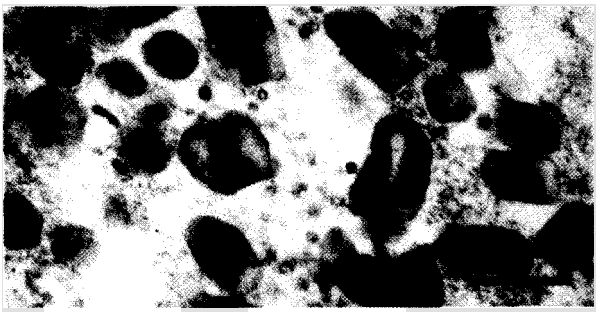


Figure 5.
Formation of cubic type capsules in the Malpighian tubule cells infected with granulosis virus. Bar = 0.5 μm

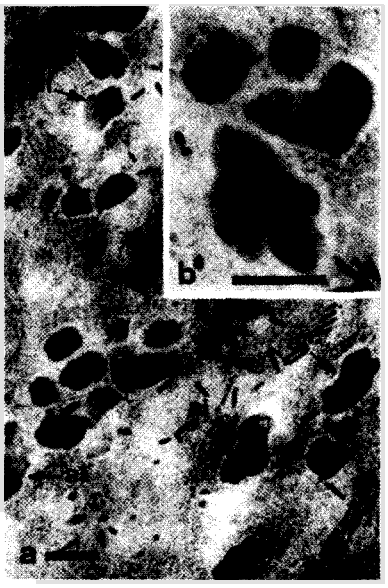


Figure 6.
right a. Formation of agglomerated inclusion (ai) bodies in fat body cells infected with granulosis virus. b. Enlarged view of agglomerated inclusion body. Bar = 0.5 μm

Multiplication sites and Morphogenesis

Multiplication of DBM GV occurs in the cytoplasm of fat body cells, Mulpighian tubules, brain, and epidermal cells. Virus multiplication was not observed in the cuticle

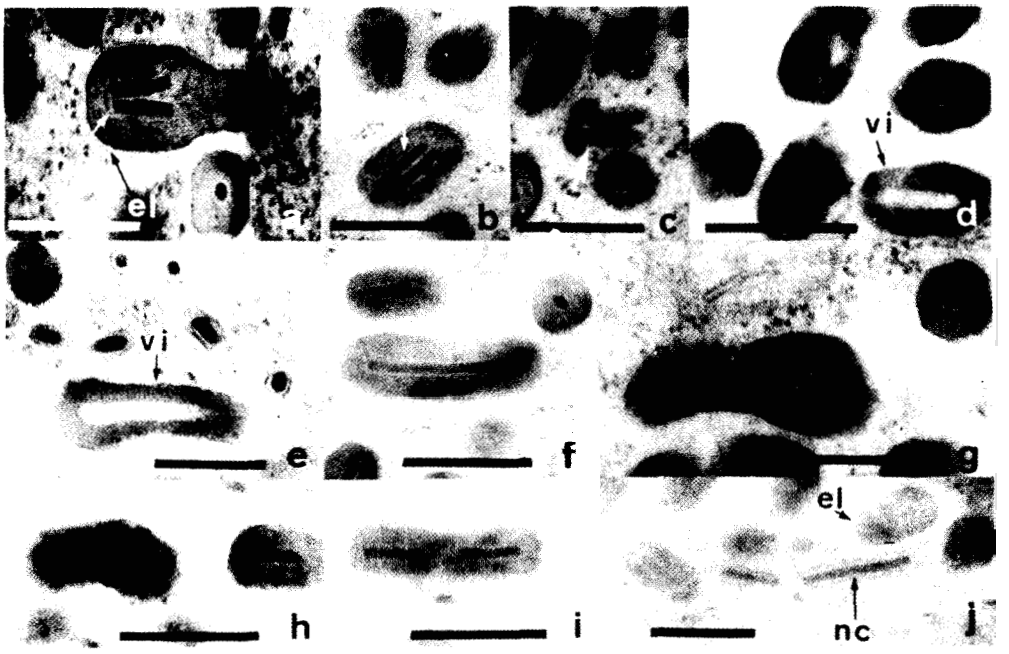


Figure 7. Inner structures of capsules of different shapes. a-c; two nucleocapsids (nc) arrayed side by side within a capsule. d; vesicular inclusion body (vi). e-i; elongate capsule. j, long nucleocapsid (nc) and epicapsular layer (el). Bar = 0.5 μm

layer of the integument, nor in goblet and columnar cells of the mid gut, tracheal matrix, muscules, or silk glands (Asayama and Inagaki 1975b, Asayama 1976b).

The sequence of morphogenesis of the GV in fat body cells of DBM larva was as follows (Asayama 1975a): (1) Appearance of nucleocapsids associated with the endoplasmic reticulum (Figure 8). (2) Regular stacking array of nucleocapsids (3) Dispersal of nucleocapsids from the cluster to the cytoplasmic matrix. (4) Envelopment of nucleocapsids by a membrane which originates from *de novo* membrane morphogenesis in the cytoplasmic matrix (Figure 9). (5) Encapsulation and (6) Completion of capsule formation with epicapsular layer (Figure 10). Figure 11 shows a diagrammatic representation of sequence of morphogenesis of DBM GV.

There was no difference in the sequence of virus morphogenesis between GV and nuclear polyhedrosis virus (NPV). The sequence was as follows: (1) Protrusion of nucleocapsids, (2) morphology of stacking array of nucleocapsids, (3) dispersal of nucleocapsids mass, (4) envelopment, (5) incipient deposition of the inclusion body protein on the enveloped nucleocapsid, (6) formation of inclusion body (capsule or polyhedron), and (7) formation of inclusion body membrane (epicapsular layer or polyhedral membrane) (Asayama 1982).

The enveloped nucleocapsid of DBM GV was distinguishable by the presence of a spicular structure at the posterior end of enveloped nucleocapsid. However, no marked structure was observed at the anterior end of enveloped nucleocapsid. Deposition of capsule protein started from the anterior part of the enveloped nucleocapsid.

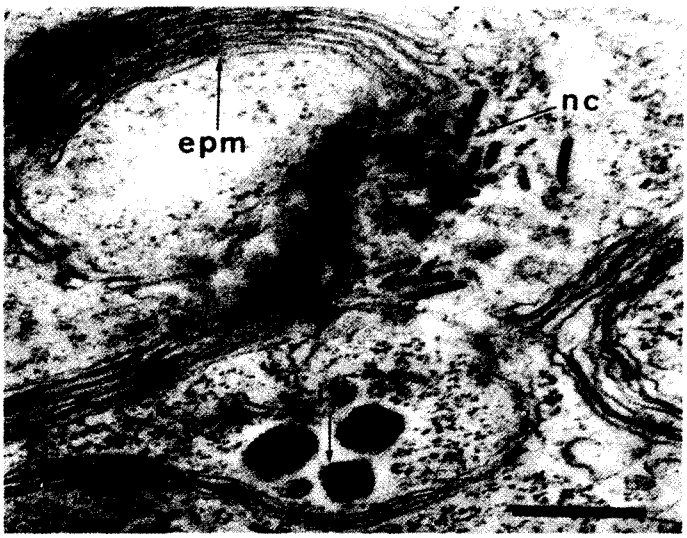


Figure 8. Protrusion of nucleocapsids (nc) associated with the endoplasmic reticulum (epm) within the cytoplasm. ib = inclusion body. Bar = 0.5 μm

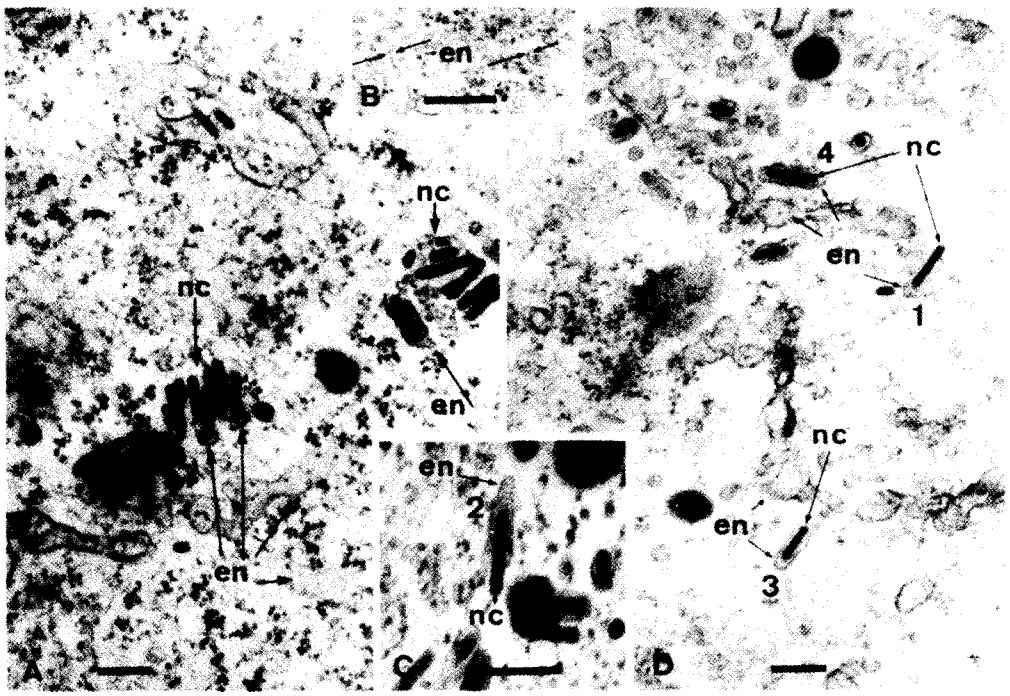


Figure 9. Formation of envelope (en) and envelopment process (1-4) of nucleocapsid within the cytoplasm. Bar = 0.25 μm

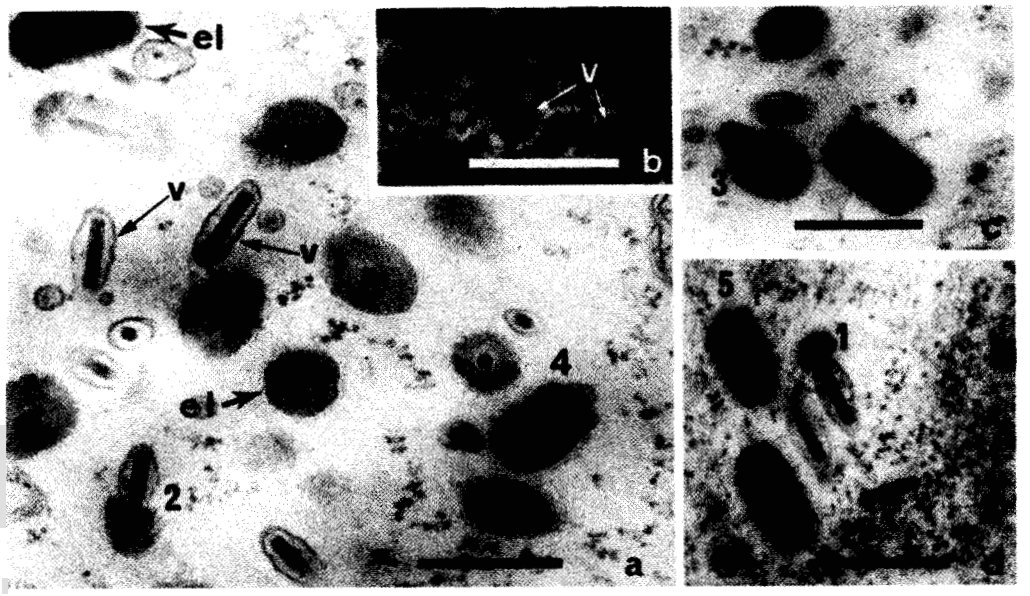


Figure 10. Encapsulation process (1-5) of the virions (v) within the cytoplasm. el = epicapsular layer. Bar = 0.25 μm

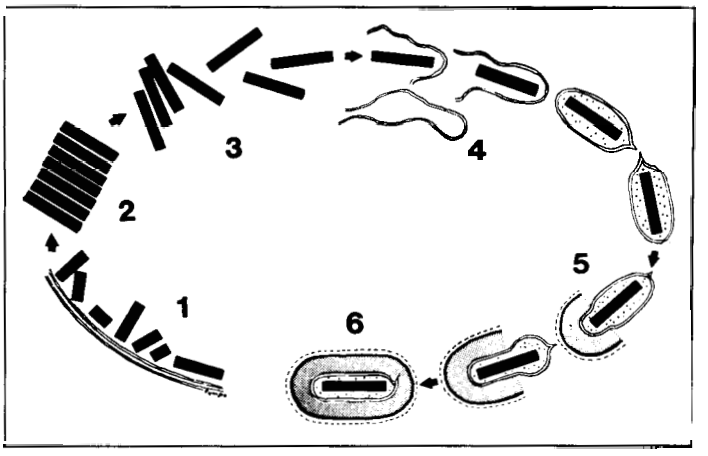


Figure 11. Diagrammatic representation of sequence of GV morphogenesis in fat body cells of DBM larva. (1) Appearance of nucleocapsids, (2) regular stacking array of nucleocapsids, (3) dispersal of nucleocapsids, (4) envelopment, (5) encapsulation, and (6) completion of capsule formation

Cytopathology

Fat body cells of GV infected DBM larvae showed hypertrophy of nucleus, protrusion, subsidence, and partial disappearance of nuclear membrane. However,

appearance of virions within the nuclear matrix was not confirmed. Mitochondria of such cells changed into balloon-shaped structures with fragmented cristae. The endoplasmic reticulum exhibited multilayered and whorl shaped figures (Asayama and Inagaki 1975a). In advanced stages of GV infection, these disintegrated cell organelles dispersed in the cytoplasmic matrix (Figure 12).

Homogeneous fine granules appeared inside the curved endoplasmic reticulum. Ring-shaped structures associated with the endoplasmic reticulum were also observed in the cytoplasm of GV-infected cells. However, these structures disappeared due to the degeneration of endoplasmic reticulum. Compact and clumped masses appeared in the area of sequestration of cell organelles.

Characteristic tubular structures were also observed in the cytoplasm of GV infected cells (Asayama 1975b). These structures were 35-90 nm in width and were randomly branched in two to four directions (Figure 13). These structures proliferated at the site of GV capsule formation. However, they were not connected with virions or capsules. These tubular structures aggregated to form clusters of 6-8 μm in length and 3-4 μm in width in the GV infected cells.

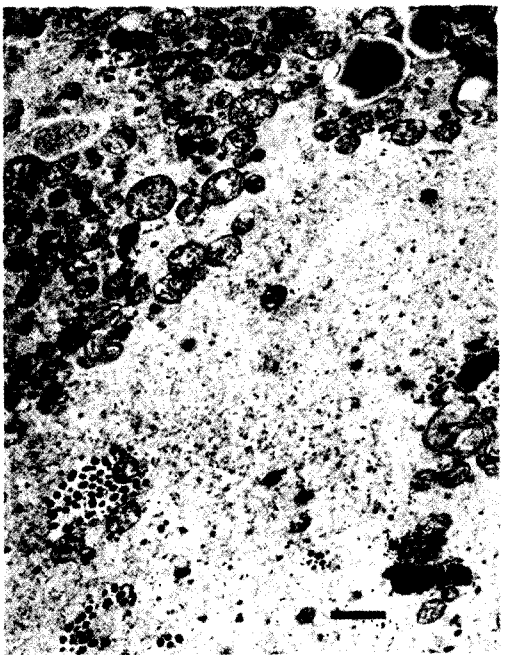
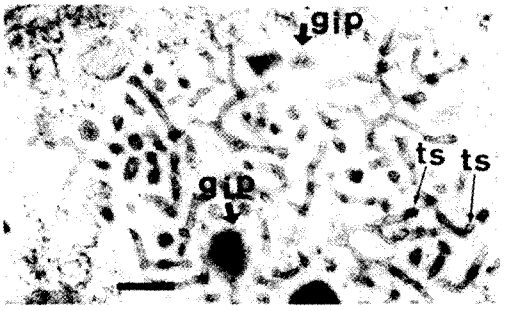


Figure 12.
GV-infected cells showing the cytopathological changes in cell organelle. Bar = 2 μm

Figure 13.
Proliferation of the tubular structures (ts) in the GV-infected cells. gip = granular inclusion body protein. Bar = 0.25 μm



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The Control of Diamondback Moth with Thuricide

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Abstract

Thuricide, a *Bacillus thuringiensis* formulation, is active against more than 200 lepidopterous species in their larval stage. Best efficacy is obtained when Thuricide is applied at hatching time and/or on 1st to 3rd larval instars during their intensive feeding period. Since Thuricide must be eaten by the insect to be effective, thorough leaf coverage is essential for best results. Thuricide HP is used in most areas of Asia where diamondback moth (*Plutella xylostella* L) is a serious pest. In our trials in Malaysia, Indonesia, India, and Australia, this product has given control of diamondback moth comparable to or better than standard organophosphorus insecticides. Thuricide has no adverse effect on hymenopterous parasites of diamondback moth.

General Aspects

Introduction

Insect pathogens are microorganisms that kill insects. They may be bacteria, fungi, protozoa, or viruses. They may kill by infecting the insect and causing a fatal disease, or they may produce a toxic chemical that poisons the insect. Since pathogens do kill insects, but have a limited spectrum of insecticidal activity, they offer the possibility of selective insect control. *Bacillus thuringiensis* Berliner var *kurstaki* (*Bt*), the best known and most widely used pathogen, produces a toxin that attacks larvae of many lepidopterous species.

Thuricide

Thuricide is a biological insecticide, the active ingredient of which is based on *Bt*. It is only active against the larval stages of Lepidoptera, which comprise many economically important insect pests. It is selective against lepidopterous larvae and has no harmful effects on humans, domestic animals, honeybees, wildlife, fish, and predator and parasitic insects. Due to its specificity, Thuricide does not disrupt the natural balance between pests and beneficials.

This product is exempt from tolerance requirements in the United States and other countries for all recommended uses. It does not leave harmful residues.

Biological Action

Thuricide acts specifically against species of Lepidoptera. Only larvae are susceptible, whereas eggs or adults are not affected. Thuricide is a stomach poison and has no contact action. Larvae feeding on the treated plants stop feeding within a short

time (less than two hours) after the ingestion of a lethal dose. The death usually occurs within three to five days during which there is no further feeding.

Insect resistance

The build-up of resistance to *Bt* among target insects has never been observed in the field even though it has been used throughout the world for more than 25 years. A recent report (McGaughey 1985), however, does indicate the possibility of storage insects becoming resistant to *Bt*. DBM has not shown any resistance to *Bt*.

Biological Properties

The biological properties of *Bt* have been studied worldwide in laboratory and greenhouse tests, as well as numerous field trials, which were conducted by our own research and development organizations, and by other investigators or government institutions.

Spectrum of activity

More than 200 lepidopterous species in their larval stages were found to be susceptible in some degree to *Bt*. Best efficacy is obtained when Thuricide is applied at hatching time and/or on 1st to 3rd larval instars during the intensive feeding period. Since Thuricide must be eaten by the insect to be effective, thorough leaf coverage is essential for best results.

Crop safety and residual efficacy

Thuricide does not injure foliage or taint the produce when applied as directed. *Bt*, a naturally occurring microorganism, is commonly found in the environment. A commercial application of this product may significantly increase the local density of the bacterium, but this density slowly returns to its natural, low level equilibrium, depending on environmental conditions. Under average field conditions, Thuricide normally retains residual effectiveness for 4 to 10 days. Reapplication depends mainly on the growth of the crop and the population dynamics of the pest.

Effect on beneficial insects

No adverse effect on beneficial arthropods, predators or parasites has been observed up to now in all laboratory tests and field experiments with Thuricide. The major species against which Thuricide was tested are shown in Table 1. This is of particular advantage for control programs of forest pests and others where it is desirable to maintain a natural balance of beneficials to suppress the resurgence of damaging insects.

Safety Data

Since the active ingredient of Thuricide is a living organism, safety assessment has included investigations of infectivity and persistence, in addition to classical toxicological tests. No mortality, infectivity, irritation, sensitization reaction, or any topical response, was observed in any exposure which could be attributed to *Bt* itself or to formulation ingredients.

Table 1. Beneficial arthropods against which Thuricide has been tested[a]

Class Order	Family	Genus	Common name
Arachnida	—	—	Spider species
Insecta			
Heteroptera	Anthocoridae	Orius	predaceous bugs
	Lygaeidae	Geocoris	big eyed bugs
	Nabidae	Nabis	damsel bugs
	Reduviidae	Zelus	assassin bugs
Neuroptera	Chrysopidae	Chrysopa	lacewings
Coleoptera	Coccinellidae	Hippodamia	lady bird beetles
	Melyridae	Collops	soft-winged flower beetles
Hymenoptera	Trichogrammatidae	Trichogramma	parasitic wasps
	Vespidae	Polistes	paper-nest wasps
	Apidae	Apis	honey bees

[a] Data from Thuricide Technical Bulletin, Sandoz Ltd, Basle, Switzerland.

To ensure the purity of each Thuricide production batch as well as the continued safety to man and the environment, quality control screens including intraperitoneal injection toxicity/infectivity tests in mice, immunoassay, are routinely performed. Because of this safety record, Thuricide may be used on crops up to harvest.

Thuricide Trials in Various Countries

Malaysia

In the lowlands, Mohamad et al (1979) used Thuricide HP along with three chemical insecticides to control diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), on cabbage. A total of six applications were made at seven-day intervals, starting two weeks after transplanting. A randomized complete block design with 4 x 13 plant replicates per treatment was employed. Assessment was done by pre-spray counting of the larvae on every third plant of each treatment, totalling five plants per plot. Leaf damage was assessed weekly, commencing at seven-week old plants.

All insecticides reduced the population of DBM larvae and foliage damage compared to the check plot (Table 2). In this trial, Thuricide was evaluated at half of the normally recommended dosage rate. At full rate, it is expected to give better DBM control. There was no statistically significant difference in yield obtained among the insecticide treatment. However, these yields were more than twice as much as the untreated plots.

Table 2. Efficacy of insecticides against DBM on lowland cabbage in Malaysia[ab]

Insecticide	Rate kg AI/ha	No.DBM larvae/ 10 plants	Foliage protection index[c]	Mean weight cabbage head (g)
Thuricide HP	0.450[c]	35.01a	75.2a	712a
Acephate 75EC	0.340	36.81a	82.9a	733a
Diflubenzuron 25EC	0.070	32.50a	77.5a	594a
Methamidophos 60EC	0.270	31.00a	81.7a	722a
Control		61.31b	53.8b	300b

[a] Source: Mohamad et al 1979. [b] Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [c] Product/ha. [c] According to Chuo (1973).

Indonesia

In an insecticide screening trial in North Sumatra, Hutabarat (1975) compared the efficacy of Thuricide HP with a standard organophosphorus compound, quinalphos, to control DBM on cabbage. The insecticides were applied at a seven-day interval eight times during the season. Efficacy evaluation was accomplished by recording the number of DBM larvae on 10 plants per plot (35 sq m).

Thuricide HP sprayed at 0.10% to 0.15% reduced the number of insects feeding on plants considerably and consequently increased yield substantially (Table 3). The chemical insecticide was not effective, indicating the possibility of insecticide resistance. Based on these and other observations, *Bt* was successfully incorporated in DBM control programs with the introduction of a parasite, *Diadegma eucerophaga*, in vegetable production areas of North Sumatra.

Table 3. Screening of Thuricide HP for the control of DBM on cabbage at Karo Highland, North Sumatra[a]

Insecticide	Spray conc. % AI	No. larvae/ 10 plants[b]	Yield kg/plot
Thuricide HP	0.100	17.59	149.7
Thuricide HP	0.125	6.07	176.7
Thuricide HP	0.150	0.00	185.7
Quinalphos 25EC	0.200	58.40	91.7

[a] Source: Hutabarat 1975. [b] Arcsin transformation.

Similarly, in a laboratory trial, Sudarwohadi and Said (1977) compared the efficacy of Thuricide HP with that of standard organophosphorus compound, quinalphos. As expected there was low initial mortality in the Thuricide HP treatment, but with time the mortality increased and was comparable with that of the standard organophosphorus compound (Table 4).

Table 4. Efficacy of Thuricide to DBM in laboratory[a]

Insecticide	Spray product %	Average % mortality[b] days after treatment		
		1	3	7
Thuricide HP	0.20	46.72	55.44	56.94
Thuricide HP	0.15	43.33	54.00	58.61
Thuricide HP	0.10	37.50	54.00	56.94
Quinalphos 25EC	0.20	52.55	53.78	58.45
Control		0.00	0.00	0.00

[a] Source: Sudarwohadi and Said 1977. [b] Average of four replicates, data are Aresin transformation.

India

Sandoz (India) Ltd conducted several trials with Thuricide HP in different parts of the country between 1977 and 1981 to control DBM on cabbage and cauliflower. In all cases, applications were made at pre-blossom stage in cauliflower and pre-head formation stage in cabbage. In most cases useful levels of mortality were observed only two days after first application. The mortality continued to increase up to 10 days. The dose response studies indicated that Thuricide HP need be applied at the rate of 1.0 to 1.5 kg/ha. In the case of reinfestation by succeeding generations of DBM, a second

or third application at a 10 day interval was necessary. A sharp rise in DBM mortality was observed in the first few days after the second or third application. Under Indian conditions an application interval of 10 days was adequate; shortening the interval to five days did not have any beneficial effect.

Australia

Clarke (1976) tested Thuricide HP for the control of DBM on cabbage in southern Victoria. Thuricide was used at the rate of 0.28 and 0.56 kg product/ha applied at 7 and 14-day intervals. Triton B-1956 at 280 ml was added to a spray volume of 1000 l/ha. The efficacy evaluation was made at six and two weeks before harvest and consisted of counting DBM and pupae/10 plant/plot. The plants were also rated for damage on 1 to 7 scale (1 = severe damage, 7 = no damage).

The results are summarized in Table 5. Thuricide HP used at 0.28 and 0.56 kg/ha and at both 7 and 14-day intervals significantly reduced DBM larval populations over the untreated check and a methomyl treatment. The pupal population was significantly reduced especially when Thuricide was applied at weekly intervals. Weekly applications also significantly reduced plant damage over control and two other treatments. According to Clarke (1976) the wetting agent helped to extend the life of Thuricide and also helped to spread the product to more inaccessible parts of the host plant.

Table 5. Efficacy of Thuricide in controlling DBM on cabbage in Victoria, Australia[ab]

Insecticide	Rate kg product per ha	Spray interval (days)	No.larvae per 10 plants	No. pupae per 10 plants	Damage rating[c]
Thuricide HP	0.28	7	8.2a	43.2ab	4.6a
Thuricide HP	0.56	7	8.3a	51.3bc	4.6a
Thuricide HP	0.28	14	19.0bc	155.3e	3.0bc
Thuricide HP	0.56	14	16.1b	111.8de	2.8c
Methomyl 90EC	0.56	14	40.3cd	133.0e	3.2bc
Control	—	—	73.5d	409.1f	2.0d

[a] Source: Clarke 1976. [b] Mean in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [c] 1 = severe damage, 7 = no damage.

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The Pathogens of Diamondback Moth and Their Potential for its Control — a Review

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Abstract

The larvae and less frequently the pupae of *Plutella xylostella* (L) are sometimes attacked naturally by pathogens, particularly two fungi of the family Entomophthoraceae, *Erynia blunckii* and *Zoophthora radicans*. Other pathogens recorded include one other entomophthoraceous fungus, a granulosis virus, one or possibly two nucleopolyhedrosis viruses and *Bacillus thuringiensis* var *kurstaki*. In the laboratory, larvae were also susceptible to strains of several deuteromycete fungi, other nucleopolyhedrosis viruses and several varieties of *B. thuringiensis*. Of these pathogens, only *B. thuringiensis* is produced commercially and the derived products are used to control *P. xylostella* in the field. The bacterium, however, spreads inefficiently between host individuals and for effective control, as with chemical insecticides, repeated applications are necessary. Laboratory tests indicate that *E. blunckii, Z. radicans*, some of the deuteromycetes and certain viruses, all of which spread readily between individuals, may have potential as control agents. While none of these is produced commercially, methods for their mass cultivation are available though they need development. For each of these pathogens further laboratory and field trials are needed to select the most infective strains and to test application methods and formulations.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), occurs throughout the world wherever crucifers are grown. Its recorded distribution has been mapped (CIE 1967). In many areas DBM causes little damage, probably because its numbers are held in check by natural enemies (Hardy 1938). In the UK the insect is widespread but causes only sporadic damage chiefly in the east. The most recent outbreak of the pest in the UK, in 1958, resulted from easterly winds bringing vast numbers of the moths from countries bordering the east shores of the Baltic Sea, across the North Sea (French and White 1960). Serious damage was limited by chemical pesticides, chiefly DDT. In some parts of the world, however, notably in the Far East, DBM causes damage regularly and repeated applications of insecticides are required for its control. As a result, resistance has developed to many of the previously suitable compounds (Sudderuddin and Kok 1978). This, coupled with an increased awareness of the environmental consequences of excessive pesticide use, encourages further interest in non-chemical methods of control including the use of pathogenic microorganisms and viruses.

This paper describes the pathogens that attack DBM in nature, reviews the results of laboratory and field trials in which the insect has been challenged by these and a range of other pathogens and considers the prospects for the microbial control of this pest.

Pathogens Naturally Attacking DBM

The ecology of DBM, including the effects of natural enemies, has been studied in a number of countries. It is clear that the moth has become adapted to many diverse environments and the time scale of different stages in its lifecycle has been modified accordingly. Nevertheless records of pathogens are consistently restricted to those affecting the larvae and rarely the pupae. Most references are to infection by fungi of the family Entomophthoraceae though there are a few records of virus infections and one of infection by the bacterium *Bacillus thuringiensis* Berliner (Table 1).

Table 1. Records of pathogens of DBM

Pathogen	Country	Reference
Viruses		
granulosis	Japan	Asayama and Osaki (1970)
multiple-embedded nucleopolyhedrosis	Japan	Zeya (1968) according to Biever and Andrews (1984)
nucleopolyhedrosis	?	Varma and Gill (1977)
Fungi		
Zoophthora radicans	New Zealand	Robertson (1939), Kelsey (1965)
	South Africa	Ullyett and Schonken (1940), Ullyett (1947)
	Finland	Kanervo (1946, 1949)
	Chile	Aruta et al (1974)
	Malaysia	Ooi (1979, 1981)
	Philippines	Velasco (1983)
	Japan	Yamamoto and Aoki (1983)
Erynia blunckii	Germany	Lakon (1935), Zimmermann (1978)
	Finland	Kanervo (1946)
	USSR	Woronina (1971) according to Zimmermann (1978)
	Japan	Tomiyama and Aoki (1982)
Erynia sp. probably *virescens*	Finland	Kanervo (1946)
Bacteria		
Bacillus thuringiensis var. *kurstaki*	Yugoslavia	Purrini (1977), Vankova and Purrini (1979)

Viruses

Asayama and Osaki (1970) recorded many DBM larvae infected with a granulosis virus (GV) in a cabbage plantation in Aichi Prefecture, Japan in May 1968. The color of the larvae at an advanced stage of infection changed to pale yellow from the normal dull green. After death they turned dark brown and swelled. A white fluid was often discharged from the integument. The capsules of this GV were uniformly ovo-cylindrical, $411 + 17 \times 240 + 13$ mμ and the rod-snaped virus particles were 260 to 280 x 40 to 45 mμ. The structure of the virus and its effect on host tissues are described in a series of articles published in Japanese (Asayama and Inagaki 1975a, 1975b; Asayama 1975a, 1975b, 1976).

Biever and Andrews (1984) studied the susceptibility of some lepidopterous larvae to a multiple-embedded nucleopolyhedrosis virus (NPV) isolated in Oxford, UK by A. Zeya, from DBM originating in Japan. No details are given of the degree of mortality caused in the larval population.

An NPV isolated from DBM was also used in experiments described by Varma and Gill (1977). No details of its origin are given except that it was supplied by T. Sunkaran of the Commonwealth Institute for Biological Control, Bangalore, India, and no description of the infected host or of the virus is provided. It is not known whether this virus corresponds to that studied by Biever and Andrews (1984).

Fungi

Zoophthora radicans (Brefeld) (= *Entomophthora sphaerosperma*) (Phycomycetes: Entomophthoraceae) infects insects from several orders and is a widespread pathogen of DBM (Table 1) attacking usually the larvae but also sometimes the pupae (Robertson 1939, Kanervo 1945). Larvae killed by this fungus are attached to the substrate by strong rhizoids emerging along the ventral surface of the abdomen. The fungus may then form a mat of conidiophores that extends over the larvae and beyond its margins so that the detailed shape of the host is no longer recognizable (figured in Ullyett and Schonken 1940, Kanervo 1946, Ullyett 1947). The primary conidia develop from these conidiophores and are violently discharged to a distance of a few millimeters, forming a halo around the dead larvae. The conidia (Figure 1) are uninucleate and elliptical with a rounded apex and roundly conical base demarcated from the body of the conidium by a slight 'collar' marking the ring of attachment to the conidiophore. The conidia range in size from 15 x 5 to 26 x 8 . Secondary conidia, developing directly from the primary ones, are of two types: either they resemble the primary ones or they are capilloconidia formed on a slender capillary tube arising from the primary conidium. The capilloconidia (Figure 1) are fusiform, tapering to base and apex and have dimensions of 13 x 5 to 25 x 8 μ.

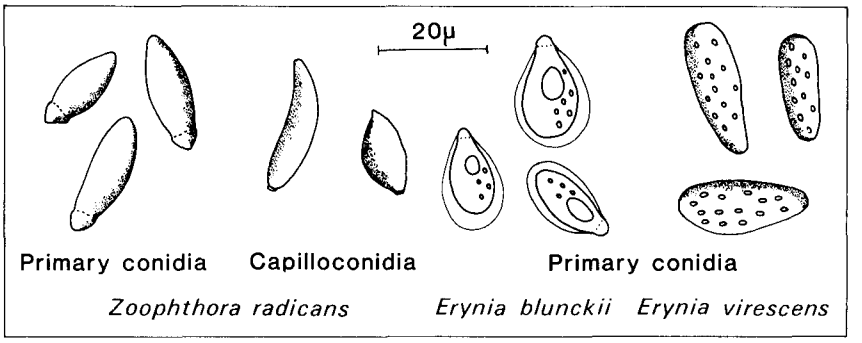

Figure 1. Conidia of entomophthoraceous fungi recorded from DBM

In some larvae, instead of conidiophores, thick-walled spherical resting spores (about 24 to 28 μ diam.) develop within the body of the infected host. On death such larvae shrivel slightly, darken in color and remain firm when touched with a needle.

Z. radicans periodically causes high mortality in DBM populations in most of the countries where the fungus has been recorded (Table 1). Kelsey (1965) found that under natural conditions in New Zealand the fungus almost eliminated a population of larvae in only 10 days. Usually the same effect was noted only after about 30 days. However, following detailed surveys in England, Hardy (1938) concluded that it is rare to find caterpillars dying from any species of fungus in this country. Further, there are no references to DBM infection by *Z. radicans* in the rest of Europe nor in North America, even though it is a frequent pathogen of many other hosts, including Lepidoptera, in these regions.

Robertson (1939) considered that the most important factors governing the mortality caused by the fungus are moisture and a high density of the host. Epizootics can be expected when these conditions coincide. To this should be added that a strain of the fungus infective for DBM must also be present, and in some regions as in England where the pest occurs infrequently there is little opportunity for the fungus to persist from one outbreak population to the next. This may explain why the fungus is not recorded more frequently from England and most of Europe.

Ullyett and Schonken (1940) showed that in South Africa the natural control of DBM provided by *Z. radicans* was sometimes so complete that hymenopterous parasitoids of the pest, which normally have an important regulatory effect on numbers, were eliminated through the absence of their host. When the fungus subsequently disappeared, the pest population developed more quickly than that of the parasitoid and caused more damage than it had before the intervention of the fungus. Kelsey (1965) also recognised this occurrence but considered, nevertheless, that in programs of biological control the advantages of introducing *Z. radicans* outweighed the disadvantages.

DBM is the only know host of another entomophthoraceous fungus, *Erynia blunckii* (Lakon). This fungus has been recorded from fewer countries (Table 1) and less frequently than *Z. radicans*. Larvae killed by *E. blunckii* are fixed to the substrate by rhizoids and become covered in a felt-like mat of conidiophores (figured by Zimmermann 1978) similar to that formed by *Z. radicans*. Pseudocystidia, sterile fungal processes, extend far beyond the tips of the conidiophores, and the conidia are discharged in vast numbers forming a heavy deposit around the dead host. The conidia are morphologicaly distinct from those of *Z. radicans* (Figure 1). They are uninucleate, pyriform and range from 13 x 7 to 20 x 11 u. In water and in other liquids the outer membrane of the wall often separates from the inner one so that the conidium appears to be contained in a bubble from which only the basal papilla protrudes. As in the conidia of *Z. radicans*, the line of attachment to the conidiophore is marked by a faint collar. Secondary conidia resemble the primary ones and capilloconidia are not formed. Resting spores of *E. blunckii* have not been found.

Tomiyama and Aoki (1982) recorded an epizootic caused by this species in a radish field near Tokyo, Japan but no details are given in this or any other publication of the degree of mortality caused or the conditions in which outbreaks of infection occur.

The only other pathogenic fungus from DBM was recorded in Finland and identified tentatively as *Entomophthora virescens* Thaxter (= *Erynia virescens* (Thaxter) (Phycomycetes: Entomophthoraceae) by Kanervo (1946). This species was originally described from larvae of an *Agrotis* species (Lepidoptera: Noctuidae) by Thaxter (1888) in North America. The conidia (Figure 1), according to Kanervo (1946) range in size from 18 x11 to 30 x15 u. They are irregular in shape, ovoid to pyriform with a rounded apex and base. There are no details of the effect of this fungus on populations of DBM nor of the conditions which favor its spread.

Bacteria

The only pathogenic bacterium recorded from DBM is *B. thuringiensis* var *kurstaki*. Purrini (1977) and Vankova and Purrini (1979) discovered DBM larvae infected with this bacterium apparently in old watermills in Yugoslavia but it is not clear what the larvae were feeding on. Infected larvae of stored product moth pests, much more usual hosts for *B. thuringiensis* than phytophagous larvae, were found at the same time and were probably the primary hosts.

B. thuringiensis is a spore-forming bacterium characterized by the production of a protein crystal comprising the so-called delta endotoxin, which is toxic for larvae of Lepidoptera and the aquatic larvae of certain Diptera including mosquitoes and black

flies, but harmless to all other organisms including man. Currently, 19 serotypes of this organism, distinguished by their flagellar or H-antigens, have been characterized and some of these serotypes have been further divided into biotypes. Some isolates of several serotypes produce, in addition to the crystal endotoxin, the beta exotoxin which has a wider spectrum of toxicity and is slightly harmful to birds. Certain isolates of *B. thuringiensis* are produced commercially but those producing the exotoxin are not permitted for most pest control purposes.

Larvae become infected with *B. thuringiensis* by ingesting the bacteria from cadavers or the faeces of infected insects. The endotoxin paralyzes the gut, causing feeding to cease, and lowers the pH. In these conditions the bacterium multiplies, sporulates, breaks down the gut wall and enters the haemocoel causing a lethal septicaemia.

Experimental Infections

Several of the pathogens described in the previous section have been tested in the laboratory for their infectivity for DBM and others, not associated naturally with this host, but which may have a similar or even greater potential for use as control agents, have also been tested (Table 2).

Table 2. Pathogens infective for DBM in experimental tests

Pathogens	Reference
Viruses	
Multiple embedded nucleopolyhedrosis (from DBM)	Biever and Andrews (1984)
Polyhedrosis (from DBM)	Varma and Gill (1977)
Multiple embedded nucleopolyhedrosis (from *Autographa californica)*	Vail et al (1972), Vail and Jay (1973), Burgerjon (1977)
Multiple embedded nucleopolyhedrosis (from *Galleria mellonella*)	Burgerjon (1977)
Chilo iridescent virus	Ohba (1975)
Granulosis virus (from DBM)	Asayama references
Fungi	
Beauveria bassiana	Fargues et al (1979, 1983), Ignoffo et al (1979), Robert and Marchal (1980)
B. brongnartii	Fargues et al (1979), Robert and Marchal (1980)
Metarhizium anisopliae	Robert and Marchal (1980)
Paecilomyces fumoso-roseus	Robert and Marchal (1980)
Erynia blunckii	Tomiyama and Aoki (1982)
Zoophthora radicans	Ullyett and Schonken (1940), Wilding and Mardell (unpublished)

Viruses

Vail et al (1972) tested an NPV isolated from *Autographa californica* (Speyer) (Lepidoptera: Noctuidae) for control of *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae) in the field and from one plot recovered subsequently a DBM larva infected with NPV. Laboratory tests with this virus confirmed that it was infective for DBM when fed at a dose of 10^4 polyhedral inclusion bodies (PIB)/mm^2 of diet surface (Vail et al 1970). The virus from DBM was then tested against *T. ni* by feeding 2.4 x 10^3 PIBs/mm^2 and the results confirmed the cross infectivity of the virus. The symptoma-

tology of the infection of DBM larvae and several other Lepidoptera by the same virus isolate was reported by Vail and Jay (1973). DBM larvae died three to four days after ingesting the virus. Infected larvae became swollen and flaccid and the integument became shiny before disintegrating.

Burgerjon (1977) tested two serologically and morphologically indistinguishable isolates of NPV for their infectivity for a number of lepidopterous larvae including DBM. One isolate was that from *A. californica*, considered above, and the other was isolated in the USSR from *Galleria mellonella* (Linnaeus) (Lepidoptera: Pyralidae). The larvae were inoculated by sraying an aqueous suspension to the surface of the cabbage leaves on which they were fed. The *G. mellonella* isolate was slightly more infective than the *A. californica* one but even a dose of 4 x 10^4 PIBs/mm^2 of leaf surface killed only about 86% of the test larvae. Further, the same virus isolates were much more infective for certain other host species.

Another NPV, isolated from DBM by A. Zeya (Table 1), also had a high LC_{50} (1.5 x 10^4 PIBs/mm^2 of diet surface for 3rd instar larvae) (Biever and Andrews 1984). This contrasts with LC_{50}s of less than 1 PIB/mm^2 for *T. ni* and *Spodoptera ornithogalli* (Guenee) (Lepidoptera: Noctuidae) with the same virus. The authors concluded that DBM was not the natural host for this virus.

An NPV described as a 'nuclear polyhedrosis virus of *Plutella*' was applied as one treatment in an experiment comparing its efficacy with that of four *B. thuringiensis* preparations for DBM control (Varma and Gill 1980). The suspension of the virus was prepared by homogenizing one cadaver, presumably of DBM, in distilled water, filtering through cheesecloth and making the volume up to one liter with water. The leaves of the plants were sprayed, using an atomizer, at 15-17 ml/plant and the treated plants were kept in screened cages. The virus produced 42% mortality after seven days.

Larvae of DBM were among 65 species of Lepidoptera to become infected with *Chilo* iridescent virus after per os inoculation but details of the dosage and mortality are not given (Ohba 1975).

In studies on the histopathology of the infection of DBM by granulosis virus, Asayama and his co-workers (Asayama 1975a, 1975b, 1976, Asayama and Inagaki 1975a, 1975b, Asayama and Osaki 1970) infected larvae experimentally but give no details of the dose applied or the degree of mortality caused. This virus was non-infective per os for *Pieris rapae* (L) (Lepidoptera: Pieridae), *Bombyx mori* (L) (Lepidoptera: Bombycidae) and four noctuid species (Asayama and Osaki 1970).

Fungi

Ullyett and Schonken (1940) infected DBM larvae with *Z. radicans* by applying a suspension of the conidia from an *in vitro* culture to the cuticle of the larvae with a wet brush. No figures for the success of this method are given but the authors state that the results were better than those obtained with the method described by Sawyer (1933) who enclosed larvae of *Rhopobota naevana* (Hubner) (Lepidoptera: Tortricidae) in vessels plugged with potato slices on which the fungus was growing. They also stated that they were unable to obtain infection with any degree of certainty with either method.

We have begun to develop a method for infecting DBM larvae with *Z. radicans* (Wilding and Mardell, unpublished). Third to 4th instar larvae were exposed to spore showers from 2 cm diam discs cut from *in vitro* cultures on agar medium of a strain (NW 33 = No. 633, Collection of G. Remaudiere, Institut Pasteur, Paris) isolated from *Tortrix viridana* (Linnaeus) (Lepidoptera: Tortricidae) in France in 1975 and stored subsequently in liquid nitrogen. The larvae were exposed to the shower of conidia for three hours and then kept in a moist box for a further 24 h. No attempt in this preliminary experiment was made to assess the dose of conidia applied. In two replicate tests four

and seven individuals became infected out of 20 inoculated in each. A few larvae also became infected after confinement with a deposit of conidia from the same fungus. The results of these experiments using a culture isolated many years ago from a heterologous host suggest that the techniques used are suitable for development.

In their studies on the histopathology of *E. blunckii* on DBM, Tomiyama and Aoki (1982) infected larvae using a similar technique to that we employed with *Z. radicans*. The larvae were confined for 24 h in a cage while exposed to a shower of conidia from cultures of the fungus on agar discs. No information is given about the dose administered or the mortality that resulted.

Robert and Marchal (1980) compared the infectivity of a number of entomogenous hyphomycetes for larvae of DBM to determine whether this insect was a suitable target host for screening such fungi. Both surfaces of 50 mm diam leaf discs were sprayed with a suspension of the spores and placed in a box containing 20 3rd instar newly molted larvae in an atmosphere kept moist for 48 h. These fungi invade the larvae through the cuticle, not through the gut wall, and the purpose of treating the leaf discs was to ensure that the larvae made contact with the inoculum while they were eating.

The larvae were treated with two strains of *Beauveria bassiana* (Balsamo), two of *B. brongnartii* (Saccardo), five of *Metarhizium anisopliae* (Metschnikoff), one of *M. flavoviride* Gams and Roszypal, one of *Nomuraea rileyi* (Farlow) and one of *Paecilomyces fumoso-roseus* (Wize) all at 10^8 spores/ml (equivalent to 4 x 10^5 spores/cm^2 leaf surface). The mortality recorded after six days was significantly greater than that of the untreated larvae for all the *Beauveria* strains, two *M. anisopliae* strains and *P. fumoso-roseus*. Further trials gave LC_{50} values, in spores/ml, of 2.2 x 10^7 for conidiospores of one strain of *B. brongnartii* and of 2.3 x 10^7 (unformulated), 7.5 x 10^6 (leophilized) and 1.5 x 10^7 (clay-coated) for three blastospore formulations of a strain of *B. bassiana*.

The infectivity of lyophilized blastospores of *B. bassiana* for DBM was unimpaired after one month storage at 5°C and only slightly diminished after five months (Fargues et al 1979). Clay-coated blastospores were still infective for DBM after three weeks in soil whereas the unformulated spores lost most infectivity after only two weeks. This and associated findings led the authors to suggest that clay-coating may be a satisfactory way of formulating entomopathogenic hyphomycetes for field use.

Ignoffo et al (1979) tested the mycoinsecticide Boverin against DBM using a similar method to that of Robert and Marchal (1980). Boverin is a preparation of conidiospores of a strain of *B. bassiana* selected for its activity against Colorado beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae). The LC^{50} for three-day old larvae of *P. xylostella* was 2.7 x 10^8 spores/ml (equivalent to 1.5 x 10^6/cm^2 of leaf surface).

Bacteria

There have been several studies on the effects of *B. thuringiensis* varieties on DBM (Kreig and Langenbruch 1981) but only some of these will be discussed here.

Burgerjon and Biache (1967) compared the susceptibility of 24 species of Lepidoptera including DBM to seven strains of *B. thuringiensis* of serotypes H-1, H-3, H-4, H-5 and H-6. DBM was susceptible to each of the serotypes tested. The different strains were prepared in an identical way and formulated as a dry powder. For a given concentration of the powder in water, serotype H-6, var *subtoxicus* was most toxic. Serotype H-5, var *galleriae* contained many more viable spores per gram of powder yet it was slightly though non-significantly less toxic than var *subtoxicus*.

Commercial preparations of two of the serotypes examined above, Dipel (serotype H-3a/3b, var *kurstaki*) and Bactospeine (serotype H-1, var *thuringiensis*) were compared

for their toxicity to 3 day-old DBM larvae (Ooi 1981). Both were effective, with Dipel just 1.3 times as toxic as Bactospeine. Rautapaa (1967) recorded that another commercial product, Biotrol (serotype H-1, var *thuringiensis*), at 13 x 10^5 spores/cm^2 of leaf surface, killed larvae in two days. However, serotype H-14, var *israeliensis* now available commercially for black fly and mosquito control was non-toxic to DBM (de Barjac 1978).

In an attempt to produce strains with increased toxicity for pests and reduced toxicity for *B. mori*, Jangi and Ibrahim (1983) gamma-radiated a strain of serotype H-7, var *aizawa* isolated from the commercial preparation Bacillex. Some of the isolates obtained had diminished toxicity to *B. mori* but of more interest here is an up to six fold increase in toxicity to DBM of some isolates.

Certain pesticides and *B. thuringiensis* acted synergistically in killing DBM in combined treatments (Hamilton and Attia 1977). However, combinations of Dipel with two widely used organophosphorus insecticides, demeton-S-methyl and dimethoate, reduced the effectiveness of the *B. thuringiensis* preparation alone by 4 and 10 times respectively.

There is no evidence for any pest having developed resistance to the delta endotoxin of *B. thuringiensis* but resistance to the beta exotoxin has been induced in houseflies, *Musca domestica* (L) (Diptera: Muscidae) by exposing successive generations to the toxin in the laboratory (Harvey and Howell 1965). A strain of DBM held under high selection pressure from var *thuringiensis* for 10 generations failed to show a difference in susceptibility from the untreated strain (Devriendt and Martouret 1976).

Field Trials

Pathogens other than *B. thuringiensis* have rarely been field tested against DBM and the results of these few trials are mostly poorly documented.

Granulosis viruses isolated from *P. rapae* and DBM were sprayed on crucifer crops in Taiwan and reduced numbers of both pests (Wang and Rose 1978). Studies in 1974 and 1975 showed that the mortality caused by the DBM GV decreased from 97.6 to 6.5% as the duration of exposure to sunlight increased from 4 to 60 h (Kao and Rose 1976). Of several protectants tested, India ink protected the virus and prolonged its effectiveness best. The same virus has been field tested in Malaya but details of the results are not yet published (Kadir 1984).

According to Biever and Andrews (1984), an NPV of DBM from Japan has been used in Malaysia and India for the control of this pest. No field data are available and Biever and Andrews consider from their laboratory studies that DBM is not the natural host of this virus and that it would probably more effectively control larvae of other Lepidoptera.

Only Kelsey (1965) has described the application of a fungus for DBM control. Two fields of crucifer forage crops in New Zealand in each of two years were treated with a macerate of larvae infected with *Z. radicans*. The time taken to give adequate control was only reduced in fields where the fungus was not already present but even in such cases the author concluded cautiously that artificial introduction 'may have some merit'. However, only one application was necessary whereas when organophosphorus insecticides were used a second spray was sometimes needed to prevent reinfestation. Farmers were advised not to treat a crop with chemical insecticides when the fungus was present in the field.

Most of the work on the use of *B. thuringiensis* for DBM control has been done either in the US or in southeast Asia. In the US there is a complex of damaging

lepidopterous pests on crucifers, including *T. ni* and *P. rapae* as well as DBM. Consequently the success of various pesticides, either chemical or those based on *B. thuringiensis*, in protecting the crop, is as much a measure of their ability to control these other pests as it is that of DBM. Most publications, however, include figures for the reduction in numbers of each of the species. For example, Creighton and McFadden (1975) field tested three commercial preparations of *B. thuringiensis*, several chemical insecticides and combinations of the bacterial preparations with the chemicals, on cabbage crops in South Carolina. Each of the *B. thuringiensis* preparations, Dipel wettable powder, Bactospeine wettable powder, and Bactospeine 'flowable', applied weekly, significantly reduced numbers of DBM. Dipel was tested at a range of doses and gave reasonable control of DBM and *P. rapae* but not *T. ni*, at 0.7 kg/ha. A combination of Dipel and chlordimeform hydrochloride each at this concentration gave significantly better protection against the complex of lepidopterous larvae than either product applied independantly.

Results from the same laboratory (Creighton et al 1981) also established that the protection of cabbage by *B. thuringiensis* from caterpillars differed according to the cabbage cultivar but whether this was caused by an interaction between the cultivar and the treatment or merely the result of differential tolerance to larval damage between cultivars, irrespective of treatment, is not made clear.

Libby and Chapman (1971) compared the effectiveness of different commercial preparations of *B. thuringiensis* for control of DBM, *P. rapae* and *T. ni* on cabbage crops and determined that weekly applications of Dipel at 1.12 kg/ha and Thuricide (var *kurstaki*) at 0.56 kg/ha gave low foliar damage ratings and very acceptable control. They were more effective per weight of formulation than the then commercial preparation of var *thuringiensis*, Biotrol.

Eckenrode et al (1981) noted that *B. thuringiensis* is one of the two most widely used products for control of caterpillars on sauerkraut cabbage in New York State. Because this crop is processed for the market, it can tolerate more peripheral feeding damage than a cabbage crop destined for the fresh market. Consequently insecticides are applied relatively infrequently. Nevertheless, *B. thuringiensis* appears to give reasonable control especially of DBM.

In southeast Asia, DBM is the principal lepidopterous pest on crucifers and its control can be considered in isolation. Ho and Ng (1970) compared the efficacy of Thuricide with that of chemical insecticides for control of DBM on cabbage crops in 1968 and 1969. In an initial trial in which the products were applied weekly, Thuricide (at a concentration in water expressed as 1/80 (volume/volume)) gave better protection than any of the 16 chemicals but yields were low because soil conditions were poor and other pests were numerous. In further experiments, applications of Thuricide, at 1/80 and 1/160 (volume/volume), at four day intervals reduced larval numbers more than when applied at seven day intervals but not sufficiently to affect yield. Similarly, mortality though not yield was increased by raising the concentration from 1/250 to 1/100. These experiments lacked untreated control plots so that larval numbers and yields in the absence of any control measures were not determined. The authors, however, stated that Thuricide gave effective control and that on good soils, yields exceeding 100 t/ha were easily obtainable. Only when such yields were produced was the cost of treatment justified.

In more recent work, the success of Thuricide in controlling DBM was confirmed (Mohamad et al 1979). Control was as effective as that provided by a range of chemical insecticides including bendiocarb, acephate, methamidiphos, and diflubenzuron. These authors have also shown that, in the laboratory, *B. thuringiensis* retains 50% of its effectiveness after five days on leaves of turnip (Mohamad et al 1980).

Discussion

This account has shown that many different pathogens are active against DBM but of these only *B. thuringiensis* has been adequately field tested and is used commercially. The currently available preparations of this bacterium based on serotype 3a/3b, var *kurstaki* are highly infective for this pest. However, field tests show that its activity begins to diminish after only a few hours in daylight. Further, it spreads inefficiently between host individuals. Consequently, like many chemical pesticides, it has to be applied repeatedly to ensure control. Its use is also limited in those regions of the world where DBM co-exists with other lepidopterous pests of crucifers against which *B. thuringiensis* is only partially successful. Nevertheless, because it is commercially available at a competitive price, this organism will continue to provide by far the greatest potential for the microbial control of DBM for several years to come. Further, current research on genetic improvement of *B. thuringiensis* should lead to the development of strains of the bacterium with a greater potency than those currently available.

A number of viruses infective for DBM have been described but only the GV discovered in Japan by Asayama and Osaki (1970) appears to have caused a high level of mortality in a field population of DBM. Experimental work with the other viruses isolated from the larvae indicates a rather low susceptibility suggesting that DBM is not the principal host. However, further intensive screening of these viruses and those from other hosts for their infectivity for DBM in the laboratory and field should be undertaken. Although none of these viruses are available commercially in quantities required for field use, the related NPV of *Heliothis* species (Lepidoptera: Noctuidae) is used for the control of caterpillars on cotton and the techniques required for the mass production and application of such viruses are therefore available (Ignoffo and Couch 1981).

Some fungi are highly infective for DBM and cause an important natural mortality. Others have proved infective in laboratory tests. However, none of them has been adequately field tested for control of DBM. Methods for the large-scale production of some of them, those of the Deuteromycetes, are available (Hall and Papierok 1982). One of these, *B. bassiana*, causes allergenic reactions in sensitive people and is therefore unlikely to be developed for commercial use (Hussey and Tinsley 1981) but all the available evidence suggests that other fungi of potential are harmless to mammals. No species of Entomophthoraceae is produced commercially but methods for their production have been developed and research into the possibility of using them for control of aphids, delphacids and certain Lepidoptera is current (Wilding 1981, Latge 1982).

Z. radicans, the most important of the naturally occurring pathogens of DBM is relatively well researched. A US patent for its production has been applied for by Drs D. McCabe and R. S. Soper (R. S. Soper, Boyce Thompson Institute, USA, personal communication) and provisional attempts to use strains of this fungus for control of aphids in Australia (Milner et al 1982) and spruce budworm, *Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae) in the US (Soper 1982) have demonstrated that the fungus can be artificially introduced into insect populations and provide some control.

All fungi require a saturated or near-saturated atmosphere for the completion of those stages in their lifecycle that occur outside the host. Their effectiveness as control agents is therefore limited in dry conditions. The duration for which moist conditions must persist, however, differs according to the species and strain of fungus. Often, the microenvironment within the crop canopy remains moist for long enough each day, particularly during the night, to ensure the infection of the host. In many of the regions where DBM is a problem, for example the Cameron Highlands of Malaysia, the nights are cool and humid providing apparently suitable conditions for fungus spread.

A disadvantage of pathogens for pest control is that most, other than *B. thuringiensis* which paralyzes the gut wall and thereby prevents feeding soon after it

is ingested, allow their host to continue damaging the crop for several days before death. Consequently the timing of application is crucial and adequate forecasting of potential infestation highly important. Against this, the ability of most pathogens to persist and multiply in the host populaiton should ensure that a single application is sufficient. This, coupled with the advantage that a microbial pesticide is unlikely to kill any of the natural enemies of the pest suggest that their use for the control of DBM should receive greatly increased attention.

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Discussion

O. MOCHIDA: I understand DBM is serious in the Cameron Highlands, what methods do you recommend to farmers? and what methods do farmers use?
G. S. LIM: We recommend to spray only when necessary and preferably with the biological insecticide *Bacillus thuringiensis*. However, farmers more often than not prefer to stick to their old habits, such as spraying with 'cocktails' of insecticides at three to four day interval. We need to educate farmers first on pesticide usage.

A. SIVAPRAGASAM: Why didn't you use the Random Parasitoid equation of Royania/Roger to evaluate the parasitoids since it provides better evaluation of the parasitoids?
T. H. CHUA: I don't think the difference is substantial. In fact the Royania/Rogers equation involves more variables which could confuse the issue.

A. SIVAPRAGASAM: Did you consider the mobility of the host in your search rate evaluation between *Diadegma* (or *Apanteles*) and *Thyraella* since we know that the former is larval parasitoid and the latter a pupal one.
T. H. CHUA: No idea, though it is suggested that the stage of DBM larval parasitized could be a factor.

A. SIVAPRAGASAM: Why did you observe a large variation in the developmental time of *Diadegma* (12.5 to 19 days)?
T. H. CHUA: The slope of the line log a vs log P gives the values of m and they are: 0.63, 0.47 and 0.30 for *Apanteles, Thyraella* and *Diadegma* respectively.

E. D. MAGALLONA: Your formula for ' area of discovery' ends up with the unit area/number or the inverse of density. Considering that ' area' has an estabished usage worldwide, I think you could consider using different terminology for better understanding of your data amongs laymen and vice-versa.
T. H. CHUA: You may be right. However to avoid confusion, the standard terminology has been used.

M. P. FERINO: One reason you mentioned why *Diadegma* did not perform very well in the field as it did in the laboratory is the possibility that the parasitoid is susceptible to the effect of insecticides. Are you saying that the release area was treated with insecticide?
T. H. CHUA: With the possible exception of MARDI Research Station, all the other release areas (Table 1) were and are still frequently treated with insecticides. Even at MARDI Station, insecticide trials may sometimes be carried out.

Y. I CHU: Are there any host and habitat segregation or interspecific competition among those parasitoid wasps?
T. H. CHUA: No segregation of any sort has been observed. Interspecific competition is rather limited, even though the same stages of host may be acceptable to *Apanteles* (which actually prefers DBM larvae of instar II-IV) and *Diadegma*. Furthermore, Lloyd (1940) found that when *Apanteles* and *Diadegma* occurred together in a DBM host, neither showed any sort of superiority over the other.

I. MANTI: According to G. S. Lim, DBM parasitoids are dominant in Malaysia. Why the population of *Diadegma eucerophaga* is so low especially considering the fact that it is the most effective parasite? I wish you can introduce this parasite from Indonesia.
T. H. CHUA: We really do not know. However, indiscriminate and heavy use of insecticides cause high mortalty of *Diadegma*, is a possible explanation.

O. MOCHIDA: Do you have any recommendation for DBM control in your country, if yes do the farmers follow it?
G. S. LIM: Yes, We have, but essentially on chemical usage only. Some farmers in Malaysia do follow it but most do not.
S. SUDARWOHADI: An integrated control program for DBM is being developed in Indonesia. The key component is biological control of DBM by parasitoid *Diadegma eucerophaga* Horstm. Application of insecticide should be done only when the population of DBM reaching the action threshold of 0.3 caterpillar/plant. We recommend the use of selective insecticide, *Bacillus thuringiensis*, to suppress the population of DBM. Farmers not always follow our recommendation and they regularly spray their cabbage fields once every week. As indicated everywhere, we need time to change the farmers' attitude.
E. D. MAGALLONA: It depends on the population in the particular area. In areas where pesticides use is quite heavy, there will be problems in overnight shift to other control agents. However, in low infestation areas or areas which are newly opened for crucifers, the use of cultural practices like crop rotation, barrier plants and physical barriers may be feasible. Definitely, the use of parasitoids and predators have not been adopted at a practical level. At the present time, in the absence of a concerted extension effort, the farmer relies solely on insecticides.

L. C. CHANG: Is there any difference in parasitism in open field and isolated area such as greenhouse. Do you think they will work better in isolated area?
G. S. LIM: In general parasitism will be higher in artificially-isolated conditions such as greenhouses or cages, because hyperparasitism is excluded. But there is no evidence that better control will be achieved in isolated areas than in the open field.
S. SUDARWOHADI: Rate of parasitism in open field depends on the host populations, while in isolated area such as greenhouse nearly 100% parasitism is possible. The parasitoid will work better in isolated area. However, the maintenance of an adequate supply of hosts is very important to maintain the parasitoid populations.

E. Y. CHENG: A larval parasite is the least desirable choice of parasite for the biological control of DBM. Why then is *Apanteles plutellae* still receiving so much attention?
G. S. LIM: It is not true that larval parasite is the least desirable choice of parasite for the biological control of DBM. In fact, larval parasites constitute the more effective agents and should be given priority. The successful deployment in Indonesia of *Diadegma eucerophaga*, a larval parasite of DBM, clearly demonstrates this. Similarly, the useful contribution of *Apanteles plutellae* (another larval parasite of DBM) as part of a parasite complex in Australia cannot be ignored.

E. D. MAGALLONA: Knowing the constraints in developing countries both from the stand point of institutional expertise and of operational capabilities, how do you propose to implement a successful biological control program against DBM?
G. S. LIM: This is a difficult question in that the successful implementation of a biological control program generally requires a good amount of initial resource, support

and understanding, from a fairly wide range of people (besides the scientist himself) who might be involved with the pest. Assuming the availability of only just the basic support but given a highly motivated staff I would advise that the first step is to import the key parasitoids if these are not already present. This may be done cheaply through the help of fellow scientists from another country where there is a stock culture or where the parasitoid(s) may be collected from the field. Following introduction, release and establishment, the impact may then be evaluated. If the pest is managed satisfactorily then studies need to be carried out to find means of maintaining the effective suppression. On the other hand if the control is inadequate investigations must then be pursued on how to exploit them effectively withn the integrated control strategy.

P. J. SALINAS: What about birds and other vertebrates? In England birds are important predators of DBM. In Venezuela birds are probably more important than other predators. Do you have any observations to this effect?
G. S. LIM: I am aware of your studies in England regarding the importance of birds in relation to DBM management. In Malaysia we have also observed birds feeding on DBM larvae. However their real contributions have not been quantitatively evaluated.

N. WILDING: Your argument for the relationship between the abundance of parasitoids and DBM importance is very convincing but seems to have been considered in isolation; you did not mention predators, diseases, and abiotic factors. In the tropics, DBM seems to multiply faster and thereby outstrip its natural enemies.
G. S. LIM: I do agree with you that my treatment of this presentation deals only with the impact of parasitoids on the DBM in isolation from other biotic and abiotic factors which can be important as well. I am fully aware of this and the main reason, as explained in the introduction to my talk, is because studies and information on these other agents have been scanty and incomplete. Nevertheless, even with the parasitoid component alone biological control contributions can be enormous, and one of my objectives is to illustrate this here.

Although DBM multiplies faster in the tropics and may appear to be able to outstrip its natural enemies this may be so only if the latter are weak or are inefficient species. Devoting a lot of effort to such inherently inefficient species is evidently wasteful of time and resource. That was why I emphasized the need to be selective in the choice of the parasitoid species involved.

Appropriate exploitation of a crucially important species cannot be overemphasized, as may be illustrated by the introduction of *Diadegma eucerophagus* into Indonesia, where it provided successful control of DBM. This same example also negates the view that in the tropics natural enemies will be outstripped by the host's faster multiplication.

Y. I CHU: Have you observed any host feeding behavior of the parasitoid wasps?
G. S. LIM: No, we have so far not observed any host feeding behavior of the few parasitoids that we have personally studied, namely *Apanteles plutellae, Tetrastichus sokolowskii* and *Diadegma eucerophaga. Thyraeella collaris* female enters the host cocoon and feeds at the site of pupation.

E. Y. CHENG: Alternative hosts are important for providing high parasitoid populations when the host population is low. How does this factor influence the DBM parasitoids?
G. S. LIM: Only a few alternate hosts of DBM parasitoids have so far been recorded, particularly for *Apanteles plutellae.* Even among these few, some are noted to be unnatural hosts while few have actually been confirmed as true hosts through proper

breeding studies. In general, it seems obvious that *A. plutellae* is oliophagous. In Malaysia, its range of alternative host species is restricted only to *Agrostis ypsilon* and *Crocidolomia binotalis*, both of which are also observed to be poorly exploited by the parasitoid.

Under more equable climatic conditions and the ever-presence of DBM in an environment of continuous and overlapping cropping as in many parts of the tropics, the alternative hosts, even if present, will usually not be of any importance as they are by contrast in the case of *Swammerdamia lutaria* on hawthorn, where the alternative host (*S. lutaria*) serves to bridge an overwintering larval generation of *Diadegma fenestralis* which is an important parasitoid of DBM in the United Kingdom.

E. D. Magallona: I do not quite agree with you that our salvation from DBM lies with biological control alone. Other contol methods are still being used, and so is biological control. We are all aware of the adoption problem with biological control.
G. S. LIM: I did not say that biological control alone is the only solution to the DBM problem. It certainly constitutes a fundamental component that has proved to be highly effective, either by itself or supplemented by other methods. It should be noted that except for chemical insecticides and biological control, all other potentially useful approaches have yet to be demonstrated as being practically effective in large scale farm situations. However, with chemicals, many undesirable side effects exist and these are already well known.

While the inclusion of key natural enemies of DBM may not guarantee complete biological control (though complete successes do exist and have been achieved), marked improvements in the overall pest situation can invariably be expected.

With respect to adoption problems, this is not confined to biological control alone. Evidently, everything has its price. For example, in the case of chemical control its adoption may seem simpler, more straightforward and easier: probably it is because so simply adopted that we are facing so many problems in using chemicals. In order to minimize the latter, adoption at once becomes much more difficult through trying to use the chemicals judiciously and safely. It is thus my belief that each approach will have its own problem of adoption, and that for one this problem is not in anyway measurably less than for another, especially if we are considering proper and satisfactory adoption.

I. HELLWIG: The chemical industry recognizes the importance of biological control. Are your data on biological control based on field studies or lab studies?
G. S. LIM: The data presented here are predominantly from field studies.

T. MIYATA: On seriously damaged plants, the carrying capacity would be low and insect populations on them will be less than on treated plants. What were the initial populations of DBM in control plots?
G. S. LIM: In all the plots the initial population of DBM was negligible. Over time the build-up increased, largely in the control and Sevithion plots. That for the latter was however many times that of the control.

T. MIYATA: Sevithion seems to be selective against parasitoids. Elimination of parasitoids causes DBM resurgence. Did you find resurgence in parasitoid free-condition?
G. S. LIM: Sevithion is evidently selective against *Apanteles plutellae* but we do not know if other parasitoids will also be affected similarly. With regard to DBM resurgence in parasitoid-free condition, this has been observed to be common.

S. A. RAHMAN (COMMENT): Natural epizootics of GV of DBM occur in watercress fields in Hawaii, but not to a high degree. I presume GV of NPV will cause

epizootic in the tropics if conditions are right. Generally many factors such as high population, and type of food induce epizootics.

N. S. TALEKAR: Although GV works very well against DBM in laboratory, we find it is not effective in the field. We must apply frequently. Is there anything that can be done to improve persistence of GV in the field.
T. ASAYAMA: Granulosis is induced by dipping the DBM larvae in endrin solution for a few minutes in laboratory experimentes. GV plus endrin may enhance the GV infection in the field. I think induction of latent virus is associated with the improvement of persistence.
R. I. ROSE (COMMENT): Early published work at AVRDC showed that activated carbon was the only adjuvant that appeared to provide UV protection, but it left the cabbage too dirty to be marketable.
T. ASAYAMA: We are conducting research on the control of the tobacco cutworm, *Spodoptera litura* by virus. In this project, we use amorphous silica, so called 'white carbon' as UV protectant at 0.1 - 0.2% of the spray solution.

R. F. HOU: Do you find any cross infection of DBM GV to other lepidopterous insects?
T. ASAYAMA: No, DBM GV is not infectious to any other lepidopterous insect pest of cabbage as evidenced by peroral inoculation studies.

R. F. HOU: Have you found NPV in DBM in Japan?
T. ASAYAMA: I have never seen the naturally occurring epizootics of NPV of DBM in my country. But P.V. Vail et al (J. Invertebr. Pathol. 20:216-217, 1972) show that NPV isolated from the alfalfa looper infects DBM as well as the cabbage looper in America.

I. MANTI: How effective is GV in the field for the control of DBM?
T. ASAYAMA: I have not yet tried the field application of DBM GV.

R. YEH: Do you have any data on comparative effectiveness of Bactospeine, Dipel, and Thuricide on the control of DBM?
E. BRUNNER: Yes, we do have limited comparative efficacy data for other competitive *Bt* products on the control of DBM. However, because experience has shown that it is extremely difficult to ensure statistically valid reliability when comparing biological insecticide efficacies, even for the same product in a given trial, we decided to publish no such comparisons in this paper dealing specifically with Thuricide HP.

R. YEH: Is there any difference between serotype I and serotype III in terms of DBM control?
E. BRUNNER: We have no data. Serotype I, for regulatory reasons, has been replaced by serotype III.

E. D. MAGALLONA: *Bacillus thuringiensis* appears to be a good control agent and yet it is not widely used. It may have acceptance problems. Could you comment on this?
E. BRUNNER: Factors affecting product acceptance are — selectivity (this can be regarded both as advantage and disadvantage), toxic action only by ingestion, time of application, feeding habit of larvae, the lower reliability of product against some genera such as *Heliothis* and *Spodoptera*, and relative high cost of *Bt* products.

C. N. SUN: Is there any possibility of isolating a much more potent strain of *Bt* against DBM?

E. BRUNNER: We are working in this direction.
R. I. ROSE: Different strains of *Bt* have now been found that show enhanced activity against *Heliothis* sp and *Spodoptera* sp and now possibly DBM. Genetic engineering is also making new varieties of *Bt* available. Tests are underway to identify and develop *Bt* strains more specific to important pests like DBM.

S. A. RAHMAN: Your data show high DBM mortality five to ten days after *Bt* application. We know *Bt* is inactivated by sunshine. Is the mortality due to residues of *Bt* or high innoculum level to start with?
E. BRUNNER: It is indeed true that the activity of *Bt* deposits decline with the passing of time, depending on formulation type, due to a number of factors such as sunlight radiation, as happens also with many chemical insecticides. However, once *Bt* deposit has been ingested by larvae of susceptible lepidopterous species, the larvae surely succumb, provided that they have ingested enough viable crystals to generate sufficient gastric tract infection. Feeding activity is important, as well as larval body weight, when considering mortality due to *Bt*. Early larval stages are more susceptible to *Bt*, and hence the need for properly timed applications to coincide with the presence of early larval stages. After ingestion of *Bt*, the larvae stop feeding, causing no further damage to the crop, yet the death of these larvae occurs only two to five days later.

R. S. REJESUS: What is your prediction or speculation regarding DBM developing resistance to *Bt*?
E. BRUNNER: Todate, there has been no case reported of development of resistance by any insect species to *Bt* under field conditions. Therefore, we consider it to be extremely unlikely in the case of DBM.

Botanical Insecticides Against the Diamondback Moth

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Abstract

The paper presents a review of the plants reported to be insecticidal against *Plutella xylostella* in other countries and the results of studies in the Philippines. Six plant species (*Aristolochia elegans, A. tagala, Ageratum conyzoides, Blumea balsamifera, Caesalpinia pulcherrima, Derris philippinensis*) from the Philippines have been added to the 82 species previously reported in 1984 to be insecticidal against *P. xylostella*. Extracts from these plants exhibited any one, or a combination of two or more, of the following effects: toxic, antifeedant, repellant, sterilant, and growth inhibiting.

Introduction

The diamondback moth (DBM) *Plutella xylostella* L (Lepidoptera: Yponomeutidae) is considered the most serious insect pest of crucifers throughout southeast Asia. Repeated and continuous chemical sprayings have now resulted in the development of resistance in DBM to insecticides. In the Philippines, the insect exhibited multiple resistance to malathion, methyl parathion, DDT, diazinon, mevinphos, dichlorvos, and carbaryl (Barroga and Morallo-Rejesus 1976). Vegetable farmers in Mountain Province also reported the rapid development of resistance to new groups of insecticides such as cartap and pyrethroids.

The search for alternative ways of controlling this insect has led to the investigation and re-examination of plant sources for naturally occurring compounds which may have toxic, repellant, antifeedant or anti-hormonal characteristics. This paper includes the plants that have been reported to be insecticidal against DBM in other countries and the results of studies in the Philippines.

Insecticidal Plants

Of the 1,800 plant species reported by Grainge et al (1984) to possess pest control properties, only 82 species (Table 1) have been reported to be active against DBM. This information was obtained from literature searches and from responses to a survey received from national and international organizations based in Bangladesh, China, Costa Rica, England, France, Fiji, India, Malaysia, Mauritius, Mexico, New Zealand, Pakistan, the Philippines, Sri Lanka, Switzerland, Thailand, USA, Vietnam, and West Germany.

The plant families Asteraceae, Fabaceae and Euphorbiaceae contain most of the insecticidal plant species reported. The first widely used botanical insecticides, pyrethrum and rotenone, were isolated from plant species belonging to Asteraceae and Fabaceae, respectively.

Table 1. Plants reported in the literature to be insecticidal to DBM

Family/ Scientific name	Common Name	Plant Parts	Activity[a]	Reference
Annonaceae				
Annona reticulata	custard apple	bark, fruit	I, AF, R	Grainge et al 1984, Jacobson 1975
Annona squamosa	sugar apple	roots, fruit, oil	I, CP, SP, AF	Grainge et al 1984, Jacobson 1958
Acanthaceae				
Fittonia argyroneura		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
F. verschaffeltii		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Apocynaceae				
Nerium oleander	common oleander	roots, bark, stem, leaves, flowers	I, AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Araliacea				
Hedera helix		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Aroideae				
Philodendron sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Astereae				
Chrysanthemum cinerariaefolium	pyrethrum	whole plant, flowers	I, AF	Grainge et al 1984
Matricaria matricarioides	rayles chamo	flowers	I	Grainge et al 1984, Jacobson 1958
Senecio cineraria	dusty miller	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Tithonia diversifolia	wild sunflower	leaves	CP	Carino et al 1982, Grainge et al 1984
Balsaminaceae				
Impatiens sultani	zanzibar balsam	leaves	I, AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Begoniaceae				
Begonia pearcei	not known	leaves	I	Grainge et al 1984, Jacobson 1975
Buxaceae				
Buxus sempervirens	common buxus	leaves	AF, R	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Caryophyllaceae				
Dianthus sp		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Celastraceae				
Euonymus japonicus	spindle tree	leaves	R	Grainge et al 1984, Gupta et al 1960, Jacobson 1975

Family/ Scientific name	Common Name	Plant Parts	Activity[a]	Reference
Tripterygium wilfordii	thunder-God vine	roots, tubers bark	I, SP, AF	Jacobson 1958, Swingle 1941
Clusiaceae				
Mammea americana	mamey	roots, tubers, bark	I, CP, SP	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Columelliaceae				
Tagetes erecta	African marigold	roots	CP	Grainge et al 1984, Morallo-Rejesus et al 1978
T. patula	French marigold	roots	CP	Grainge et al 1984, Morallo-Rejesus et al 1978
Commelinaceae				
Tradescantia sp		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Compositae				
Dahlia sp		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Gynura sp		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Convolvulaceae				
Ipomoea batatas		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Citrullus colocynthis	Bitter gourd	roots,tubers, leaves,fruit	I	Grainge et al 1984,
Cucumis sativus		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Ericaceae				
Azalea sp		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Euphobiaceae				
Acalypha indica	Indian nettle	leaves,bark	I	Grainge et al 1984.
Euphorbia lathyris	Caper spurge	leaves	I	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Euphorbia splendens	not known	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
E. poinsettiana Buist		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Phyllantus acuminatus	berryleaf flower	roots, tubers	CP, SP	Grainge et al 1984, Jacobson 1958
Fabaceae				
Derris malaccensis	not known	roots, tubers	I, SP, CP, R, AF	Grainge et al 1984

Family/ Scientific name	Common Name	Plant Parts	Activity[a]	Reference
Pachyrhizus erosus	chinese yam	whole plants, fruits, sap, seeds	I, CP, ST, AF	Grainge et al 1984, Jacobson 1958
Piscidia acuminata	not known	roots, tubers, leaves	I	Grainge et al 1984, Jacobson 1958
Piscidia piseipula	Jamaica dog wood	roots, tubers, bark, leaves	I, CP, SP, AF	Grainge et al 1984, Jacobson 1958
Tephrosia vogelii	vogel tephrosia	leaves, seeds	I, AF, R	Grainge et al 1984
Gentianaceae				
Exacum sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Geraniaceae				
Geranium sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Pelargonium sp.	geranium	leaves, stem, oil	AF, SP, AT, R	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Gesneriaceae				
Negelia hyacinthi	not known	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Coleus sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Leguminoceae				
Calopogonium coerruleum	jicama	seeds, pods	I	Grainge et al 1984, Jacobson 1958
Liliaceae				
Lilium longifiorum	white trumpet	leaves	I, AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Hemerocallis dumortieri	not known	leaves	I, AF	Grainge et al 1984 Gupta et al 1960, Jacobson 1975
Tulipa sp.	tulip	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Malvaceae				
Abutilon pictum		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Hibiscus syriacus		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Marantaceae				
Maranta bicolor		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Mellaceae				
Azadirachta indica	neem tree	whole plant, bark, stem, leaves, fruit, seeds	I, CP, ST, GI, AF, R	Grainge et al 1984

Family/ Scientific name	Common Name	Plant Parts	Activity[a]	Reference
Melianthaceae				
Melilotus officinalis		leaves	R	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Onagraceae				
Fuchsia sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Orchidaceae				
Blettia striata	not known	leaves		
Oxalidaceae				
Oxalis deppei	lucky clover	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Passifloraceae				
Passiflora alata		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Piperaceae				
Peperomia sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Piper nigrum	black pepper	seeds	CP	Grainge et al 1984, Javier 1981
Punicaceae				
Punica granatum	ponegranate	leaves	I, AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Ranunculaceae				
Clematis sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Dalphinium chinensis		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Eranthis hyemalis	winter aconite	bulbs	I	Grainge et al 1984, Jacobson 1958
Rhamnaceae				
Rhamnus crenata	not known	leves	AF	Grainge et al 1984, Gupta et al 1960 Jacobson 1975
Rosaceae				
Rosa sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Rubiaceae				
Chinchona calisaya	Peruvian bark	roots, tubers, bark, wood	I	Grainge et al 1984, Jacobson 1958
Randia nilotica	not known	roots, tubers	I	Grainge et al 1984, Jacobson 1958
Xeromphis spinosa	not known	roots, tubers, fruit	I, AF, R	Grainge et al 1984, Jacobson 1958
Rutaceae				
Citrus aurantium	sour orange	leaves	I, AF, R	Grainge et al 1984, Jacobson 1975

Family/ Scientific name	Common Name	Plant Parts	Activity[a]	Reference
Sapotaceae				
Medhuca latifolia	mahuva	bark, stem, leaves	I	Grainge et al 1984
Madhuca longifolia	mowra	seeds	I	Grainge et al 1984
Saxifragaceae				
Heuchera sanguinea	coral bells	leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Hydrangea sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Simarolibaceae				
Balanites aegyptica	desert date	roots, fruits, seeds	I	Grainge et al 1984, Jacobson 1958
Solanaceae				
Lycopercicum esculentum Mill		whole plant, stem, fruits, leaves	I, AF, R, AT	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Petunia sp.		flowers, leaves	I	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Solanum tuberosum		leaves	AF	Grainge et al 1984, Gupta et al 1960 Jacobson 1975
Solanum sp.		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Theophrastaceae				
Jacquinia aristata	not known	roots, fruits, leaves	I	Grainge et al 1984, Jacobson 1958
Urticaceae				
Ficus carica		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Pellionia pulchra		leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Verbenaceae				
Lantana camara	common lantana	flowers, leaves	AF	Grainge et al 1984, Gupta et al 1960, Jacobson 1975
Vitex negundo	Indian privet	leaves, stem, seeds, oil	I, GI, R	Grainge et al 1984
Vitaceae				
Cissus rbombifolia	Venezuela treebine	stems, leaves	AF, SP	Grainge et al 1984, Gupta et al 1960, Jacobson 1975

[a] I = insecticidal, AF = antifeedant, R = repellent, CP = contact poison, SP = stomach poison, GI = growth inhibitor.

The plant parts used for extraction or assay were the leaves, roots, tubers, fruits, seeds, flowers, the whole plant, bark, sap, pods, bulbs, and wood. The most commonly

utilized part was the leaf (62 species) followed by the root (16 species) and tuber (12 species). A few reports did not specify the plant parts used.

Most of these plants were reported to be insecticidal without specifying the type of action. In these cases I assumed that the reports meant that these plants were toxic as contact and/or stomach poisons. Many plants were reported to be antifeedants.

Only very few plants were assayed using semi-purified or purified extracts. The minimum effective dilution ratio (weight of plants or volume of extract to volume of solvent or diluent) ranged from 1:2 to 1:100,000.

In the Philippines, about 80 plant species have been claimed to be insecticidal against pests of various crops. Sixteen of these species have been bioassayed against DBM (Table 2).

Table 2. List of plants studied for insecticidal activity against the DBM in the Philippines

Family/ Scientific name	English or local name	Plant parts used	Type of extracts	Response[a]	Reference
Aristolochiaceae					
Aristolochia elegans		leaves		A	Caasi 1983
Aristolochia tagala					Caasi 1983
Asteraceae					
Ageratum conyzoides	Bulak manok	leaves	oil	C	PI
Blumiea balsamifera	Sambong	leaves	oil	C	PI
Tithonia diversifolia	Wild sunflower	leaves		C	Carino et al 1982
Caesalpiniaceae					
Caesalpinia pulcherrima	Peacock flower	flowers	oil	C	PI
Columelliaceae					
Tagetes erecta	Big (African) marigold	roots	purified	C	Morallo-Rejesus et al 1978
T. patula	French marigold	roots	purified	C	Morall-Rejesus et al 1978
Fabaceae					
Derris philippinensis	Tubli	root	ethanol	C	Maghanoy et al 1975
Tephrosia vogelii		leaves	chloro-form	C	Reyes 1982
Libiatae					
Coleus amboinicus	Oregano	leaves	oil	C	PI
Meliaceae					
Azadirachta indica	Neem	seeds	oil	C	PI
Menispermaceae					
Tinospora rumphii	Makabuhai	stem	ethanol	C	del Fierro et al 1976
Piperaceae					
Piper nigrum	Black pepper	seeds	ethanol	C	Javier 1981
Verbenaceae					
Lantana camara	lantana	flowers	oil	C	PI
Vitex negundo	lagundi	leaves	oil	C	PI

[a] A = antifeedant, C = contact action, PI = present investigation.

Contact Toxicity

The contact action of the plant extracts was evaluated by topical application and/or leaf spraying. The larvae of the test insect, DBM, were reared on pechay (*Brassica campestris* ssp *chinensis*) leaves. The parent populations were collected from La Trinidad, Mountain Province, and exhibited resistance to malathion. First generation 2nd instar larvae were used. One microliter of diluted extract was topically applied on the thorax. The treated insects were placed in petri dishes containing a cabbage leaf. Treatments, including control (treated with acetone only) were replicated three times. All mortality data were taken at 24 h after the treatment and corrected for natural mortality using Abbott's formula (Abbott 1925) and analyzed using probit analysis (Finney 1971) to determine the LD_{50}.

Table 3. Topical toxicity of plant extracts to second instar larvae of DBM[a]

Plant source	Type of extract[b]	LD_{50} (mg/g body weight)	Fiducial limits (P = 0.05) lower	upper
A. conyzoides	Essential oils	0.423	0.333	0.506
A. indica	"	27.356	22.413	33.644
B. balsamifera	"	1.669	1.508	1.093
C. pulcherrima	"	3.473	3.958	3.981
C. amboinicus	"	0.671	0.453	0.996
L. camara	"	5.498	5.153	6.109
V. negundo	"	3.041	3.342	3.424
T. erecta[c]	purified			
Hybrid				
PA	4.149	3.895	4.421	
PB		4.316	4.053	4.605
Mixture		2.754	2.640	2.886
Local				
PA		1.686	1.605	1.763
PB		12.318	11.731	12.200
Mixture		2.500	1.737	2.289
T. patula[d]	Purified			
PA		1.228	1.088	1.386
PB		12.522	10.859	14.449
Mixture		2.860	2.785	3.053
P. nigrum[de]	chloroform[f]	1.181	1.042	1.361
	ethanol[g]	1.819	1.583	2.083
Tephrosia[dh]	chloroform[g]	11.0	—	—
Tithonia[di]	Fraction D[f]	1.366	1.342	1.389
Malathion		4.488	3.481	5.787

[a] 24 h exposure. [b] Oil extracted by standard method of Osol (1975). [c] From Morallo-Rejesus and Eroles (1978). [d] Evaluated on 3rd instar larvae. [e] From Javier (1981). [f] Semi-purified extract. [g] Crude. [h] From Reyes (1982). [i] From Carino and Morallo-Rejesus (1982).

The topical toxicity of the extracts are shown in Table 3. The LD_{50} values reported previously for other plants are also included for comparison. The pure oils isolated from the leaves of *A. conyzoides, B. balsimefera, C. pulcherrima*, and *C. amboinicus* were highly toxic to the larvae. The LD_{50} values are 3 to 10 times greater than the LD_{50} of malathion. These findings are very significant considering the fact that DBM has already developed resistance to malathion. Barroga and Morallo-Rejesus (1981) reported a 305 fold and 735 fold malathion resistance in College and La Trinidad

populations, respectively. Furthermore, the oil extracts were more toxic than methyl parathion and trichlorfon (Table 4).

In fact, all the plant extracts except for principle B from *T. patula* and *T. erecta* (local) and *A. indica* have lower LD_{50} values than malathion and methyl parathion on resistant populations (Table 4).

Table 4. Reported topical LD_{50} and resistance factor of different insecticides to two populations of DBM[a]

Insecticide	College		La Trinidad		Reference
	LD_{50}[b]	RF[c]	LD_{50}	RF	
Malathion	0.02[d]	S[e]	–[f]	—	
	0.41	17.8	16.77	729.1	Barroga and Morallo-Rejesus 1976
	7.03	305.6	16.91	735.2	Barroga and Morallo-Rejesus 1981
	11.32	492.2	—	—	
Mevinphos	0.02	1	—	—	Barroga and Morallo-Rejesus 1976
	0.04	2	0.04	2	Barroga and Morallo-Rejesus 1981
Acephate	0.97	—	—	—	Morallo-Rejesus and Eroles 1978
Methyl parathion	5.69	463.3	31.97	1389.8	Barroga and Morallo-Rejesus 1976
Dichlorvos	0.34	14.7	2.50	108.7	Barroga and Morallo-Rejesus 1976
Diazinon	0.64	2.8	0.59	25.8	Barroga and Morallo-Rejesus 1976
Trichlorfon	3.13	—	18.20	—	Barroga and Morallo-Rejesus 1981

[a] Two to three day old third instar larvae tested. [b] mg/g body weight. [c] Resistance factor. [d] Unpublished data of Morallo-Rejesus, B. (1972). [e] Susceptible. [f] Data not available.

Antifeedant and Repellent Activity

Antifeedant and repellant activity are being evaluated for some of the plants. A true antifeedant gives insects the opportunity to feed on the plant, but the food intake is reduced until the insects die from starvation (Wright 1963). Repellants, on the other hand, drive the insects away after exposure to the plant without necessarily feeding.

In the present investigation, feeding inhibition or repellency was demonstrated by treating 50 x 50 mm cabbage leaf squares with water extract of the plants under test. The extract was prepared by homogenizing 100 g of the leaves in 100 ml of distilled water (1:1), and then filtering the solutions. Five milliliters of the filtrate was sprayed on both sides of the leaf squares. Each leaf square was then placed in a separate Petri dish. The leaf squares in one series of dishes were air-dried after treatment before the introduction of the larvae (dry method) while the leaf squares in an other series of dishes were treated after the introduction of the larvae (wet method). Leaf squares of cabbage without any treatment and others treated with malathion (0.05%) were included in the tests. All treatments were replicated three times. Ten 3rd instar larvae were used for each replicate. The larvae were starved for six hours before exposure. The leaf squares were exposed to the larvae for 24 h.

The behavior of the larvae was observed immediately after exposure for an hour and the leaf consumption measured after 24 h. The results are given in Table 5. The *C. amboinicus* and *B. balsimefera* treated air-dried leaves were ingested to an appreciable degree and this feeding was more than the feeding on the control leaf. Of the eight plant species tested, the extracts from the leaves of *C. pulcherrima, T. diversifolia, L. camara, A. tagala* and *A. elegans* greatly reduced feeding regardless of the method of treatment. This indicates that the extract contained chemical(s) which deter feeding. The extracts of *V. negundo* and *T. erecta* were inhibitory only when the cabbage leaf squares

were sprayed after the introduction of DBM larvae. In all plants tested, more feeding was observed on air-dried leaves than on wet leaves. Probably, the component(s) of the extract which deter feeding were volatilized during drying. The reduced feeding on wet leaves could be either due to direct toxic action of the extract on the larvae and/or to the presence of a feeding deterrent as exhibited by the *L. camara* leaf extract, which is both toxic and antifeedant (Table 6). Note that 76.7% mortality was exhibited at 24 h when the leaf squares were sprayed after introduction of the larvae.

Table 5. Feeding of DBM on cabbage leaves treated with various plant extracts

Plant extract	Area consumed[a] (cm^2)
T1 C. amboinicus (D)[b]	10.17a
T2 (W)[c]	6.33abc
T3 B. balsimefera (D)	7.17abc
T4 (W)	7.25ab
T5 V. negundo (D)	7.75ab
T6 (W)	1.02g
T7 T. erecta (D)	4.17cde
T8 (W)	1.83efg
T9 L. camara leaves (D)	2.25def
T10 (W)	1.00g
T11 L. camara seeds (D)	7.17abc
T12 (W)	6.08bcd
T13 L. camara flowers (D)	5.75bcd
T14 (W)	5.08bcd
T15 C. pulcherrima leaves (D)	3.02defg
T16 (W)	0.92g
T17 A. elegans (D)	1.92efg
T18 (W)	1.58fg
T19 A. tagala (D)	2.42efg
T20 (W)	1.42fg
T21 T. diversifolia (D)	2.48efg
T22 (W)	1.65fg
T23 Standard	6.75abc
T24 Control	5.50bcd

[a] Average of three replicates, means followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [b] Leaf square was air-dried after spraying before introduction with larvae. [c] Leaf square was sprayed with larvae on it.

Table 6. Mortality of DBM larvae exposed to cabbage leaf squares treated with water extracts from *L. camara*

Treatments[a]	Mean moratlity (%) after			Total mortality %
	24 h	48 h	72 h	
Sprayed and introduced	26.7	6.7	50.3	83.7
Sprayed with insect	76.7	3.3	6.7	100
Air dry and introduced	10	3.3	26.7	40.0
Control	0	3.3	20.0	23.3

[a] Leaf squares sprayed with 1 ml of 1 g/ml extract with and without the larvae placed on the leaves.

No repellant activity was observed in one hour. At 24 h all larvae were still on the leaf. Perhaps the extract inhibited the dispersive tendencies of the larvae. Gupta and

Thorsteinson (1960) reported that the odor of the essential oils prevents the larvae from wandering away from the food plant. The purified extract of *T. erecta* and *T. patula* was also reported to be non-repellant to the larvae (Morallo-Rejesus and Decena 1982).

Caasi (1983) conducted an intensive study into the growth inhibitory and antifeedant effects of *A. tagala* and *T. elegans*. She evaluated the antifeedant effect of ethanolic crude extract by two methods: 'no-choice' and 'choice' experiments. Five milliliter of 0.1 g/ml of the extract was sprayed on the cabbage leaves. After air-drying, the leaves were placed in Petri dishes and arranged in a circular fashion. In the choice tests, untreated leaves were included and the third instar larvae were released in the center of the cage. For no choice tests, insects were placed on the treated leaves.

The feeding of the larvae as an indicator of antifeedant effect was determined by the weight gain or loss in the larvae at 24 h. Behavioral observations were made for two days at 30 min, 1 h and 2 h, intervals thereafter.

The number of larvae that visited the treated cabbage leaves was much lower as compared to the control (Figure 1). The number of larvae found on the untreated cabbage leaves increased with time. Extracts of both *T. tagala* and *T. elegans* proved repellant to the larvae.

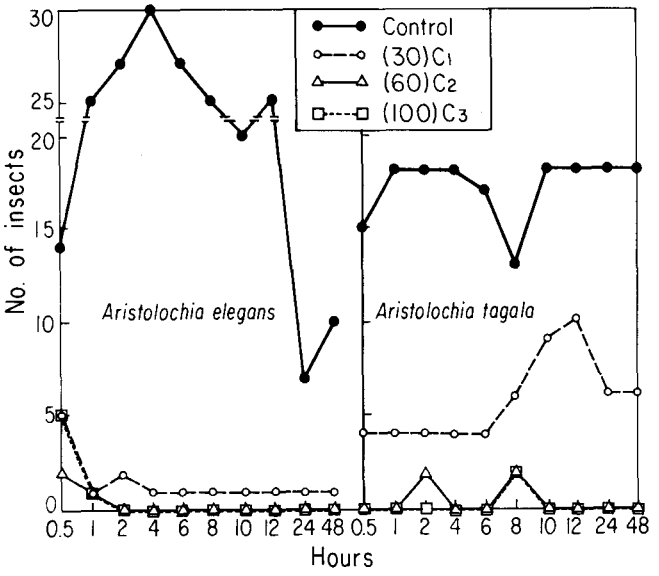

Figure 1. Response of DBM to the extracts of *A. elegans* and *A. tagala* as indicated by the number of larvae that visited the cabbage leaves treated with either *A. elegans* or *A. tageta*. Free-choice test, 30 insects per test. $(30)C_1 = 30$ mg/ml, $(60)C_2 = 60$ mg/ml, $(100)C_3 = 100$ mg/ml extract

In the no-choice test, almost 75% of the test larvae moved away from the leaves treated with either 60 or 100 mg/ml extract (Figure 2). The extracts, therefore, were less repellant at lower concentrations where more than 50% of the test larvae remained on the leaf.

Significantly less feeding was observed on the treated leaves (Table 7). The data indicate that although the insects remained on the leaves, most of them did not feed. Larval weights were much lower for larvae which fed on the treated leaves than those that fed on the control leaves. The antifeedant effect is demonstrated by the percent

weight loss observed after 24 h (Table 8). The inhibitory substance in *A. elegans* and *A. tagala* could be the aristolochic acid which is present in the plant, as suggested by the histochemistry test.

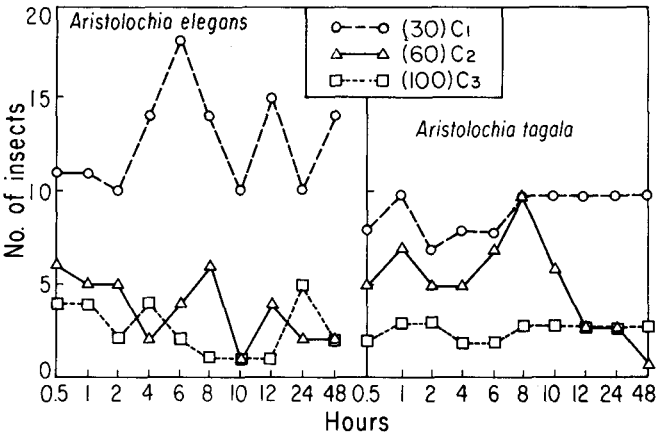

Figure 2. Response of DBM to the extracts of *A. elegans* and *A. tagala* as indicated by the number of larvae that visited the cabbage leaves treated with either *A. elegans* or *A. tageta*. No-choice test, 30 insects per test. (30)C_1 = 30 mg/ml, (60)C_2 = 60 mg/ml, (100)C_3 = 100 mg/ml extract

Table 7. Consumption of *Aristolochia* extract treated cabbage leaves by DBM larvae[a]

Concentration (mg/ml)	Leaf area (cm^2) consumed/larva			
	A. elegans		*A. tagala*	
	Choice	No-Choice	Choice	No-Choice
Control	20.00a		12.5a	
C1 30	2.25b	3.88a	0.67b	3.67a
C2 60	0.75b	1.19b	0b	1.40b
C3 100	0.25b	1.12b	0b	0.38b

[a] Leaf squares sprayed with 1 ml of 1 gm/ml extract with and without the larva. Source: Caasi 1983.

Table 8. Body weight gain or loss in DBM larva fed with cabbage leaves treated with *Aristolochia* extracts[a]

Time	Control	Weigh gain (+) or loss (−) at concentration (mg/ml)		
		30	60	100
		A. elegans		
12	+0.040	+0.0063	+0.0042	+0.0035
24	+0.028	−0.0023	−0.0014	−0.0114
48	+0.045	−0.0132	−0.023	−0.0063
		A. tagala		
12	+0.013	+0.0160	+0.0063	+0.0042
24	+0.066	−0.0027	−0.0023	−0.0014
48	+0.073	−0.076	−0.0130	−0.023

[a] After 24 h, based on 30 3rd instar larvae. Source: Caasi 1983.

Growth Inhibitory Effects

The growth inhibitory effects of *Aristolochia* spp were studied by Caasi (1983). Thirty 3rd instar larvae were reared on pechay leaves treated with 5 ml of 0.1 g/ml of the solution. The number of normal pupae, and of normal adults which emerged, was noted. The percent pupation and adult emergence are presented in Table 9.

Table 9. The rate of normal pupation and adult emergence in DBM larvae reared on pechay leaves sprayed with *A. elegans* extracts[a]

Concentration (mg/ml)	Normal Pupae (%)	Normal Adults (%)
Control	83.3	76.6
30	40.0	6.7
60	23.3	0
100	13.3	0

[a] Based on 30 3rd instar larvae. Source: Caasi 1983.

The toxic and growth inhibitory effects of *A. elegans* ethanol extract on DBM were very apparent. Larval and pupal mortalities were observed. At 60 and 100 mg/ml concentrations there was no adult emergence. In this experiment 75% of the larval population was observed to move away from the treated cabbage leaves and die from starvation. Those larvae that fed did pupate but there was no adult emergence.

These results clearly indicate that *A. elegans* contains a growth inhibitory substance. The abnormalities observed were very similar to those observed on corn borer, on cutworms, and on DBM treated with *Attacus* juvenile hormone and triflubenzuron (Morallo-Rejesus 1979, Paguia and Morallo-Rejesus 1980, Morallo-Rejesus and Alcala-Carilo 1981). The results indicate that the principle has a juvenile hormone-like action.

Identification of the Active Principles

The active principles from *T. erecta* roots were identified as 5-(3-butenyl l-l-ynl)2-2 bithienyl (PA) and alpha-terthienyl (PB) (Morallo-Rejesus and Decena 1982). Principle A shows a strong blue fluorescing broad zone (fractions 2-31 by column chromatography) and is immediately followed by principle B (fractions 32-100) which is greenish and less fluorescing. The crystals recovered from roots were 0.03-0.04% by weight of principle A and 0.01-0.02% of principle B.

Gas chromatographic analysis of *T. vogelii* crude extract showed that it contains 1.20% rotenone while the liquid concentrate from this extract and leaves contained 3.0 and 0.70% rotenone respectively (Reyes 1982).

The active fraction D from *T. diversifolia* contains alpha-lactone with a hydroxyl group attached either to the lactone ring or to the alkyl substituent (Carino and Morallo-Rejesus 1982). The unsaturation may be present in the ring itself or alpha to the carbon as indicated by the strong IR absorption at 1670 cm^{-1} and by the failure of the sample to decolorize bromine in carbon tetrachloride. The histochemistry of *Aristolochia* showed the presence of aristolochic acid, saponins, alkaloids, and tannins. The general natural components of Philippine plants were reported in a review by Santos et al (1981).

Studies of the characterization and identification of active insecticidal principles of the other plants are being pursued at the University of the Philippines at Los Banos.

Prospects

The latest data presented in this paper are a part of my ongoing five-year project on 'Isolation, Bioassay and Field Evaluation of Philippine Plants. I. Shrubs and Weeds' which was started in November 1983. The initial findings indicate that there are plants that are toxic, antifeedant, repellant, and growth inhibiting to the DBM.

Four of the plants, (*B. balsimefera, C. pulcherrima, C. amboinicus, C. negundo*) which were found to be highly toxic against DBM, are being used already by the people in rural area as medicinal plants for fever, diarrhea, headache, malaria, and so on. These plants can easily be grown and multiplied in farmers' backyards.

These positive findings could pave the way for the development of a safe, potent, and cheaper plant protection component, which could be used either alone or in combination with other methods in the future to make crucifer production non-polluting, non-hazardous and at the same time profitable, especially in the developing countries.

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The Potential Use of CME 134 for the Control of Vegetable Pests

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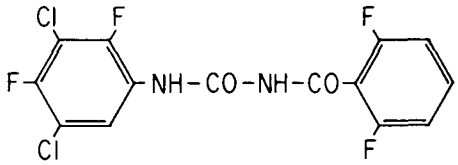
Abstract

CME 134 is an insect growth regulator of the benzoyl urea group. Its proposed common name is teflubenzuron. CME 134 is active as a stomach poison, interfering with chitin formation. It has ovicidal properties and may influence the fecundity of adult beetles and to a certain extent also of moths. It also controls insecticide-resistant insect strains. Its extremely low acute mammalian toxicity and its species-specific activity make it an interesting insecticide which also fits into IPM programs. A broad spectrum of beneficial arthropods is not harmed at concentrations that are considered for practical use. Preliminary residue data indicate that withholding periods in edible crops can be expected to fall in the range of conventional insecticides, and may even be shorter. Due to the excellent rain fastness of the SC formulation, the number of sprayings can be reduced in some crops.

Introduction

CME 134, 1-(3, 5-dichloro-2, 4-difluorophenyl)-3-(2, 6-difluorobenzoyl)-urea, is an insect growth regulator belonging to the benzoyl urea group. It is being produced by Celamerck GmbH & Co. KG and is formulated as a suspension concentrate containing 150 g AI/liter. Its proposed common name is teflubenzuron and it has the following chemical structure:



It is a stomach poison and interferes with chitin synthesis in immature lepidopterous and coleopterous insects and is relatively non-toxic to most beneficial arthropods (Becher et al 1983).

In laboratory studies, CME 134 appeared to be more active at lower dosages than was diflubenzuron against diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae) and *Spodoptera littoralis* larvae (Becher et al 1983). In several registration trials conducted in Asia (Kohyama 1985, Sagenmueller and Rose 1985) and elsewhere, CME134 has given excellent control of DBM. This report gives brief basic information on the compound and the results obtained on certain vegetable pests.

Toxicology

Studies concerning the acute toxicity, the skin and eye irritation potential, the teratogenicity, and the mutagenicity (Ames-test and micronucleus test) are completed.

CME 134 is not acute toxic (LD_{50} for rats being greater than 5000 mg/kg) and skin and eye irritations are not induced. It is not mutagenic or teratogenic in rats up to 250 mg/kg body weight, the highest rate tested. In the 90 days feeding study with rats, the no-effect level was 100 ppm AI.

In ecotoxicological studies with fish (carp and rainbow trout) and algae, LC_{50} and EC_{50} figures could not be determined as CME 134 proved to be non-toxic to these organisms.

Mode of Action

Stomach poison activity

CME 134 interferes with chitin synthesis after ingestion and is active mainly against the larval stages of insects. The formation of the exoskeleton is disturbed, and as a result during moulting the larvae cannot free themselves from the old cuticle. Due to this mode of action the chemical has slow initial activity. Its activity is also dependent on environmental conditions like temperature which influences feeding activity and metabolism in the larvae. Full activity, therefore, can only be seen about seven to eight days after treatment. The treated larvae, however, show symptoms of CME 134 treatment a few days after chemical application. Their movement and feeding activity are reduced which results in reduced crop damage by these insects.

Due to this mode of action it is necessary to apply CME 134 as early as possible, especially to control freshly hatched larvae which do not cause heavy damage. When moulting to the next larval stage, the effect of the treatment will be visible, provided the larvae have ingested lethal doses of the chemical.

It has not yet been possible to determine which of the larval stages is most sensitive to CME 134 treatment. If the chemical is applied just before moulting, the ecdysis passes symptomless as the necessary chitin synthesis has already taken place. These larvae, however, show distinct CME 134 poisoning, provided, that they continue feeding on treated surface, soon after moulting.

It has been observed that the phenology of the host plant, and prevailing temperature, greatly influence the effectiveness of the treatment.

Ovicidal activity

In addition to the stomach poison activity in larvae, CME 134 also shows ovicidal activity which is species-specific and is dependent on the age of the eggs. In laboratory tests, the ovicidal effect was evaluated with *Carpocapsa pomonella* L eggs of various ages. Serial dilutions of CME 134 15 SC were prepared into which young (two-day to three-day old) and older (five-day to seven-day old) eggs were dipped for five seconds and incubated at 21 to 23 °C and 80% RH. The results of the twice replicated tests (Figure 1) indicate that hatching was completely suppressed with 5 ppm AI in young eggs, whereas with older eggs 100% reduction in hatchability could only be achieved when mineral oil was added to the CME 134 dilution. For practical use, this means that spraying should be done at the beginning of egg-laying in order to take full advantage of the ovicidal potential of CME 134.

Similar findings were obtained from tests with *Cryptophlebia leucotreta* Meyr on citrus. Dipping of citrus fruit on which female moths had layed eggs did not reduce the hatchability to the same degree as could be achieved when females deposited their eggs on fruits already dipped in CME 134.

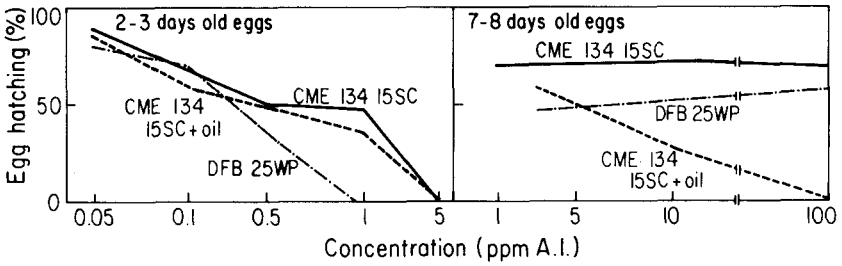


Figure 1. Ovicidal activity of CME 134 15SC on codling moth eggs of various ages

Contact toxicity

Although for chitin synthesis inhibition activity CME 134 must be ingested, a certain contact activity was also observed with *Spodoptera littoralis* Boisd larvae of two larval weight groups. Exposing 100 mg larvae for 90 min to CME 134 residues in petri dishes resulted in 73% larval mortality with 0.0005 g AI/m^2 (ED_{50} being 0.00033 g AI/m^2). Two hundred milligram larvae were not affected at the larval stage, but the ED_{50} for cumulative percentage mortality up to the adult stage was 0.00017 g AI/m^2 (Ascher and Nemny 1984). The same authors also demonstrated the contact activity of CME 134 to *S. littoralis* by topical application.

Contact activity has also been observed to a certain extent in other insects, but the effect of this mode of action is of lesser magnitude than the effect from feeding.

Influence on reproduction

That CME 134 influences reproduction in insects was first observed in laboratory tests with *Epilachna varivestis* Muls when adults, after feeding on CME 134 treated beans, layed sterile eggs (Becher et al 1983). Similar effects were observed in laboratory tests with *Anthonomus grandis* Boh, *Sitophilus granarius* L, and *Carpophilus hemipterus* L. The results from tests with *Leptinotarsa decemlineata* Say are given in Figure 2. After feeding for two days on CME 134 treated potato foliage, females layed sterile eggs.

Although CME 134 treatment results in complete inhibition egg hatching in Coleoptera, in Lepidoptera, until now, the level of sterilization has proved to be only

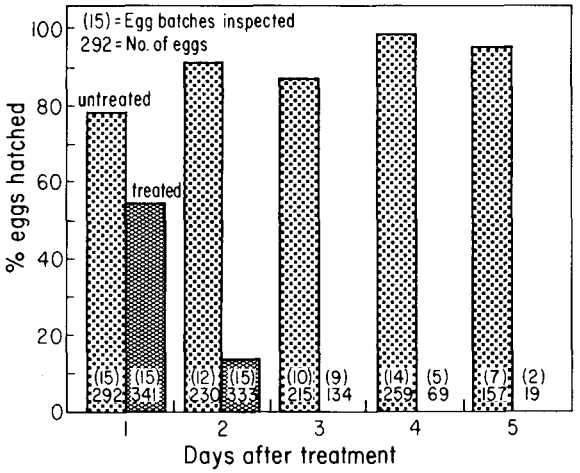


Figure 2.
Influence of CME 134 on the reproduction in *Leptinotarsa decemlineata*

moderate. This is probably correlated to the specific feeding behavior of adult moths, which do not take up enough of the chemical to effect complete sterilization. Tests with *Cnaphalocrocis medinalis* Guen achieved 55-79% sterility of eggs after keeping females for two days in contact with CME 134 in a petri dish. Whether oral uptake of the chemical by the female moth will result in more complete sterility of eggs needs to be investigated.

Timing of Application

The timing of CME 134 application influences its effectiveness. Comparative trials were carried out in 1983 and 1984 in field corn against *Ostrinia nubilalis* Hubn using different application dates. The results show that with too early spraying (when the moths first appear) the full insecticidal potential is not achieved. This is attributed to the dilution effect caused by the growth of the plant after spraying until the hatching of the young larvae. Drawing on this experience, it appears necessary to apply CME 134 strictly according to official spraying recommendations (Table 1).

Table 1. Influence of timing on the effectiveness of CME 134 against *Ostrinia nubilalis*

Chemical	Rate l/ha	Control (%) when sprayed at[ab]	
		Beginning of moth flight activity	Two weeks after start of moth flight activity
CME 134 SC 15	1.0	71.9 (2)	87.3 (2)
Deltamethrin EC 25 g/l	0.5	75.7 (1)	91.3 (1)
Tetrachlorvinphos EC 700 g/l	3.0	—	76.9 (1)

[a] In untreated check plots, 539 live larvae were found in 200 maize plants. [b] Figures in the brackets indicate the number of trials.

Rain Fastness of the CME 134 Formulation

The rain fastness of the SC formulation of CME 134 was studied under laboratory and field conditions in the United States. Tender oak seedlings were sprayed in a laboratory chamber using five seedlings per CME 134 treatment dose. After two hours of drying, 20 newly moulted 2nd instar larvae of gypsy moth, *Lymantria dispar* L, were introduced onto each treated plant. Simultaneously another group of CME-134 treated oak seedlings was subjected to simulated rainfall after the insecticide spray layer had been allowed to dry for two hours. After the 'rainfall', the plants were dried again before 2nd instar larvae of gypsy moth were introduced. The results, given in Table 2, indicate that one week after spraying there was no difference in the insect mortality between two treatments.

Table 2. Effectiveness of CME 134 against *Lymantria dispar* after artificial rainfall[a]

CME 134 AI kg/ha	Rainfall (mm)	Mortality (%) at days after treatment		
		2	3	7
0.073	0	16	56	100
0.073	25.6	6	38	100
0.036	0	5	48	100
0.036	25.6	3	50	100
check	—	3	3	3

[a] Source: Dr. W. H. McLane, USDA, Otis Air National Guard Base, MA, USA, unpublished data.

Ascher and Nemny (1984) also report excellent resistance to weathering, when in controlled field and laboratory tests the residual activity of CME 134 SC 15 was tested against *S. littoralis*. Their findings confirm our laboratory test results with *S. littoralis*. In our study, sprayed bean plants were exposed to normal weather conditions for a period of five weeks during which 52.5 mm rainfall was recorded. The leaves were sampled at 0, 2, 3, 4, and 5 weeks of weathering and fed to *S. littoralis* caterpillars. Insect mortality data were recorded at two and five days after feeding. The results are summarized in Table 3. CME 134 gave 100% insect mortality from leaf samples taken up to 5 weeks of weathering.

Table 3. Influence of weathering of dried CME 134 spray layers under field conditions on its effectiveness against *Spodoptera littoralis* in the laboratory

Formulation	Spray concentration (ppm AI)	Insect mortality (%) at weeks of aging[a]				
		0	2	3	4	5
CME 134 15 SC	10	100	100	100	98	100
"	50	100	100	100	100	100
Diflubenzuron 25 WP	10	96	47	42	33	4
"	50	100	66	70	56	37
untreated check		3	3	3	0	0

[a] Mortality counts were taken at five days after the caterpillars were fed on treated bean leaves.

Toxicity of CME 134 to Beneficial Arthropods

According to laboratory and field trials, CME 134 has not shown any adverse effects on a wide range of beneficial arthropods when applied at rates which are considered practical. Beneficial arthropods which were not harmed by the chemical were: *Aphytis holoxanthus, Campoletis* sp, *Coccophagus rusti, Coccygomimus turionellae* L, *Drino inconspicua* Meig, *Geocoris* sp, *Nabis* sp, *Orius* spp, *Typhlodromus pyri* and spiders. Laboratory tests with *Encarsia formosa* Gah indiate that, although certain larval mortality could be observed, severe damage of this parasite by CME 134 is unlikely to occur (Oomen and Wiegers 1984). Although laboratory tests with the honey-bee, *Apis mellifera* L, showed that at concentrations considered practical, CME 134 will not harm the brood. However, erratic results from field trials indicate that there is need for more detailed investigations into possible effects under field conditions. The effect of CME 134 on larval coccinellids also needs further investigation.

Biological Experience from Vegetable Trials

Results of CME 134 trials with forest trees, apples, pears, grapes, and field crops have been reported recently (Adlung et al 1984, Becker et al 1984, Holtmann et al 1984). Extensive experience on the performance of CME 134 has been gained with vegetable crops including cabbage, cauliflower, red cabbage, Chinese cabbage, brussels sprouts, and broccoli. In Europe the most important lepidopterous pests, like *Pieris brassicae* L, *P. rapae* L, *Mamestra brassicae* L, and DBM, can be controlled at reasonable dosages by CME 134.

Based on the encouraging results obtained in our own trials, official trials have been conducted since 1983 in Germany. Although, according to the existing trial procedures, evaluations have been carried out 1, 3, and 7 days after treatment — which in respect to the mode of action of an insect growth regulator would usually be too

short — the results are positive. In some cases, even during this short observation period up to 100% insect mortality was observed. Hommes (1984) reported that CME 134 at a rate of 60 g AI/ha was the most effective of the tested insect growth regulators. After three applications at fortnightly intervals it not only controlled detrimental caterpillars in round cabbage, but also reduced feeding damage with comparable effectiveness as a mixture of deltamethrin + pirimicarb.

In the Netherlands, where in 1983 CME 134 was tested at 90 g AI/ha against *Mamestra brassicae* on brussels sprouts, excellent control was achieved resulting in high quality marketable yields. The results indicated that lower rates could be expected to perform well. Therefore in 1984 rates from 30 to 60 g CME 134 AI/ha were tested. The results indicated that the higher rate gave a better reduction of feeding damage than the 30 g AI/ha. The addition of a spreader slightly increased the efficacy of the treatment, and this was also observed with red cabbage and cabbage in Germany. Nevertheless, it is not necessary to mix CME 134 with spreaders because of the excellent rain fastness of CME 134 15 SC.

In the United States CME 134 has also been tested since 1982. Rates from 16.5 to 33 g AI/ha in many cases were as effective as fenvalerate and metamidophos standards. The CME 134 treatments increased the percentage of marketable heads of cabbage. The major target insects were *Pieris rapae* and *Trichoplusia ni* Hubn.

Spodoptera frugiperda J. E. Smith, a leaf folder of tomato, was controlled by CME 134, whereas *Heliothis zea* Boddie may continue to cause damage when feeding inside the fruits. Preliminary results from trials for the control of *Liriomyza* spp on tomatoes are not very encouraging since the adults cannot be effectively controlled by an insect growth regulator. Due to the peculiar egg-laying behavior of this insect, ovicidal activity of CME 134 should not be expected. In none of these trial could aphids be controlled using this chemical. On leek, *Acrolepia assectella* Zell was better controlled by CME 134 than by methomyl.

Residue Studies

Supervised trials in Germany have been carried out on potatoes, maize, Savoy cabbage, apples, and grapes. Generally the residues in food crops at harvest time are at a low level. In Savoy cabbage, CME 134 is only detectable during the initial phase after application; the highest level at application date amounted 0.99 ppm.

Discussion and Outlook

CME 134 is a selective insecticide of low mammalian toxicity. It controls lepidopterous and coleopterous defoliators and mining insects of sawfly species. Its insecticidal activity, although slow in the initial stages, can in many cases be compared with that of conventional organophosphorous or pyrethroid insecticides. At the same time it is harmless to a large number of beneficial arthropods at rates which effectively control detrimental pre-imaginal stages of pests. Thus this insecticide fits well into integrated pest management programs.

Since the growing habit of the plant is of importance for the performance of CME 134, crops with especially reduced terminal growth give good results. In crops which do not grow rapidly after treatment, such as cabbage, soybeans, and potatoes, the grower can take advantage of the residual activity of this insect growth regulator.

CME 134 can be applied according to conventional recommendations and can be used effectively for the control of insecticide resistant insect strains. For a final estimation

of its performance, it is essential not only to evaluate its insecticidal activity as judged by insect mortality, but also to consider its potential in preventing crop damage and in increasing yields. Insect larvae, after feeding on the protective spray layer, stop feeding and become sluggish. This reduces crop damage without immediate insect kill.

In instances where a mixture of pest species need to be controlled but certain species, such as aphids, are not controlled by CME 134, a tank mixture of CME 134 with other insecticides can be utilized. It must be understood, however, that by mixing CME 134 with non-selective chemicals, certain advantages of this insect growth regulator may be lost. Care should be taken, therefore, when selecting a tank mixture chemical.

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Insecticidal Activity of MK-139 (CME 134) Against Diamondback Moth

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Abstract

A chitin synthesis inhibitor, MK-139 (CME 134) (1-(3,5-dichloro-2, 4-difluorophenyl)-3-(2, 6-difluorobenzoyl)-urea) was tested on various stages of diamondback moth, *Plutella xylostella*. The hatching of the eggs that were oviposited on the MK-139-treated surface, or that were dipped into an aqueous solution of MK-139 was greatly inhibited. When different instars were fed on an MK-139-treated diet until pupation, the activity of MK-139 did not differ with the instar under test. Treatment of larvae at the final instar stage with a low concentration (0.04 ppm) of MK-139 resulted in inhibited reproduction of the adults derived from treated larvae. In a field trial, MK-139 controlled a strain of *P. xylostella* against which a mixture of pyrethroid and organophosphorus insecticides was not effective.

Introduction

The insecticidal activity at CME-134(1-(3, 5-dichloro-2, 4-difluorophenyl)-3-(2, 6-difluorobenzoyl)-urea) was first discovered by scientists at Celamerck GmbH. This chemical is patented by Celamerck, and Mitsubishi Chemical Industries Limited is developing it under the code number of MK-139 in Japan and certain other Asian countries. In many laboratory tests and field trials, MK-139 exhibited exceptionally good insecticidal activity against Lepidoptera, Coleoptera and Hemiptera species (Becher et al 1983).

It is well known that benzoylphenyl urea insecticides affect the development of various stages of insect (Hammann and Sirrenberg 1980, Hajjar and Casida 1979). Some test results suggest that MK-139 influences various stages of diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae). This report describes the influence of MK-139 on the eggs, larvae, and adults of DBM.

Materials and Methods

Activity against adults

The acetone solution of MK-139 was applied on a glass petri dish to make a dry film of the active ingredient. The solution was allowed to evaporate for two hours. Male and female pupae, just before adult emergence, were placed on the treated dish separately. The insects were maintained at 25 ± 1 °C and 65 ± 5% RH. The newly emerged moths were allowed to remain in contact with the MK-139 film for two days. One treated female moth was mated with one treated male moth. The number of eggs laid per female and the hatchability were investigated two days after the initiation of oviposition and five days after the end of oviposition, respectively.

Activity against eggs

Pre-treatment Cabbage leaves, ca 5 cm long, were dipped into an aqueous solution of MK-139 for one minute. The aqueous solution used for all tests contained different concentrations of MK-139 and 200 ppm of the spreader, Sorpol 3005X. After drying, the treated and untreated leaves were left in a plastic cage (35 cm x 27 cm x 30 cm) where 100 pairs of three day old adult moths were maintained. The insects were maintained at 25 ± 1 °C and 65 ± 5% RH. The adult moths were allowed to oviposit on the leaves for 12 h. The hatchability of eggs laid was investigated five days after oviposition.

Post-treatment The untreated cabbage leaves were left in a plastic cage where 100 pairs of three-day old moths were kept. The adult moths were allowed to oviposit on the leaves for 12 h. The leaves with DBM eggs on them were dipped into an aqueous solution of appropriate concentration of MK-139 for one minute. After drying, the treated leaves were maintained at 25 ± 1 °C and 65 ± 5% RH. The hatchability of the treated eggs was investigated five days after the end of oviposition.

Activity against larvae

Pieces of cabbage leaf (4 cm x 4 cm) were dipped into an aqueous solution of appropriate concentration of MK-139 for one minute. After drying, the treated leaf pieces were fed to 1st instar larvae of DBM. The MK-139-treated leaf pieces were fed successively and changed once every three days. The larvae were bred on treated leaf pieces until they became pupae. In the case of tests with 2nd, 3rd, and 4th instar larvae, insects freshly emerged from molting were used. The other procedures were similar to those of the tests with 1st instar larvae. All insects were maintained at 25 ± 1 °C and 65 ± 5% RH. Mortality of larvae, pre-pupae, and pupae was recorded five days after treatment irrespective of the stage at which the insects had been treated. The death of each pre-pupa and pupa was confirmed by the nature of pupation or the absence of adult emergence from the pupae. LC_{50} value was calculated by the probit analysis (Bliss 1935).

Inhibition of reproduction by MK-139

Cabbage leaves were dipped into an 0.04 ppm aqueous solution of MK-139 for one minute. The 4th instar larvae, within three hours after molting, were fed with treated leaves until they became pupae. Male and female larvae were bred separately. The pupae derived from the treated larvae were graded by their appearance. Only pupae that appeared normal were used for the test, in order to give the best chance of effective mating. In each case one male and one female pupa derived from treated larvae were put into plastic cup (7 cm diam). The progress of each pair was observed until death. The male/female pairings were as follows:

Treated female x untreated male
Untreated female x treated male
Untreated female x untreated male

The oviposition period, when females did lay eggs, was two days. The number of eggs laid, and their hatchability, were investigated.

Field trial

An official field trial of MK-139 was conducted at Aira-gun, Kagoshima prefecture, Japan where a DBM strain has developed resistance to pyrethroids. Each insecticide was

sprayed twice onto the cabbage at a spray volume of 2000 liter/ha for the first application and 3000 liter/ha for the second application, respectively.

Results and Discussion

The number of eggs laid by MK-139 treated DBM adults was less than those laid by untreated adults (Figure 1). The higher the MK-139 concentration, the lower the number of eggs laid. Similarly, the total number of eggs hatched was reduced considerably by MK-139 treatment of the adult insects. The higher the MK-139 concentration, the lower the number of eggs hatched. Statistically, however, the difference between the numbers of eggs laid and eggs hatched for untreated and treated insects was not significant. It is likely that MK-139 has an adverse effect on the reproduction in adults, but the effect is rather weak. Becker (1985) reports similar effects when *Lymantria dispar* was treated with CME-134.

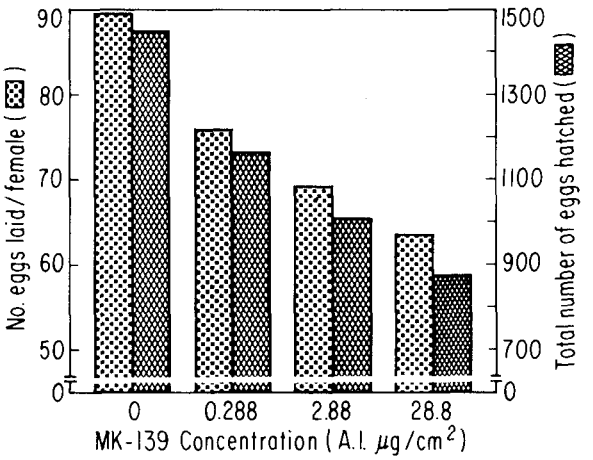

Figure 1.
Influence of adult exposure to MK-139 film on the fecundity of DBM

The hatching of DBM eggs laid on the cabbage leaves treated with MK-139 (pre-treatment) was greatly reduced (Figure 2). As described above, contact with MK-139 did not greatly reduce the fecundity of the adults. Therefore, the reduction of egg hatch is considered to be caused by the contact of eggs with the MK-139-treated surface. Although the contact area between egg and treated cabbage was quite small, most of the eggs did not hatch even at a 5 ppm concentration.

Egg hatching was markedly inhibited by the dipping of the eggs into an aqueous solution of MK-139 (Figure 2). In this test, the ovicidal activity of MK-139 was very high and most of the treated eggs did not hatch even at a 0.5 ppm treatment. The intensity of egg hatch inhibition—as reflected in EC_{50}—by treatment after the eggs were laid was six times higher than when cabbage leaves were treated prior to egg laying. This difference is considered partially due to the difference in area of eggshell that came in contact with MK-139. In both tests, the embryo of the unhatched egg when treated with MK-139 developed completely but could not hatch from the eggshell.

Since the lifecycle of DBM is relatively shorter than that of most other lepidopterous species, and because MK-139 acts quite slowly, it is difficult to evaluate the activity of MK-139 against DBM within one larval stage. For this reason, mortality at five days after treatment of larvae, irrespective of whether the insect was still larva, or had become pre-pupa or pupa, was used for the calculation of the LC_{50} value presented in Table 1. The LC_{50} values did not vary with the instar at which treatment started. This result

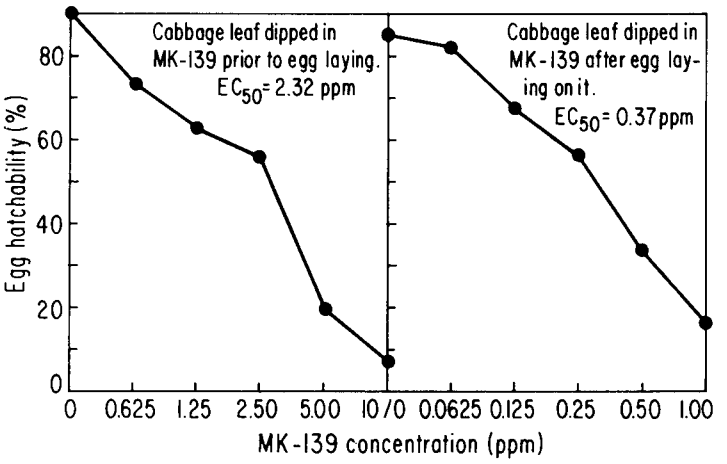

Figure 2. Hatchability of DBM eggs treated with MK-139 by two different methods

Table 1. Susceptibility of various larval stages of DBM exposed to diet containing MK-139[a]

Starting stage	LC_{50} (ppm)[b]
1st instar	0.027
2nd instar	0.061
3rd instar	0.039
4th instar	0.051

[a] Fifty larvae of each stage were used for the test. [b] At five days after treatment.

suggests that a mixed instar population can be controlled by one appropriate dosage of MK-139.

Feeding of 4th instar larvae on a diet containing MK-139 had significant adverse effect on reproduction of adults deriving from such larvae (Table 2). Hatchability of eggs from a combination of untreated female x treated male was very low. This may be attributable to sterilization and/or loss of mating ability of the male moth caused by MK-139 treatment. In this combination, although the female was untreated, fecundity was reduced considerably. This phenomenon may have been caused by the absence or reduction of oviposition stimulation by the male. In combinations of treated females x untreated males, the numbers of females that laid eggs decreased to one fourth that when untreated females mated with untreated males. Treatment with MK-139 also decreased significantly the number of eggs per treated female. The effects on the reproductive activity of both sexes are considered significant in suppression of population of succeeding generations.

The results of the field test to investigate the control of DBM by MK-139 are shown in Table 3. DBM could not be controlled by the application of a combination of fenvalerate and malathion. Application of MK-139 gave good control of DBM. MK-139 was slightly superior to IKI-7899. There was no indication of cross-resistance between pyrethroid and both benzoylphenyl urea insecticides.

In conclusion, it is obvious that MK-139 affects various stages of DBM. If MK-139 does not exhibit activity on the stage actually treated, the succeeding stage may be affected. For instance, treatment of larvae causes pupal death or inhibits the reproduction

of adults derived from treated larvae. This unique activity should contribute to the effective control of DBM.

Table 2. Effect of feeding of DBM larvae on a diet containing MK-139 on the reproduction in adults

Mating combination	No. of pairs	No. of females ovipositied	No. of eggs/fertile female[a]	No. of hatched eggs/fertile female[a]	Egg hatchability (%)
Test I					
U FXT M[b]	40	32	52.9a	3.0b	5.6
T FXU M	40	10	75.3b	63.3a	84.1
U FXU M	40	40	93.5c	81.0a	86.7
Test II					
T FXT M[c]	22	12	24.1a	2.8a	11.1
U FXU M	19	19	90.3b	83.1b	92.0

[a] Means in each vertical column for each test followed by the same letter are not significantly different at 5% level by Duncan's multiple range test. [b] U = pupae from untreated larvae, F = female, T = pupae from treated larvae, and M = male. [c] T = adults from treated larvae, U = adults from untreated larvae

Table 3. Field trial with MK-139 for the control of DBM on cabbage[a]

Compound	Rate AI (ppm)	Control (%) at	
		2 DAT[b]	11 DAT
MK-139 5EC	25	97.2	97.8
IKI-7899 5EC	25	78.3	73.8
Hakusap[c] 40WP	400	30.0	42.7
Control[d]	—	71.5	185.0

[a] Aira-gun, Kagoshima prefecture, Japan. [b] Days after treatment. [c] Combination of fenvalerate 10% and malathion 30%. [d] Number of living DBM larvae/10 plants.

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Hoe 522 (CME 134), a New Insect Growth Regulator for Control of the Diamondback Moth

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Abstract

A new insect growth regulator, Hoe 522 (CME-134), was tested in the field in the northern Philippines for the control of diamondback moth, *Plutella xylostella* L which had developed resistance to a large number of insecticides. Hoe 522 was found to be highly effective against diamondback moth populations at all rates from 15 to 105 g AI/ha and performed significantly better than reference products. A flat dose response relationship was recorded in this dosage range. Weekly and ten-day interval sprays gave better control than a spray schedule of 14 days. Under these conditions and high insect infestation levels, rates of 30-45 g AI proved to be more effective than lower dosages. A positive correlation was found between insect control and yield. Application of Hoe-522 resulted in significant yield increase and superior crop quality. Crop tolerance to Hoe 522 was excellent.

Introduction

In southeast Asia the diamondback moth (DBM) *Plutella xylostella* L (Lepidoptera: Yponomeutidae) is a destructive pest of cruciferous crops, especially cabbage, and is a limiting factor for profitable cultivation (Barroga and Morallo-Rejesus 1981, Chuo 1973, Gandhale et al 1982). Continuous vegetable growing and favorable climatic conditions favor high population densities with overlapping of all developmental stages the year round. Only during the rainy season is a decrease in population level to be observed. More than 20 generations per year are reported (Sun et al 1978).

Without insecticide treatment complete crop losses may occur due to DBM attack. Untreated plants normally die during the first two months after transplanting, or survive only long enough to produce few marketable heads or leaves or none at all (Ho 1965, Butani et al 1977).

More intensive use of insecticides has become necessary as the susceptibility of DBM to a number of conventional insecticides has decreased (Liu et al 1981, 1982, Sudderuddin and Kok 1978). To overcome the problem, farmers shorten the spray intervals, increase dose rates, and apply mixtures of different insecticides (Ho et al 1983).

In the last few years, only a limited number of new chemicals have been introduced into the vegetable market of southeast Asia for DBM control. Recently a new experimental product coded Hoe 522 OI 01 (hereafter referred to as Hoe 522) was investigated for its potential to control DBM on cabbage. This product, with internal code CME-134, 1-(3,5-dichloro-2,4-difluorophenyll)-3-(2, 6-difluorobenzoyl)-urea, was discovered in the laboratories of the Celamerck Company, Germany. Properties were described by Becher et al (1983) and Becker (1985).

This paper presents our results concerning the effectiveness of Hoe 522 against DBM on cabbage in the Philippines.

Materials and Methods

Field trials on cabbage, *Brassica oleracea* var *capitata* (cv Grobe King, Scorpio Hybrid, and Green Parade) and leafy cabbage, *Brassica campestris* ssp *chinensis* (cv Black Behi), were conducted in La Trinidad near Baguio during the dry and wet seasons of 1984. Seedlings were raised in a seedbed and transplanted after about three weeks for leafy cabbage or six to nine weeks for cabbage. For protection against early DBM attack and for softrot control, seedlings of leafy cabbage were sprayed at 5 to 15 and 20 days after sowing (DAS) with a tankmix of 500 g AI profenofos and 750 g AI chlorothalonil/ha. For cabbage the same tankmix was applied at 6, 16, 21, 30 and 35 DAS.

Cabbage trials received a basal NPK fertilizer dose of 30 kg/ha at two days after transplanting (DAT), followed by an overall distribution of 200 kg organic fertilizer (Sagana 100)/ha and a handful of chicken manure/plant at 15 DAT. Another 30 kg NPK/ha was applied at 25 DAT during hilling up.

A randomized complete block design with four replicates was used. Plots were 1 m wide and 5 m long with a spacing of 35 cm between plants in the row and 40 cm between rows. Each treatment normally consisted of 39 plants per plot.

The insecticides were applied with a hand-held knapsack sprayer. A hollow cone nozzle was used. The spray volume ranged from 600 up to 800 and 1000 liters/ha, depending on the plant growth; smaller plants received lesser volumes. The first application was made when there was visible feeding by DBM.

Numbers of larvae and pupae were counted on 10 or 15 randomly selected plants/plot at regular intervals according to the spray schedule. Normally the counting was made one day before and one day after the first or subsequent applications. The percent efficacy was calculated on the basis of the number of living larvae in treated and control plots. Feeding damage was assessed as percentage overall damage/plant one day before each application.

The effectiveness in terms of yield was recorded from the whole plot as total weight of marketable crop. The marketable heads were classified into three groups according to the local practice. Class A heads had no visible damage; class B had slight feeding damage (heads marketable after peeling-off three to four leaves), class C had severe damage (heads only marketable after removal of more than four leaves). For leafy cabbage total yield of all marketable leaves was recorded without further classification. For statistical analysis Duncan's multiple range test was used. Laboratory studies revealed that the DBM population in the experimental area was highly resistant to organophosphorus and pyrethroid insecticides.

Results

Trial seasons I and II/1984—Cabbage

Trials were performed during the dry season beginning from March to May 1984 onwards. DBM population density decreased at the end of the trial period due to the beginning of the wet season. Hoe-522 was tested at 30, 60 and 105 g AI/ha. Methamidophos and profenofos were used as reference compounds. Insecticides were applied at seven-day intervals. The results are summarized in Table 1.

Table 1. Efficacy of Hoe 522 against DBM and yield response in head cabbage (trial 1, season I & II)

Insecticides	Rate g AI per ha	Control efficacy[bcd]	Marketable heads per four plots[a]		Weight (kg) of heads in grading class		
			Number	Wt (kg)	A	B	C
Hoe 522	30	80.5b	116a	59.1a	45.9	10.2	3.0
Hoe 522	60	85.6bc	119a	61.5a	54.8	6.7	0.0
Hoe 522	105	87.5c	124a	68.2a	58.8	7.5	1.9
Methamidophos	600	38.6a	71b	27.8b	7.4	7.5	12.9
Control	—	81.6	0c	0.0c	0.0	0.0	0.0

[a] Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. Plot size: 5 sq m. [b] According to Abbott (1925). [c] Average of four replicates and 10 observations. [d] In control plots the data represents actual number of larvae per 10 plants.

At all rates Hoe 522 gave better efficacy than methamidophos. The initial efficacy was low, but one week after application efficacy was considerably better than methamidophos. The maximum control level was reached two weeks after the beginning of application. Differences in efficacy between Hoe 522 application rates were relatively small. There was significant increase in number and weight of the marketable heads in Hoe 522-treated plots compared with methamidophos-treated plots. Cabbage quality, as indicated by the distribution pattern within the three classes, was considerably improved by Hoe 522 treatment. There were no statistically significant differences in yield within the range 30 to 105 g AI/ha of Hoe 522.

Table 2 presents the average efficacy of a second trial with the same rates of Hoe 522 in comparison to profenofos. The highest rate of Hoe 522 gave the best result. Total weight of marketable heads was up to three times higher than in untreated plots and more than twice that of profenofos-treated plots. An overall quality increase was obtained by the treatments. No cabbage heads were graded in class C in Hoe 522 plots whereas in untreated plots all marketable heads were in class C.

Table 2. Efficacy of Hoe 522 against DBM and yield response in head cabbage (trial 2, season I & II)

Insecticides	Rate g AI per ha	Control efficacy[abc]	Marketable yield, kg per four plots[a]	Weight (kg) of heads in grading class		
				A	B	C
Hoe 522	30	84.5b	115.8ab	93.1	22.7	0.0
Hoe 522	60	87.8b	101.4b	85.4	16.0	0.0
Hoe 522	105	91.7c	127.0a	107.6	19.4	0.0
Profenofos	500	65.0a	61.7c	27.2	26.3	8.2
Control	—	98.3	41.1	0.0	0.0	41.1

[a] Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [b] Average of four replicates and 13 observations. [c] In control plots the data represents actual number of larvae per 10 plants. Plot size 5 sq m.

Trial season III/1984—Leafy cabbage

Trials were conducted during the wet season when DBM population pressure was moderate. Up to three applications were made at weekly intervals. Based on previous results, dosages of Hoe 522 were reduced to 15, 30 and 45 g AI/ha to observe the marginal effective rate.

Efficacy of Hoe-522 was in the range of 70-80%. No rate dependant effect could be observed. The combined application with 1000 g product/ha of *Bacillus thuringiensis* Berliner did not improve the efficacy. Yield increases of up to 20% were found in all treatments including the reference cartap.

A second trial involving leafy cabbage was performed to observe whether an acceptable control level could be maintained with longer spray intervals. Two applications of Hoe 522 were made at 10-day intervals. After the second application, over 80% efficacy was achieved with 30 and 45 g AI/ha. Neither the 15 g treatment nor the reference product increased yield whereas dosages of 30 and 45 g Hoe 522 resulted in increased marketable yield.

In another test, with 15 and 30 g AI/ha Hoe 522 the control of DBM larvae was better than with 250 g/ha diflubenzuron (Figure 1). Control efficacy increased with time after the treatment with Hoe 522.

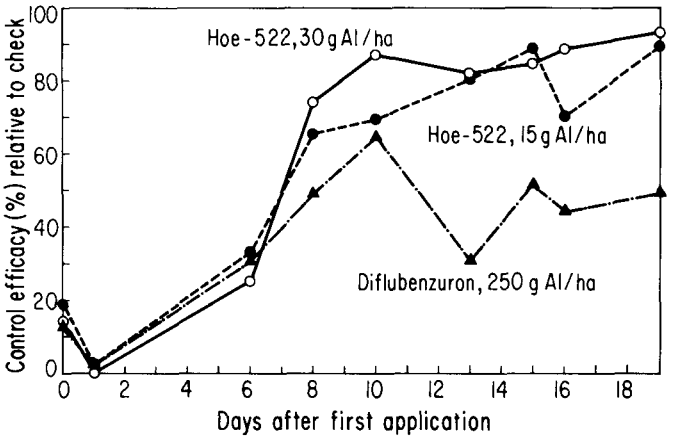

Figure 1.
Efficacy of Hoe 522 against DBM on leafy cabbage

Trial Season IV/1984—Cabbage

Figure 2 presents results from larval counts after Hoe 522 application at seven-day intervals. Eight sprays were applied to head cabbage. During this dry period the population pressure of DBM increased remarkably. In untreated plots more than 400 larvae/10 plants were counted. Even under these conditions the application of Hoe-522 gave a high level of DBM control with efficacy of more than 90%. This level was reached at two weeks after the first application. Differences in efficacy between 15 and 45 g AI/ha were small. Only the 45 g rate showed significantly different efficacy from the low rates. The yield response data are given in Table 3. An increase of marketable head weight was observed with increasing dosage rates. Minor fluctuations were noticed at 30 g AI/ha dosage rate. In the 37.5 and 45 g AI/ha plots the head quality was best.

The application interval for Hoe 522 was further extended to 10 days. Figure 3 shows the results of the 15 and 45 g treatments in comparison to cartap 500 g AI/ha which was applied at seven-day intervals. The 90% efficacy level was achieved three weeks after the first application of Hoe 522. The differences between the rates were more pronounced here than at a seven-day interval spray schedule. The activity of the reference compound decreased during the trial period. The dose response curve for Hoe 522 between 15 to 45 g AI/ha was relatively flat; similar observation were made by Becher et al (1983). The highest yields were recorded in the 37.5 and 45 g plots (Figure 4).

In a 14-day interval spray schedule, and at an extremely high infestation level, the performance was reduced and differences between the rates became more pronounced.

The 45 g treatment gave a significantly better control than the lowest dosage of 15 g. The yield data (Table 4) show that even under these conditions all Hoe 522 rates increased total weight of marketable heads from four to eight times in comparison with untreated plots. A relatively high number of class C cabbage heads were harvested. In all trials crop tolerance to Hoe 522 was excellent.

Preliminary results from residue trials in head cabbage showed that after seven weekly-sprays of 60 g AI/ha Hoe 522, and with the last treatment 10 days before harvest, no residues could be detected in the marketable heads at harvest. Further data will be available later.

Table 3. Yield response of head cabbage to Hoe 522 treatment for DBM control (trial season IV)

Hoe 522 rate, g AI/ha	Marketable yield kg per 4 plots[ab]	Head weight kg per head	Distribution (%) of heads in grading class		
			A	B	C
15.0	126ab	0.86	65	33	2
22.5	131ab	0.87	67	28	5
30.0	122b	0.90	69	29	2
37.5	136ab	0.93	88	12	0
45.0	144a	0.97	76	24	0
Control	9c	0.38	0	0	100

[a] Means in vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [b] Plot size: 5 sq m.

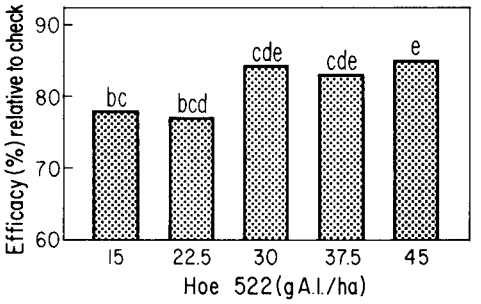

Figure 2.
Efficacy of Hoe 522 against DBM on cabbage. Mean separation by Duncan's multiple range test, $p = 0.05$

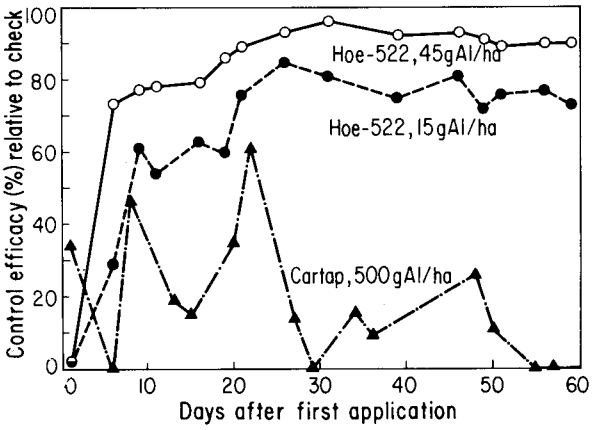

Figure 3.
Comparison of efficacy of Hoe 522 and cartap against DBM

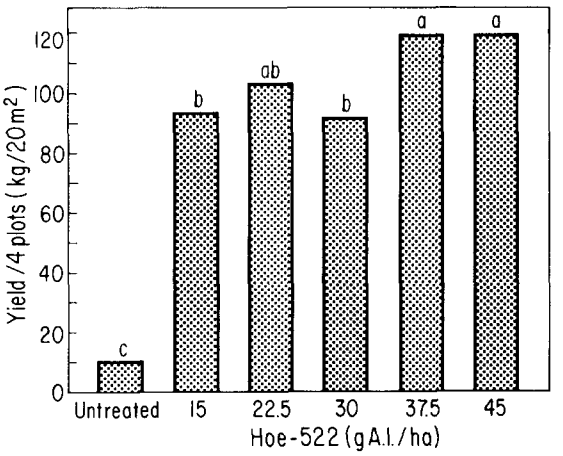

Figure 4.
Influence of application of Hoe 522 for DBM control on the yield of cabbage. Mean separation by Duncan's multiple range test, $p = 0.05$

Table 4. Influence of Hoe 522 treatment on the yield and quality of cabbage

Hoe 522 rate g AI/ha	Marketable yield per four plots[ab]		Distribution (%) of heads in grading class		
	absolute kg	relative %	A	B	C
15.0	53.10b	450	4	41	55
22.5	77.85a	660	35	38	27
30.0	84.50a	716	23	48	29
37.5	85.65a	726	42	39	19
45.0	94.05a	797	37	43	20
Control	11.80c	100	0	87	13

[a] Means in each vertical column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [b] Plot size: 5 sq m.

Discussion

Hoe 522 has shown very high efficacy for control of insecticide-resistant DBM populations at rates ranging from 15 to 105 g AI/ha. Even the lowest rate of 15 g AI/ha had some effect on DBM and might be sufficient to control the pest under conditions of low infestation. The highest rate of 105 g AI/ha had the best biological effect. There were no significant differences in yield in the range of 30 to 105 g AI/ha.

Population density and spray interval each had a more pronounced influence on the performance of Hoe 522. Under high population pressure, even at a seven-day spray schedule, efficacy differences between rates were more prominent.

The same tendency was observed when the spray interval was extended to 14 days. Under these conditions the low rates gave insufficient control. At a 14-day spray interval, yield increase and quality of cabbage was lower than with a seven-or ten-day interval despite the well known long residual effect of IGR compounds (Becher et al 1983, Hammann and Sirrenberg 1980). Apart from high population pressure, therefore, some other factors might be involved.

It is well known that benzoyl urea compounds mainly act as larvicides after oral uptake of the chemicals (Mulder and Gijswijt 1983). Consequently a spray deposit on the plant is necessary to obtain sufficient uptake of active material. Especially during periods of rapid growth, a dilution may occur if the spray interval is too long.

Furthermore new plant growth may be unprotected for a longer time. Short interval treatments may thus minimize the risk to unprotected plant parts.

In common with other IGR compounds, Hoe 522 exhibits delayed initial activity. Our findings showed that, dependent on spray interval, peak activity was reached two or three weeks after the first application. Magallona and Velasco (1980) stated that shortly after transplanting some damage may be tolerated without negative influence on yield. Limon (1982) reported that the most susceptible growth stage of cabbage occurs two to four weeks after transplanting. Therefore, rapid initial activity is not critical at this stage. Moreover it is general practice to start treatment soon after transplanting so that high activity of Hoe 522 will coincide with the fast growing stage of the host plant and result in required control.

Conclusions

In achieving optimum DBM control, rates of 15-105 g AI/ha Hoe 522 were superior to reference products. A flat dose response curve was observed for these Hoe522 rates. Even under severe population pressure Hoe522 at 30-45 g AI/ha effectively controlled DBM and achieved considerable increase in yield. An application interval of seven to ten days gave better control than a spray schedule of 14 days. Crops showed excellent tolerance to Hoe 522. No residues could be detected in marketable heads. Hoe 522 has proven its outstanding efficacy for the control insecticide-resistant DBM populations and is a valuable alternative for cabbage crop protection.

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The Status and Effectiveness of IKI-7899 in Controlling Diamondback Moth in the Lowlands and Highlands of Malaysia

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Abstract

IKI-7899 (N-2, 6-difluorobenzoyl-N'-4-(3-chloro-5-trifluoromethyl pyridin-2-yloxy)-3, 5-dichlorphenyl urea), a novel benzoyl urea chitin inhibitor, was evaluated along with conventional insecticides and other insect growth regulators for the control of diamondback moth (*Plutella xylostella* L) which has developed resistance to many conventional insecticides both in lowland and highland vegetable growing areas of Malaysia. IKI-7899, formulated as WP and used at 125 to 1000 ppm, was first observed to exhibit excellent insecticidal activity against diamondback moth in 1981 on lowland cabbages. Later tests showed that the EC formulation is superior to the WP formulation. The type of formulation was probably important in the coverage of insecticide on plant surface, and cuticular pick-up and penetration, as well as gut penetration. Numerous trials on lowland and highland cabbages have consistently indicated that IKI-7899 was superior to diflubenzuron and triflumuron. Conventional insecticides fail to control the pest. The optimal rate of IKI-7899 against the diamondback moth appeared to be around 25 ppm spray at weekly or 50 ppm spray at fortnightly intervals. Six days after the fourth weekly spray, cabbage heads had less than 0.01 ppm residues at both 25 and 50 ppm spray regimes whereas kale had 0.37 and 0.78 ppm IKI-7899 residues.

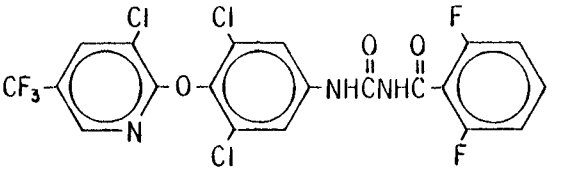
Introduction

Diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Yponomeutidae), is one of the most destructive pests of crucifers throughout southeast Asia. In Malaysia, the only approach hitherto employed by local farmers to control this pest has been the use of insecticides. Although a more integrated approach towards the management of this pest has been recognized and advocated by several workers (Lim 1974, Ooi and Sudderuddin 1978, Sivapragrasam and Lim 1982), the practicability and successes of such as approach have not been convincingly demonstrated. Adoption of this integrated pest management concept by the farmers will also prove to be a difficult extension mission. As a result of a long history of frequent and often excessive usage of insecticides, DBM has become resistant to all groups of conventional chemicals. An annotated record of the use of insecticides ranging from organochlorines to pyrethroids for the control of DBM in the Cameron Highlands and of the insect's resistance to these chemicals was produced by Ooi and Sudderuddin (1978). The pest also exhibits cross resistance to various conventional insecticides (Teh et al 1978).

In recent years, for the need to control this multiple insecticide resistant strain of DBM has resulted in excessive insecticide inputs and has escalated the cost of crucifer production. There is a need, therefore, to explore other means of managing the pest

before cultivation of crucifers ceases to be economically feasible. In a review of the insect pest control situation, Tan (1976) indicated the need for hormonal manipulation of the insect pest as an alternative tool in pest management. However, at the time of this review, he also mentioned that most insect growth regulators (IGRs) were not stable under sunlight. Advancement and progress has since been made in the use of IGRs in insect pest management. We report here results of our trials with a photostable IGR, IKI-7899, for the control of DBM in Malaysia.

IKI-7899 (common name: chlorfluazuron), also known as PP145 and CGA 112, 913, (N-2, 6-difluorobenzoyl-N'-4-(3-chloro-5-trifluoromethyl pyridin-2-yloxyl)-3, 5-dichlorphenyl urea), is a novel benzoyl urea chitin synthesis inhibitor discovered and developed by Ishihara Sangyo Kaisha, Limited of Japan. It has the following chemical structure:



IKI-7899 has a vapor pressure of 10^{-8} mmHg at 20°C. It is sparingly soluble in water (< 0.01 mg/l) but readily soluble in several commonly used organic solvents. It has good photolytic and pyrolytic stability. Its acute oral LD_{50} is >8,500 mg/kg for rats and >7,000 mg/kg for mice and its acute dermal LD_{50} to rats is >1,000 mg/kg. IKI-7899's LD_{50} to the mallard duck is >5,000 mg/kg and its LC_{50} to carp >300 ppm (48 h) and to daphnids >100 ppm (3 h). In a study with worker honeybees, IKI-7899 caused no mortality for up to 72 h after insects were dipped in a 2000 ppm solution. No insect mortality was observed when IKI-7899 at 10 μg/insect was topically applied to the bees. The insecticide does not cause skin irritation in rabbits but irritation can be caused when rabbits are exposed to large dosages of IKI-7899.

IKI-7899 is generally effective on the larvae of Lepidoptera, Diptera and Coleoptera. It is most effective when taken orally although the compound also shows a certain degree of contact toxicity. After ingestion, IKI-7899 disrupts chitin formation, thus killing the insects at ecdysis or when larvae become pupae. Like all other benzoyl urea chitin synthesis inhibitors, it is believed that it acts on an undefined step late in the chitin biosynthesis pathway (Post et al 1974, Marks and Sowa 1976, Duel et al 1978).

Materials and Methods

Field trials against DBM were conducted from 1981 to 1984 in Malaysia at two lowland locations: Malacca (altitude 100 m) and Selangor (altitude 150 m), and at one highland site: the Cameron Highlands (altitude 1200 m).

Trial 1

IKI-7899 5WP was first evaluated at 125, 250, 500 and 1000 ppm spray concentration for DBM control on cabbages (*Brassica oleracea* var *capitala*) in the lowlands. Two conventional insecticides, permethrin at 150 and 200 ppm, and prothiophos at 2000 ppm, were included for comparison.

Trial 2

In this trial WP and EC formulations of IKI-7899 were compared for DBM control on cabbage in the lowlands. IKI-7899 5WP was tested at 62.5, 125 and 250 ppm, while IKI-7899 5EC was evaluated at 31.25, 62.5 and 125 ppm. A mixture of IKI-7899 and permethrin at 62.5 + 50 and 62.5 + 100 ppm were included for comparison. Two conventional insecticides, permethrin at 250 ppm and prothiophos at 2000 ppm, were also included in the trial.

Trial 3

In this test IKI-7899 EC was evaluated at the rates of 6.25, 12.5, 25, 50, 75 and 100 ppm spray on cabbage in the highlands. Two other chitin synthesis inhibitors, diflubenzuron at 250 ppm and triflumuron at 350 ppm, were also included in this trial. Two conventional insecticides, permethrin at 200 ppm and methamidophos at 2000 ppm, were included for comparison.

Trial 4

In this trial IKI-7899 was tested on kale (*Brassica alboglabra*) in the lowland area. The IKI 7899 rates were 6.25, 12.5, 25 and 50 ppm spray. Triflumuron at 350 ppm and permethrin at 200 ppm were also included in the trial.

Trial 5

The frequency of application of IKI-7899 needed to give optimum control of DBM on cabbage in the lowlands was explored in this trial. IKI-7899 at 12.5, 25 and 50 ppm at weekly intervals and at 25 and 50 ppm at fortnightly intervals were evaluated. Triflumuron at 350 ppm, deltamethrin at 30 ppm, and permethrin at 200 ppm at weekly intervals were also included for comparison.

Trial 6

In this trial the persistance of IKI-7899 residues on lowland kale and highland cabbage was studied. IKI-7899 5EC was applied at 50, 100 and 200 ppm on both crops. A total of four applications at weekly intervals were made. The crops were sampled for residue analysis at six days after the last application.

Trial Design

Each treatment was replicated three to four times and plot size consisted of 22 to 30 plants per 4 m x 1 m plot. Treatments were arranged in a randomized complete block design. All insecticides were applied using high volume sprays at 600 to 1500 l/ha according to the growth stages of the crop, smaller plants receiving a lesser spray volume. Assessments were made on the DBM population density (number of larvae per plant) and the damage score (0 to 5 scale) throughout the growth stage of the crop. With the exception of trial 5, the chemicals were applied at weekly intervals.

Results and Discussion

Results on DBM larval population, damage rating, and cabbage yield in the first trial are given in Table 1. The lowest rate of IKI-7899 WP, 125 ppm, was inferior in

Table 1. Efficacy of IKI-7899 against DBM on cabbage in the lowlands (Trial 1)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield kg/ plot[d]
		2	4	2	4	
IKI-7899	125	1.14b	0.53a	0.6	0.5	5.74bc
IKI-7899	250	0.70b	0.36a	0.3	0.1	7.35ab
IKI-7899	500	0.85b	0.58a	0.3	0.1	9.14a
IKI-7899	1000	0.78b	0.00a	0.3	0.1	9.73a
Permethrin	125	2.35a	0.52a	1.6	3.1	2.79cd
Permethrin	200	2.05a	0.30a	1.0	2.5	4.70bc
Prothiophos	2000	2.12a	0.10a	1.3	2.9	2.97cd
Control	—	2.27a	0.10a	2.3	3.8	0.32d

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

DBM control to the higher rates of 250, 500 and 1000 ppm. The control achieved by IKI-7899 at 125 to 1000 ppm was far superior to permethrin at 100 and 200 ppm and prothiophos at 2000 ppm. These results showed tremendous potential for IKI-7899 as a new tool in DBM management. The compound was able to control strains of DBM resistant to the organochlorine, organophosphorous, carbamate, and synthetic pyrethroid insecticides.

As IKI-7899 is only effective at the moulting stages of the larvae, the kill was initially slower than that achieved by conventional insecticides. DBM larvae poisoned by IKI-7899 were killed at one to three days after treatment depending on the larval instar. Due to the inhibition of chitin synthesis, the IKI-7899 poisoned larvae became spherically expanded and the formation of pupal cases was incomplete or deformed.

Effect of formulation on efficacy of IKI-7899

The results of the comparison of EC and WP formulation are presented in Table 2. EC formulation of IKI-7899 gave better control of DBM than WP formulation. As oral ingestion of IKI-7899 is an important factor contributing to the final kill of insect pests, the coverage of the chemical on the crop is important. EC formulation probably gave better crop coverage than WP. It is also possible that the EC formulation resulted in better cuticular pick-up and gut penetration, thereby giving better DBM control.

There were no differences in control success when permethrin at 50 and 100 ppm were added to IKI-7899 at 62.5 ppm. This was expected as permethrin by alone gave poor DBM control. Permethrin was, however, able to reduce damage caused by the adult flea beetle (*Phyllotreta sinuata*) against which IKI-7899 is not effective.

The two conventional insecticides, permethrin at 250 ppm and prothiophos at 2000 ppm, failed to control DBM in these trials.

Efficacy of IKI 7899 EC on highland cabbages

The lifecycle of DBM differs between the lowlands and the highlands. For example, to complete one lifecycle, it takes 12 to 15 days in the lowlands and 25-30 days in the highlands (Ho 1965, Yunus and Balasubramaniam 1975). The critical period of greatest sensitivity to IKI-7899 and to other chitin inhibitors is at the moulting stages of the insect. Thus, insects with longer instars (or longer lifecycles) will take a longer time to

be affected by chitin synthesis inhibitors, and this results in more damage to the crop than that caused by those with shorter lifecycles. However it was found that IKI-7899 at 12.5 to 100 ppm, which gave good DBM control in the lowlands, also gave excellent control in the highlands (Table 3). The results also revealed that the lowest rate of IKI-7899, 6.25 ppm, did not provide adequate control as did the higher rates. Diflubenzuron at 250 ppm and triflumuron at 350 ppm were inferior to IKI-7899 at 12.5 to 100 ppm. IKI-7899 has been shown to be quite stable inside the larvae of *Spodoptera littoralis*, thereby blocking chitin synthesis more efficiently than diflubenzuron (Neumann and Guyer 1983). This biochemical characteristic of IKI-7899 is probably also true in the case of DBM, hence resulting in better control than diflubenzuron and

Table 2. Effect of formulation of IKI-7899 on the efficacy againt DBM on cabbage in the lowlands (Trial 2)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield plot[d]
		1	5	1	5	
IKI-7899 WP	62.5	9.60a	2.73c	1.6	1.7	8.75abc
IKI-7899 WP	125.0	4.20bcd	2.00cd	1.3	1.2	7.85abc
IKI-7899 WP	250.0	3.43cde	1.08de	1.2	0.9	8.85abc
IKI-7899 EC	31.3	0.50de	0.05e	0.9	0.2	8.98abc
IKI-7899 EC	62.5	0.80de	0.00e	0.5	0.2	12.70a
IKI-7899 EC	125.0	0.38de	0.05e	0.8	0.1	12.23ab
IKI-7899 EC + Permethrin	62.5 + 50.5	0.65de	0.05e	0.6	0.1	11.43ab
IKI-7899 EC + Permethrin	62.5 + 100.0	0.48de	0.13e	0.7	0.1	12.65a
Permethrin	250.0	7.68ab	6.90a	1.9	3.6	4.60cd
Prothiophos	2000	5.50bc	5.08b	1.3	3.3	4.03d
Control	—	6.18abc	4.48b	1.5	2.8	4.88cd

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of four replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

Table 3. Efficacy of IKI-7899 against DBM on cabbage in the highlands (Trial 3)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield kg/plot[d]
		1	4	1	4	
IKI-7899	6.3	2.90b	3.57b	1.4	1.8	10.82c
IKI-7899	12.5	2.13bc	2.70b	1.1	1.4	14.44b
IKI-7899	25.0	2.67bc	2.03b	1.3	1.0	15.64b
IKI-7899	50.0	2.20bc	0.87b	1.1	0.4	17.64a
IKI-7899	75.0	1.93bc	0.67b	1.0	0.3	15.08b
IKI-7899	100.0	1.77c	0.17b	0.9	0.2	18.18a
Diflubenzuron	250.0	4.90a	0.28b	2.4	3.7	1.31f
Triflumuron	350.0	4.20a	0.17b	2.1	3.0	8.09d
Methamidophos	2000	4.27a	11.94a	2.1	3.7	6.14de
Permethrin	200.0	4.70a	0.17b	2.3	3.5	3.82e
Control	—	4.57a	2.22b	2.3	3.2	0.25f

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] WAT = weeks after first treatment. [c] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [d] Plot size = 4 × 1 m.

triflumuron. Both the conventional insecticides, permethrin at 250 ppm and methamidophos at 2000 ppm, failed to control the pest.

Due to the severe damage caused by DBM on untreated plots and plots treated with diflubenzuron, triflumuron, permethrin, and methamidophos, there was a general decline of pest infestation on these plots at three weeks after transplanting (WAT). There was also little DBM reinfestation due to the unattractive nature of the badly damaged host plants.

Activity of IKI-7899 EC on lowland kale

Kale in the lowlands is also subjected to the same intensity of DBM destruction as cabbage. Kale is an important lowland cruciferous vegetable and therefore appears to be the most suitable crop to reconfirm the activity of IKI-7899 against DBM. The results of DBM control on kale are shown in Table 4. IKI-7899 at 12.5, 25 and 50 ppm gave excellent DBM control with a consistently low larval count and low foliar damage. Plots treated with triflumuron at 350 ppm exhibited moderate DBM infestation and were inferior to IKI-7899 at 6.25, 12.5 and 50 ppm at 2 and 3 WAT. Permethrin at 200 ppm failed to give satisfactory control.

Table 4. Efficacy of IKI-7899 against DBM on kale in the lowland (Trial 4)

Insecticide	Rate ppm AI spray	No. DBM larvae/ plant at WAT[bc]		Damage rating[a] at WAT		Yield[b] kg/20 plants
		1	3	1	3	
IKI-7899	6.3	0.4c	1.1c	0.4	0.6	2.38cd
IKI-7899	12.5	0.1c	0.9c	0.3	0.4	2.95de
IKI-7899	25.0	0.0c	0.9c	0.0	0.4	2.73cde
IKI-7899	50.0	0.2c	0.5c	0.2	0.3	3.02e
Triflumuron	350.0	0.3c	3.0b	0.3	1.7	2.30c
Permethrin	200.0	2.3a	5.7a	1.0	2.9	1.05b
Control	—	1.5b	8.5a	0.5	3.9	0.32a

[a] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. [b] Data are means of three replicates. Means in each column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test. [c] WAT = weeks after first treatment.

Frequency of IKI-7899 application

The frequency and timing of application of IKI-7899 were studied in an effort to identify the persistence of the compound in controlling DBM in the lowlands. IKI-7899 at 12.5, 25 and 50 ppm was sprayed at weekly intervals and at 25 and 50 ppm at fortnightly intervals. Results of the larval counts and damage ratings are given in Table 5. There were no differences between the two frequencies of IKI-7899 application. The optimum rate of IKI 7899 which can give effective DBM control appears to be around 25 ppm (weekly applications) and 50 ppm (fortnightly applications). Triflumuron applied weekly at 350 ppm was inferior to IKI-7899 at 12.5 to 50 ppm. There were high DBM larval counts at 1 WAT on plots treated with triflumuron. This initially high DBM population resulted in severe foliar damages to the triflumuron-treated crop at 2 and 3 WAT. Deltamethrin at 30 ppm and permethrin at 200 ppm, both applied at weekly intervals, failed to control the pest.

Table 5. Effect of frequency of IKI-7899 application on the control of DBM on cabbage in the lowlands (Trial 5)

Insecticides	Rate ppm AI spray	Application frequency (weeks)	No. DBM larvae /plant at WAT[a]		Damage rating at WAT[b]	
			1	3	1	3
IKI-7899	12.5	1	4.9	0.5	0.5	0.8
IKI-7899	25.0	1	7.1	0.6	0.3	0.6
IKI-7899	50.0	1	4.7	0.3	0.3	0.8
IKI-7899	25.0	2	3.7	1.5	0.3	1.3
IKI-7899	50.0	2	4.2	0.9	0.3	1.0
Deltamethrin	30.0	1	21.9	4.1	2.2	2.0
Permethrin	200.0	1	21.9	2.3	2.3	2.3
Triflumuron	350.0	1	16.1	1.5	2.7	1.8
Control	—	—	29.0	11.9	2.7	3.9

[a] WAT = weeks after first treatment. [b] Damage rating: 0 = no damage, 1 = slight feeding on leaves, 2 = moderate feeding on leaves, 3 = heavy feeding on leaves, 4 = skeletonizing of plant, and 5 = death of the plant. Data are means of three replicates. Plot size = 4 × 1 m.

Residue levels of IKI-7899

The results of the studies of persistence of IKI-7899 residues on kale and cabbage are shown in Table 6. At six days after four weekly applications of IKI-7899 at 25, 50 and 100 ppm, both the crops showed low residues of IKI-7899. The residue in kale was from 0.37 to 1.76 ppm while in cabbage the residue level was less than 0.01 ppm. The open leaf nature of the kale probably contributed to higher residues on the crop as compared to the close leaf morphology of cabbage.

The low residues of IKI-7899 recovered from both the vegetables, coupled with its low mammalian toxicity, will make this compound an invaluable and safe tool in the management of DBM.

Table 6. Persistence of IKI-7899 residues on kale and cabbage in the lowlands (Trial 6)

Insecticide	Rate ppm AI spray	No. of sprays	Sampling interval (days[a])	Residue (ppm)	
				kale	cabbage
IKI-7899	25	4	6	0.37	< 0.01
IKI-7899	50	4	6	0.78	< 0.01
IKI-7899	100	4	6	1.76	< 0.01
Control	—	—	—	< 0.01	< 0.01

[a] Days between last spray and sampling for residue analysis.

Effectiveness of IKI-7899 against other insect pests

Apart from DBM, IKI-7899 was also highly effective against the early instars of *Spodoptera litura, Hellula undalis* and *Crocidolomia binotalis* on cabbage. However, IKI-7899 was rather slow acting on the later instars of these pests and mortality resulted mainly when the larvae were becoming pupae. Since the late instars of these pests can cause considerable damage due to their voracious feeding habits, it is most important to give the crops a programmed spray after transplanting to prevent such damage.

IKI-7899 is not effective against sucking insects viz aphids, hoppers, and scale insects and has no contact activity against bees. In Peru, IKI-7899 at 25 to 150 g AI/ha has been shown to give excellent control of foliage-feeding Lepidoptera like *Alabama*

argillacea and *Anomis texana* but had no effect on a wide range of beneficial insects including coccinellids and predatory mites and bugs (Collins et al 1984). This selective property of IKI-7899 will play an important role in integrated management of DBM.

Conclusion

IKI-7899 at around 25 ppm applied at weekly intervals or 50 ppm at fortnightly intervals gave consistently excellent control of multiple insecticide resistant strains of DBM in lowland and highland vegetable areas of Malaysia. IKI-7899 at 12.5 to 50 ppm showed superior activity over other chitin synthesis inhibitors such as diflubenzuron at 250 ppm and triflumuron at 350 ppm against DBM. Conventional insecticides failed to give good control of the pest in both lowland and highland vegetable areas of Malaysia. EC formulation was superior to WP.

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Control of Diamondback Moth in Southeast Asia by Profenofos

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Abstract

Profenofos is a phosphoric acid ester with a broad spectrum of activity as an insecticide and acaricide. It was first developed for the control of lepidopterous pests of cotton but was found subsequently to be active against the diamondback moth, *Plutella xylostella* L. The field effectiveness of profenofos was evaluated in the Philippines, Malaysia, Thailand, and Taiwan against the diamondback moth by high volume spray applications at 7 and 10 day intervals. Results indicated that profenofos when applied at the rate of 0.25 to 0.5 kg AI/ha effectively reduced the population of diamondback moth larvae in crucifers. Yields of treated plots were increased by 41 to 100% compared to untreated plots. The effectiveness of profenofos against diamondback moth was confirmed in all countries where field tests were conducted.

Introduction

In southeast Asia crucifer vegetables are generally planted in the highlands where the climate is cool or in the lowlands during the winter season. In the Philippines, an estimated 6,000 hectares are planted annually to crucifers; in the Cameron Highlands of Malaysia, 5600 hectares; in Thailand, 57,000 hectares; and in Taiwan, 34,400 hectares.

The quality of crucifer production, however, is hampered by insect pest depredations. One of the most destructive pests is the diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), which infests the plants from seedling stage to maturity. DBM is considered a major production constraint in this region. Losses caused by this pest, when not controlled, may be as high as 50%, and are often up to 100%.

DBM was first observed as the most destructive insect pest of crucifers in Mountain Province, Philippines, in 1960 (Magallona et al 1980). Since then other workers in the Philippines have begun extensive research work to develop an effective control program.

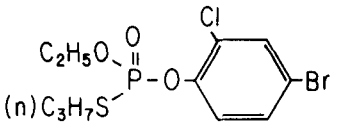
In the absence of other and more effective control measures, chemical control has been resorted to as an indispensible part of agricultural operations. Chemical control studies against cabbage pests in the Philippines were carried out by Viado et al (1957) when, amongst five insecticides tested, diazinon was found to be the most effective against the cabbage worm larvae. At that time DBM was not yet recognized as a pest. Nevertheless Ho (1965), recognizing the impending problem in Malaysia, studied the life history of the insect and conducted a screening of various insecticide candidates for its control. He found endrin, amongst others, to be effective against DBM. Later, Magallona et al (1980) established that the critical period for the protection of cabbage grown in the Philippines from DBM damage was between the fourth week and seventh week after transplanting. The first week and last three weeks of growth were less critical and required no insecticide protection.

The development of resistance by DBM was first reported in the Philippines in 1974 by Barroga (1974) when she investigated the reported reduced efficacy of commonly used insecticides such as EPN and mevinphos and confirmed the field observations. Following the discovery of resistance of DBM to presently used insecticides, various attempts have been made to over-come the resistance problem. One approach was to prepare insecticide mixtures by tank-mixing two or more insecticides with the objective of obtaining more effective treatments. In practice, many cabbage farmers in southeast Asia are already using a tank-mix of two or more different chemicals to try to obtain satisfactory control of DBM. Theoretically this is possible, but the mixtures prepared by farmers were without scientific basis. This practice had been questioned by authorities because of the high risk of residues attributed to the wrong choice of insecticide combination and farmers' practice of preparing spray mixtures two to three times the recommended dosage rates.

On the basis of the above considerations, the development of an insecticide which can be applied singly and which can be incorporated with existing pest control programs is imperative. This paper describes the physico-chemical characteristics and biological properties of profenofos together with the results of evaluations which led to the development of this insecticide as an effective chemical for DBM control.

Chemical and Toxicological Properties

Profenofos, O-(4-bromo-2 chloro-phenyl) O-ethyl S-n-propyl phosphorothioate, is an organophosphorus insecticide with the following chemical structure:



It is a nonflammable yellow liquid with a vapor pressure of 1.10^{-5} mmHg at 20°C. Its solubility in water is 20 mg/l. It is readily soluble in most organic solvents.

The acute oral LD_{50} is 916 mg/kg and acute dermal LD_{50} is more than 4600 mg/kg in rats.

The product is available under the trade name of Selecron 500EC which contains 500 g of technical profenofos per liter emulsifiable concentrate.

Biological Properties

Profenofos is a broad spectrum insecticide with contact and stomach poison activity against sucking, mining, and chewing insects. It is non-systemic but has excellent translaminar action. This property provides effective control of boring and mining pests because of the rapid uptake and penetration of the active ingredient into the plant tissue. Remarkable control of DBM was observed even when this product was applied shortly before heavy rainfall or when the product was used in heavy rainfall cabbage growing areas.

The insecticidal properties of profenofos were first described by Buholzer (1975) under CIBA-GEIGY code number CGA-15324. The product was originally developed for the control of lepidopterous pests of cotton. Since 1977-78, this product has been introduced commercially in cotton-growing areas. Subsequent development work has

resulted in the discovery that it is an effective insecticide for the control of DBM in crucifers.

This insecticide was evaluated in several countries in southeast Asia and the results are reported in this paper.

Materials and Methods

Field trials were started in 1977 and were continued up to 1979 until enough data on the biological efficacy of profenofos were obtained. The tests were initiated in Malaysia, Thailand, and the Philippines at official research stations to find the most effective rate of application and appropriate spray intervals. Tests were continued in 1983 to 1984 in these countries and in Taiwan. In addition to these tests, the commercially formulated product was made available to research institutions such as AVRDC for evaluation to confirm the results obtained in earlier tests.

The emulsifiable concentrate formulation, Selecron 500 EC, was used in all tests. Various rates of application were tested and were sprayed onto test plants using ordinary 10-16 liter capacity knapsack sprayers. The spray volumes ranged from 500 to 1000 l/ha, depending on the growth stage of the test plants.

The plot sizes used in the tests were 1 x 10 m or 1 x 20 m. Each treatment was replicated four times in a randomized complete block design. Depending on the plot size, the total number of plants sampled for efficacy evaluation per plot was 10 or 20.

Results and Discussion

Effect of various rates

The results of the trials conducted in Malaysia, Thailand, and the Philippines are shown in Tables 1 to 3, respectively.

Malaysia trial (1977) Profenofos was applied at different rates and these treatments were compared with prothiophos which was used as a standard.

The incidence of DBM in the untreated plots was high during the second to the third week after transplanting and declined onwards towards crop maturity. In the profenofos-treated plots at all application rates the DBM larval population was low (Table 1). Even during the peak population period of two to three weeks after transplanting, the profenofos-treated plots were relatively free from DBM larvae, with only 1 to 5 larvae/10 plants compared to 114 to 229 larvae/10 plants in untreated plots. This observation showed that profenofos from 0.3 to 0.6 kg AI/ha when sprayed at weekly intervals controlled DBM effectively and was equal to the standard prothiophos treatment.

The damage indices observed in all profenofos-treated plots, as well as the standard, were very low compared to the untreated plots. At five weeks after transplanting, the leaves of plants in the untreated plots were already skeletonized (damage rating 3.25) whereas the profenofos treated plots were relatively clean (damage ratings of 0.25). Yields of cabbage from profenofos-treated plots, regardless of the rate tested, ranged from 107 to 118 t/ha and were equal to the yields of plots treated with the standard insecticide, prothiophos.

Thailand trial (1978) Profenofos was compared to several promising compounds for the control of DBM on Chinese kale.

The larval populations of DBM in the profenofos-treated plots sprayed 750 ppm AI were the lowest (Table 2). Mean larval counts in the profenofos treated plots taken

Table 1. Effects of profenofos application on DBM infestation of cabbage at the Cameron Highlands, Malaysia

Insecticides[b]	Rate ppm AI spray	No. of DBM larvae /10 plants at WAT[c]			Damage rating[a] at WAT		Yield t/ha
		3	5	8	5	8	
Profenofos	425	5	0	0	0.25	0.5	112.3
Profenofos	850	1	0	0	0.25	0.5	118.3
Profenofos	1275	4	0	0	0.25	0.5	107.8
Prothiophos	550	11	0	0	0.25	0.5	119.6
Control	—	229	14	13	3.25	3.0	99.8

[a] Damage rating: 0 = no damage to leaves, 1 = slight damage or 1 to 3 leaves skeletonized, 2 = moderate damage or 2 to 4 leaves skeletonized, 3 = heavy damage or most leaves skeletonized, and 4 = severe damage or all leaves skeletonized. [b] Both insecticides were formulated as 50EC. [c] WAT = weeks after transplanting. Spray volume 600 ml/plot (10 sq m) for 1st, 750 ml for 2nd, and 1000 ml for 3rd through 8th weekly sprays.

Table 2. Effects of profenofos application on the DBM infestation of Chinese kale in Thailand

Insecticides	Rate ppm AI spray	No. DBM larvae/10 plants at days after transplanting			Yield t/ha
		15	35	55	
Permethrin 10EC	100.0	17.50	48.00	45.50	2.9
Fenvalerate 20EC	100.0	18.50	41.00	43.25	2.9
Cypermethrin 15EC	100.0	19.50	39.00	41.25	3.2
Deltamethrin 2.5EC	12.5	16.75	51.50	54.50	2.8
Prothiophos 50EC	750.0	4.50	10.75	8.75	3.4
RH-0994 48EC	750.0	14.50	20.00	43.00	2.3
Control	—	18.50	35.75	15.50	2.3

at 15, 35, and 55 days after transplanting were 4.5, 10.7, and 8.75, respectively, which were much lower than those observed in the untreated plots which were 18.5, 35.75, and 15 respectively. In this trial, profenofos showed pronounced activity against DBM and apparently had a longer residual effect compared to deltamethrin and cypermethrin which were applied at concentrations of 12.5 and 100 ppm AI, respectively.

Plants treated with 750 ppm AI profenofos were relatively free from DBM larval feeding when they were examined at 55 days after transplanting. Twenty-nine percent of the observed plants belonged to damage categories 3 and 5, while those treated with deltamethrin, cypermethrin and permethrin belonged mostly to damage categories 5 and 7. The average yield of the profenofos treated plot was 3.4 t/ha compared to 2.3 t/ha in the untreated plot.

Philippine trial (1978) In the advanced evaluation test conducted at the Baguio Experiment Station under the Bureau of Plant Industry, profenofos was tested at rates of 0.25, 0.5, and 0.75 kg AI/ha as against 0.50 AI of the standard chemical, methamidophos. Insecticides were sprayed at weekly intervals. The results are shown in Table 3.

The population of DBM larvae in the plots treated with profenofos was the lowest when counts were made at 20, 36, and 50 days after transplanting. There was either no damage or only slight damage, to the plants. The standard insecticide treated plants had considerably more damage.

Yields of profenofos-treated plots, at any tested rates, ranged from 73 to 78 t/ha compared to the standard, which yielded 55 t/ha. The lower yields obtained from the methamidophos-treated plots were attributed to the larger number of outer leaves which had to be removed prior to weighing.

Table 3. Effects of profenofos application on the DBM infestation of cabbage at Baguio, Philippines

Insecticide[a]	Rate kg AI /ha	No. of DBM larvae /20 plants at DAT[b]			Damage rating[c]	Yield t/ha
		20	36	50		
Profenofos	0.25	0.05	0.37	0.37	0.74	73.0
Profenofos	0.50	0.00	0.20	0.02	0.64	78.5
Profenofos	0.75	0.05	0.25	0.10	0.63	74.0
Methamidophos	0.50	0.05	3.42	1.20	1.06	55.0
Control	—	0.97	72.72	21.95	2.19	00.0

[a] All insecticides were formulated as 50EC. [b] DAT = days after transplanting. [c] Damage rating: 0 = no damage, 1 = slight damage or 1 to 3 leaves with holes, 2 = moderate damage or 4 to 6 leaves with holes, 3 = heavy damage or most of the leaves with holes, 4 = serious damage or all leaves with holes and skeletonized. Damage rating figures are mean of 10 damage assesements. Plants were sprayed at weekly intervals starting 10 days after transplanting.

Effect of application intervals

To test the efficacy of profenofos when applied at various spray intervals, a trial was initiated by the Baguio Experiment Station of the Bureau of Plant Industry in the Philippines. Profenofos was sprayed at various rates and applied at intervals of either 7 or 10 days. The results of this trial are shown in Table 4.

Table 4. Effect of profenofos application at various rates and intervals on infestation of cabbage by DBM

Insecticide[a]	Rate kg AI spray	Spray interval (days)	No. DBM larvae per 10 plants		Damage rating[b] at 55 DAT[c]	Yield t/ha
			Before spray	After spray		
Profenofos	0.250	7	1.9	0.5	0.8	104
Profenofos	0.250	10	2.9	0.9	0.9	107
Profenofos	0.500	7	1.6	0.5	0.7	108
Profenofos	0.500	10	3.0	0.6	0.8	99
Profenofos	0.750	7	1.8	0.4	0.7	95
Profenofos	0.750	10	2.8	0.8	0.8	102
Methamidophos	0.750	7	2.9	1.4	0.9	99
Methamidophos	0.750	10	5.9	2.1	1.0	101
Control	—	—	47.5	53.2	1.7	47

[a] Both insecticides were formulated as 50EC. [b] Damage rating: 0 = no damage, 1 = slight damage or 1 to 3 leaves with holes, 2 = moderate damage or 4 to 6 leaves with holes, 3 = heavy damage or most leaves with holes, 4 = serious damage or all leaves with holes and skeletonized. Damage rating figures are mean of four replicates and 9 (7 day interval) and 13 (10 day interval) sampling occasions. [c] DAT = days after transplanting.

Profenofos efficacy did not vary whether it was sprayed at 7 or 10 days intervals. The larval populations in the profenofos treated plots were much lower compared to the untreated plots. The mean number of larvae per 10 plants was not more than two at any of the rates tested when the treated plots were examined 55 days after transplanting. There was, however, a slight increase in the number of larvae observed in the plots which were sprayed every 10 days compared to those sprayed every seven days. The effect of profenofos on larval population at all rates tested and at both spray intervals was equal to or better than that of the standard methamidophos.

Marketable head yields obtained from profenofos-treated plots at all rates and timings were significantly higher than the untreated plots and were equal to or higher than the yields obtained from plots treated with standard insecticide.

Post introduction experience

After careful study of the results obtained in this region, the product was registered and commercially introduced for cabbage under the trade name Selecron 500EC in Thailand, Malaysia, Taiwan, and Philippines from 1978 to 1982. The product has since then been used successfully on cabbage for DBM control. Although DBM is known to develop resistance to chemicals quite rapidly, in the case of profenofos there has been no official report so far of resistance development by the insect. This was despite continuing trials conducted to monitor the response of DBM to profenofos in this region.

The trial reports shown in Tables 5 and 6 clearly demonstrate that profenofos was highly effective against DBM in Taiwan three years after the commercial product was introduced. When applied at the rate of 0.5 kg AI/ha, profenofos reduced the number of DBM larvae and pupae, more effectively than the *Bacillus thuringiensis* (AVRDC 1984). As a result, the profenofos-treated plots yielded 92% more than untreated plots, and 28% more than *B. thuringiensis*-treated plots (Table 5). When tested under farmer's field conditions from April to July 1984, profenofos at the rate of 0.5 kg AI/ha reduced the DBM population more effectively than a tank-mix combination of metamidophos + deltamethrin at 0.5 kg AI and 28 g AI/ha (Table 6).

Table 5. Effect of profenofos application on the DBM infestation of cabbage in Taiwan

Insecticide	Rate kg AI/ha	No. of DBM larvae and pupae/10 plants at DAT[a]				Yield t/ha
		44	56	65	72	
Profenofos 50EC	0.5	14.5	30.0	30.5	99.5	85.6
Bactospeine	0.5[b]	62.5	129.0	157.0	229.7	66.5
Control	—	139.0	208.3	374.5	529.0	44.5

[a] DAT = days after transplanting. Data are mean of four replicates. [b] *Bacillus thuringiensis*, actual product.

Table 6. Effect of profenofos alone and in combination with other insecticides on the DBM infestation of cabbage in Taiwan

Insecticides	Rate kg AI/ha	No of DBM larvae /leaf at 98 DAT[a]
Profenofos 50EC +	0.500	1.05
Cypermethrin 5EC	0.050	
Profenofos	0.500	1.14
Methamidophos 50EC +	0.500	3.65
Deltamethrin 2.8EC	0.028	
Mevinphos 25.3EC	0.506	5.54
Control	—	11.69

[a] DAT = days after transplanting. Data are means of four replicates of 40 leaves each; insecticides sprayed at 80, 84, and 91 DAT.

These results indicate the potential of profenofos for the control of DBM infesting crucifers in southeast Asia. The availability of profenofos in these countries will offer an opportunity for farmers to obtain higher yields.

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Chemical Control of Diamondback Moth in Japan with Special Reference to Cartap

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Abstract

Incidence of diamondback moth, *Plutella xylostella* L, in Japan is increasing as the area planted to crucifers increases. Insecticides are frequently used to control this pest. More than 50 formulated products, consisting of 29 active ingredients, have been registered for diamondback back moth control in Japan. Most of these insecticides are organophosphorus compounds, however, other compounds such as cartap methomyl, and combinations of fenvalerate and organophosphorus chemicals are frequently used. Since farmers tend to use exclusively the more potent chemicals, only a few of the registered insecticides are actually utilized. As a result of the application of only a limited number of chemicals this insect has developed resistance to some of the frequently used organophosphorus compounds. Cartap is one of the standard chemicals recommended in most prefectures of Japan. It is being used over 30% of the crucifer growing areas of Japan. As a result of cartap's characteristic mode of action, despite its widespread use over the past 15 years the incidence of diamondback moth becoming resistant to it is far lower than that recorded for most other chemicals. Because of this, cartap is adopted widely in insecticide spray rotation.

Introduction

Since the 1960s, diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), has been an important pest of crucifers in Japan. Its abundance is associated with the increased area under crucifers, especially cabbage which is grown over 40,000 ha every year (Yamada 1977, Koshihara 1981). Cruciferous vegetables are grown all year-round which provides an easily accessible food source for DBM as well as for other pests, as a result of which these crops suffer DBM depredation throughout the year (Sakai 1981). Due to its rapid generation turnover and short lifespan DBM has become the chief insect pest of crucifers.

As the area under crucifers has increased and the infestation of DBM with it, so has the use of insecticides to combat this pest. Various chemicals are playing an important role in the production of quality vegetables with high yields. More than 50 insecticide products, most of them organophosphorus compounds, are registered for the control of DBM in Japan. Among non-organophosphorus, cartap, methomyl, and fenvalerate are important. Cartap has been widely used for DBM control for the past 15 years. Our survey indicates that this insecticide is used over 30% of the total crucifer area treated with insecticides in 1983.

This paper summarizes the present status of the DBM control by insecticides in Japan in general and discusses the role of cartap in combating this pest in the field.

Cropping Pattern and Insect Damage

Cropping pattern

Major cruciferous crops in Japan are cabbage (*Brassica oleracea*), Chinese cabbage (*B. campestris* ssp *pekinensis*), and radish (daikon) (*Raphanus sativus*). Their year-round cropping pattern varies from area to area. The cropping pattern is established by the latitude, altitude, and cultivars used (Matsumura 1981). The crucifer cropping pattern of Japan is briefly described in Table 1.

Table 1. Cropping systems for important crucifers in Japan

Crops	Cropping type	Transplanting[a] or sowing time[b]	Harvesting time
Cabbage	Spring harvested 1	e Oct - l Nov	m May - l May
	2	Mar - l Apr	e Jul - l Jul
	Summer-autumn harvested	e Apr - l Jul	m Jul - mOct
	Winter harvested	m Aug - e Oct	e Nov - e Mar
Chinese cabbage	Spring harvested	m Jan - l Feb	e Mar - l May
	Summer harvested	m Apr - l Jul	e Jul - l Sept
	Autumn-winter harvested	e Aug - e Sept	e Oct - e Mar
Radish	Spring harvested 1	e Feb - l Apr	e Apr - l Jun
	2	m Apr - e May	m Jun - l Jun
	Summer harvested	Jul - e Aug	e Aug - l Oct
	Autumn-winter harvested	e Aug - l Dec	e Mar - e Apr

[a] cabbage. [b] e, early; m, mid; l, late.

Yields of cabbage differ little from season to season but those of Chinese cabbage and radish are much greater in autumn and winter than in spring or summer (Table 2). Production of cabbage is concentrated only in a few prefectures. About 30% of each spring and winter harvested cabbage is produced in Chiba, Kanagawa, and Aichi Prefectures where winter climate is mild. Summer-autumn harvested cabbage is mostly supplied from the highlands or the cooler regions of Gunma and Nagano Prefectures where 50% of the country's total cabbage is produced. Nagano Prefecture supplies about 80% of the summer harvested and Kanto district about 40% of the autumn-winter harvested Chinese cabbage. Cultivation of radish is much more generalized than that of other crucifers.

Crop damage

Although the DBM is prevalent from early spring to late autumn, the insect is more abundant from June to August. All crucifers suffer depredation by this pest practically throughout the growing season. In major production centers, cabbage is grown on a large scale. DBM prefers cabbage over other crucifers, hence the monoculture of cabbage provides an ideal niche for the insect. Recent increases in area as well as year-round production of cabbage is providing perfect conditions for insect damage to occur.

Table 3 shows the rate of injury caused by major insects to crucifers in insecticide-treated areas. DBM is the most prevalent pest followed by aphids, common cabbage worm (*Pieres rapae crucivora* Boisduval), and the cabbage armyworm (*Mamestra brassicae*). It is observed that the area infested by DBM is always greater than that infested by any other insect. Also the DBM-infested areas receive greater quantities of insecticides than other insect-infested areas. The spraying frequency is greater for summer-autumn harvested cabbage than for crops grown at other times of the year.

Table 2. Area and yield of main crucifer crops in Japan (1982 - 1983).

Harvesting time	Area planted[a] (ha)	Yield[b] (1000 t)
Cabbage		
Spring	11880	443
Summer - autumn	13250	498
Winter	17056	684
Total	42186	1625
Chinese cabbage		
Spring	2037	98
Summer	4340	222
Autumn - winter	28848	1319
Total	35225	1629
Radish		
Spring	5827	225
Summer	10901	307
Autumn - winter	50176	2177
Total	66904	2709

Source: [a] MAFF 1984a. [b] MAFF 1984b.

Table 3. Infestation and measures for three important lepidopterous insect pests of cruciferous vegetable in Japan (1982-1983)[ab]

Crop	Diamondback moth			Cabbage armyworm			Common cabbage worm or aphids		
	Infest area (ha)	Spray area (ha)	No. of sprays	Infest area (ha)	Spray area (ha)	No. of sprays	Infest area (ha)	Spray area (ha)	No. of sprays
Cabbage							Common cabbage worm		
Spring	4,351	6,052	2.3	822	5,219	1.7	1,821	4,597	1.7
	(36.6)	(50.9)		(6.9)	(43.9)		(15.3)	(38.7)	
Summer-autumn	5,076	9,572	4.2	2,256	9,279	2.9	2,879	9,374	2.9
	(38.3)	(64.7)		(17.0)	(70.0)		(21.7)	(70.7)	
Winter	8,133	10,904	3.0	5,356	9,420	2.5	4,838	7,872	2.5
	(47.7)	(63.9)		(28.4)	(46.2)		(31.4)	(55.2)	
Chinese cabbage								Aphids	
Spring	1,158	63	2.7	152	618	1.2	147	121	2.3
	(56.8)	(3.1)		(7.5)	(30.3)		(7.2)	(5.9)	
Summer	1,168	2,129	3.5	309	2,129	3.4	706	2,014	3.9
	(26.9)	(49.1)		(7.1)	(49.1)		(16.3)	(46.4)	
Autumn-winter	5,596	9,608	2.3	5,881	16,670	1.9	7,078	10,823	2.2
	(19.4)	(33.3)		(20.3)	(57.8)		(24.4)	(37.8)	

[a] Source: MAFF 1984a. [b] Figures in parenthesis are percent of planted area.

Insecticides for DBM Control

Insecticides

Table 4 lists the major insecticides registered and recommended for the control of DBM and other crucifer insect pests by various prefectures. There were 39 single formulations and 19 mixtures recommended for DBM control in Japan in 1984. These preparations have 28 active ingredients, the majority of which are organophosphorus

compounds. Cartap (tertiary amine), methomyl and carbaryl (carbamates), and fenvalerate (pyrethroid) are the only non-organophosphorus insecticides included in the recommendation. Fenvalerate is available only as mixtures with organophosphorus insecticides in Japan. One microbial insecticide, an endotoxin of *Bacillus thuringiensis* Berliner, is also recommended. Cartap, being a depressive postsynaptic blocker of the insect central nervous system (Sakai 1969), has a different mode of action from the other group of chemicals used in DBM control.

Besides DBM, these chemicals also give degrees of control over other cruciferous pests. All of the insecticides recommended for DBM control also give effective contol of common cabbage worm. Table 4 lists the other insect species that are also controlled by insecticides recommended for DBM control. The simultaneous control of a wide range of pests is useful as several injurious insects can coexist in one growing season.

Table 4. Main insecticides registered for DBM control[a]

Insecticide	Formulation[b]	Insects controlled[c]
TERTIARY AMINE		
Cartap	50SP, 2D	Pr, Mb, Ap, Hu
CARBAMATE		
Methomyl	45WP	Pr, Mb, S, Pn
ORAANOPHOSPHORUS		
Acephate	50WP, 5G	Pr, Mb, Sl, Pn
Chlorfenvinphos	5D	Pr, Ap
Chlorpyriphos-methyl	25EC	Pr, Mb, Sl, Ap
Cyanophos	50EC	Pr, Mb, Pn, Ap, Ps
Diazinon	40EC, 3D, 3G, 5G	Pr, Ap, Ps
Dichlorvos	50EC, 75EC	Pr, Mb, Sl, Pn, Ap, Ps, Hu
Dimethylvinphos	50WP	Pr, Mb
Isoxathion	50EC	Pr
Naled	46EC	Pr, Mb, Ap
Phenthoate	50EC, 2D	Pr, Mb, Sl, Ap, Ps
Piridafenthion	40EC	Pr
Pirimiphos-methyl	45EC	Pr, Mb, Ap
Prothiophos	45EC, D	Pr, Mb, Sl, Pn, Ap
Salithion	25EC	Pr, Mb, Sl, Ap
Tetrachlorvinphos	50WP	Pr, Sl
Trichlorfon	50EC	Pr, Mb, Ap, Ps, Hu
MIXTURES		
Cartap. methomyl	20.20WP	Pr, Mb, Sl, Ap
Chlorfenvinphos. dichlorvos	15.25EC	Pr, Mb, Ap
Diazinon. disulfoton	3.3G	Pr, Ap
Dichlorvos. isoxathion	30.30EC	Pr, Mb, Sl, Pn, Ap
Dichlorvos. phosalone	40.20EC	Pr, Mb, Sl, Ap
Dichlorvos. trichlorfon	20.30EC	Pr, Mb, Ap
Dimethoate. fenvalerate	15.4EC	Pr, Mb, Ap
Fenvalerate. malathion	4.30WP	Pr, Mb, Pn, Ap
Isoxathion. methomyl	30.15WP	Pr, Mb, Ap
MICROBIAL		
Bacillus thuringiensis endotoxin	7WP	Pr, Mb

[a] Only those insecticides that conform to 1984 prefectural standards are listed. [b] EC, emulsifiable concentrate; WP,wettable powder; SP, soluble powder; D, dust; G, granules; figures indicate percent active ingredient in formulations. [c] Pr, *Pieris rapae* spp *crucivora*; Mb, *Mamestra brassicae*; Sl *Spodoptera litura*; Pn, *Plusia nigrisigna*; Ap, Aphids; Ps, *Phyllotreta striolata*; Hu, *Hellula undalis*. (source JPPA 1984)

Most of the insecticides are applied as foliar sprays. Some dust and granule formulations are applied into the soil at sowing or transplanting time. With each insecticide recommendation the number of days that should elapse before harvest as well as the maximum number of applications of a particular insecticide during a cropping season, is also indicated (Table 5).

Every year each prefectural government in Japan also sets guidelines for the use of insecticides. A summary of their recommendations in 1984 indicated that 34 formulations including nine mixtures consisting of 23 active ingredients were recommended for DBM control (Table 6). Acephate, cartap, phenthoate, and mixtures of fenvalerate and organophosphorus chemicals are more common than the others. These insecticides have certain characteristics which results in their more frequent use. For example cartap,

Table 5. Directions for use of major insecticides in crucifer insect pest control in Japan

Insecticide	Formulation	Days between last spray and harvest/application frequency per season[a]		
		Cabbage	Chinese cabbage	Radish
Cartap	50SP	14/4	7/3	7/3
	2D	14/4	7/3	7/3
Methomyl	45WP	3/3	14/2	7/3
Acephate	50WP	7/3	14/3	14/3
	5G	21/3	a/3	b/1
Chlorfenvinphos	5D	14/4	—	30/3
Chlorpyriphos-methyl	25EC	7/6	30/2	30/2
Cyanophos	50EC	3/6	7/6	21/4
Diazinon	40EC	30/2	14/2	—
Diazinon	G	30/2	a/2	b/2
Diazinon	D	30/2	30/2	b/2
Dichlorvos	50.75EC	c/n.l.	7/5	14/n.l.
Dimethylvinphos	50EC	7-3	—	—
Isoxathion	50EC	21-2	—	—
Naled	46EC	3/n.l.	—	—
Phenthoate	50EC	7/4	14/4	14/4
	2D	7/4	14/4	14/4
Piridafenthion	40EC	7/3	—	—
Pirimiphos-methyl	45EC	14/4	—	—
Prothiophos	45EC	7/3	—	—
	D	21/3	—	—
Salithion	25EC	7/6	14/6	21/3
Tetrachlorvinphos	50WP	7/4	21/3	—
Acephate.carbaryl	30.20WP	7/3		
Chlorfenvinphos				
Dichlorvos	50EC	14/4	—	—
	75EC			
Dichlorvos. isoxation	30.30EC	21/2	30/2	30/2
Dichlorvos. phosalone		c/3	—	7/5
Dichlorvos. trichlorfon	20.30EC	7/6	7/6	14/6
Dimethoate. fenvalerate	15.4EC	7/3	14/3	35/3
Disulfoton. diazinon	3.3G	a/l	—	b/l
Fenvalerate. malathion	4.30WP	7/5	7/5	35/3
Isoxathion. methomyl	30.15WP	21/2	30/2	30/2
Bt[b] endotoxin	7WP	n.l.	n.l.	n.l.

[a] a: Sowing or transplanting time; b: sowing time; c: one day before harvest; n.l.: no limits. [b] *Bacillus thuringiensis*. For other abbreviations please see footnotes of Table 4.

Table 6. Status of major insecticide recommendations for DBM control (1984)

Insecticide	No.of prefectures recommending for:			
	Cabbage	Chinese cabbage	Radish	Total
Acephate WP	38	36	35	109
Cartap SP, D	38	35	31	104
Fenvalerate. malathion WP	36	33	24	95
Phenthoate EC, D	26	32	30	88
Fenvalerate. malathion WP	34	30	24	88
Chlorpyrifos-methyl EC	26	20	17	63
Methomyl WP	21	22	18	61
Salithion EC	25	13	22	60
Cyanophos EC	20	20	20	60
Dichlorvos. isoxathion EC	22	20	17	59
Acephate G	26	17	12	55
B. thuringiensis WP	20	18	12	50
Dichlorvos EC	12	15	18	45
Prothiophos EC	39	—	—	39
Pirimiphos-methyl EC	39	—	—	39

beause of it peculiar mode of action, is useful in controlling DBM strains which have developed resistance to conventional insecticides. Acephate is systemic and has a broad spectrum of activity which gives simultaneous control of several pests. The recent introduction of fenvalerate is expected to give better control of insecticide-resistant DBM strains. The addition of malathion or dimethoate would add aphicidal properties to fenvalerate mixtures.

Spray program

Some insecticides are specific to DBM while certain chemicals are more effective against other pests compared to DBM. At the same time the required interval between last spray and harvest, and the frequency of spray for each chemical, are regulated individually. Therefore, it is important to select insecticides according to insect pest complex and the mandatory spray-free time between last spray and harvest. In the early plant growth stage, when insect injury is minor, insecticides with quick action, such as phenthoate and methomyl help to suppress insect populations. In later growth stages, insecticides with longer residual action, like cartap, prothiophos, and fenvalerate mixtures, are suitable for controlling multivoltine species including DBM (Nakagome and Kato 1981).

Repeated insecticide applications are required to control DBM, especially during the peak population period. However, spraying a single insecticide or insecticides with similar modes of action increases the chances of the insect becoming resistant. Therefore, rotation application of insecticides of different chemical groups is always recommended by the prefectural authorities. Table 7 exemplifies a spray calendar provided by a local agricultural cooperative officer under the supervision of the prefectural government extension service. Atsumi is located in the warm lowlands of Aichi Prefecture. DBM infestation tends to peak in late spring and in autumn in this area (Yamada 1977, Nakagome and Kato 1981) but damage caused by DBM, noctuids, and aphids to cabbage takes place throughout the season and even into November and December. Tsumagoi on the other hand is located in the highlands of Gunma Prefecture where cabbage is extensively grown in summer. All crop growth stages are subjected to severe insect pest

infestation which peaks in August to September (Gunma Prefectural Agricultural Experiment Station 1984). Therefore, the dates of insecticide applications are not included in the spray schedule. Instead farmers are advised to establish optimum time on their own or to consult the extension service. Seven to eight or even more sprays are required in one cropping season in this area. Our survey indicates that cartap is used three times per cropping season on average.

Table 7. Examples of spray calender for controlling DBM[a]

Example 1 Atsumi, Aichi Prefecture		Example. 2 Tsumagoi, Gunma Prefecture	
Date	Chemical spray	Date	Chemical spray
Aug 15-20	(Sowing)	late Feb -late Jun	(Sowing)
early Sep	Dichlorvos	late Apr -late Jul	(Transplanting)
mid Sep	Salithion		
Sep 20-25	Acephate G (soil appl)	late Jul -mid Nov	(Harvesting)
early Oct	Salithion	May-Nov	spray the following insecticides to control common cabbage worm, cabbage armyworm, diamondback moth and beet semi-looper: cartap, fenvalerate + malathion, fenvalerate + dimethoate, prothiophos, methomyl, acephate, salithion, pirimiphos-methyl, dichlorvos.
mid Oct	Prothiophos		
late Oct	Fenvalerate + malathion		
early Nov	Cartap		
mid Nov	Acephate		
late Nov	Pirimiphos-methyl		
early Dec	Methomyl		
mid Dec	Cartap		
Mar	(Harvesting)		

[a] Fungicides are omitted. Aphicides are omitted in Example 2.

Insecticide resistance

Dichlorvos was widely used in the early years when DBM infestation first started to become severe. However, in the mid-1970s its effectiveness started declining in many parts of Japan. This was followed by reports of the insect becoming resistant to several organophosphorus compounds and even to methomyl.

From 1980 to 1982, the Japan Plant Protection Association surveyed resistance levels of DBM to various chemicals (JPPA 1980, 1981, 1982). Laboratory assays were conducted with 3rd instar larvae collected from various locations. The insects were released onto cabbage leaves dipped in concentrations of various insecticides and LC_{50} values were compared (Table 8). Dichlorvos and acephate were found to be less effective. Prothiophos and cyanophos seemed effective but results for several locations indicated the development of resistance. In the case of cartap, the LC_{50} values were smaller than for most organophosphorus chemicals and differed little among locations. This implies that DBM has not developed resistance to cartap. If any, the level of resistance is very low even in organophosphorus insecticide-resistant populations. Other examples of susceptibility of DBM to cartap are shown in Table 9. Some of the insects strains which have developed resistance to organophosphorus insecticides were assayed simultaneously with susceptible strains maintained in our laboratory (Kyoto lab S strain). The resistance factor for cartap was less than 7.1. The data obtained from Nagoya University (Noppun et al 1983) also demonstrated very low levels of resistance in DBM to cartap.

Table 8. Susceptibility of 3rd instar DBM larvae from different locations to selected insecticides (leaf dip method)

Location		Year	cartap[a]	LC_{50} ppm, (48 h) dichlorvos	acephate	prothiophos	cyanophos	fenval + [b] malathion	*Bt* endotoxin
Miyagi	Natori	'80	22	446	199	46	14	19	
		'81	38	700	160	19	4		
		'82	86	1928	360	53			21
	Miyagi	'81	46	995	346	33	7	8	
		'82		772	512	48	110		
Gunma	Kitayama	'80	86	634					
		'81	48	994	614	842	306		
	Showa	'80	66	612	220	157	26		
		'81	104(40)	1146	507	437	269		
	Higashi	'82	146(72)	822	364	448	30		
Aichi	Nagakute	'81	49	630	306	128	78		
Nara	Kashihara	'80	63	940	580		70		
	Uda	'81	313(91)	1462	658	58	47		
Kagawa	Hase	'80	133	694	241	104	5.2		
	Kawaoku	'80	158	229	48	16	6.7		
	Gogo	'80	208	421	236	23	7.4		
		'81	133						
	Susceptible[c]	1	13	229	48	16	3.7		
		2	41						
		3	(19)						
		4	49						
		5	38						

[a] Figures in parenthesis are LC_{50} after 72 h. [b] Fenvalerate + malathion. [c] 1; Sumitomo Laboratory strain, 2; Takeda Laboratory strain (tested in 1971). 3; Takeda Laboratory strain (tested in 1974), 4,5; Takeda Laboratory strain (1984). Source: JPPA 1980, 1981, 1982. (except Takeda Laboratory strain).

Table 9. Resistance factors for cartap in some organophosphorus insecticide resistant DBM larvae

Test Method	DBM strain	Resistance factor cartap[a]	organophosphate
Leaf dip	Shiojiri	1.8	acephate 6.8
	Okinawa	7.1	dichlorvos 22.3
	Prothiophos-selected[b]	3.8	prothiophos > 50
	Dichlorvos-selected	5.6	dichlorvos > 50
	Cyanophos-selected	6.1	—
Topical[c] application	Okinawa	2.6	phenthoate 136
	Aichi	0.9	phenthoate 24.5

[a] Comparison with Kyoto laboratory susceptible strain. [b] Selected strains were obtained from Kagawa Agricultural Experiment Station. [c] Data from Noppun et al (1983)

Conclusion

Use of insecticides to control DBM and most other pests is unavoidable to ensure high yields of quality cruciferous vegetables. In many cases more frequent insecticide sprays are required to control this pest as opposed to other pests. Although a number of insecticides are registered, fewer than 10 of them are actually used; others are discarded

due to their reduced effectiveness. Discarding of old chemicals will accelerate as newer more potent chemicals, such as pyrethroids, are introduced. However, since new groups of chemicals are frequently hard to come by, the chances of substitution of new chemicals for the presently used ones are diminishing. Therefore, careful timing of application and rotation of chemicals should be observed. Judicious rotation of chemicals with different modes of action will prolong the effectiveness of presently used insecticides substantially. Cartap has been used for DBM control for over 10 years, but there is little indication that DBM has developed resistance to it. This fact and its peculiar mode of action suggest that cartap should be an important chemical in any rotational spray application to control DBM or other pests.

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Present Status of Insecticidal Control of Diamondback Moth in Thailand

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Abstract

This paper gives a brief history of insecticide use against diamondback moth, *Plutella xylostella* (L) in Thailand from 1965 to 1984. Field observations indicated that the insect has developed resistance to all groups of chemical insecticides. High incidence of resistance was common on established vegetable farms where this insect had been exposed to many chemical insecticides over several years. The commercial bacterial insecticide, *Bacillus thuringiensis* Berliner, is also used. Its performance varies, due presumably to the influence of irrigation practices. Two recent (1983-1984) field tests, involving 11 insecticides belonging to various groups, conducted in the central plain where this insect has developed high levels of resistance, indicated that insect growth regulators (Tefluron and Triflumuron) give excellent control while the others are less effective. The bacterial insecticides Bactospeine still gave satisfactory control at two locations.

Introduction

Cabbage, kale, edible rape, Chinese cabbage, leaf mustard, Chinese radish, and cauliflower are common cruciferous vegetables in Thailand. Based on cultural practices adopted, commercial vegetable growing areas of Thailand can be classified into three categories. The first category consists of areas where the cruciferous vegetables are planted year-round and suburban areas where the majority of growers have been earning their living by the sale of the vegetables to urban markets for a number of decades. The second category includes the highland areas of the country. Cruciferous vegetables grown at high elevation are mostly cabbage, Chinese cabbage, and cauliflowers. Crops are normally planted for six months particularly during the rainy season when vegetables fetch better prices. The third category includes annual crops where a variety of crucifers are sporadically grown during winter season. The problem of diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), in Thailand varies according to the cropping pattern described above. This paper describes the status of DBM and its control by insecticides in Thailand from the early 1960s and discusses the present status of insecticidal control and examines remedy for the pesticide use problem in the country.

Seasonal Occurrence and Pest Status

Normally DBM in Thailand is prevalent from February to April when optimum climatic conditions and food plants are more readily available. However, in many areas of the central plain where crucifers are planted year-round, DBM damage can be observed throughout the year and it is in this area that the insect has been the most serious threat

to cruciferous crops for many years. The problem in this area is the excessive use of insecticides which has resulted in the build-up of resistance to various chemicals and makes control of this insect difficult. Crucifers grown in the highlands are subjected to a lesser degree of damage except during the brief peak outbreak periods of the year. In the lowlands the DBM problem is much less severe as compared to the other areas, possibly due to rotation with other crops.

Insecticide Use 1965-1984

Insecticides of both chemical and non-chemical origin have been introduced and evaluated extensivety since the early 1960s. A summary of field screening tests (Table 1) indicated that during 1965-1968, malathion, mevinphos, endrin, naled, azinphos-ethyl and carbaryl were tested in the northern area. All products, except carbaryl, showed good efficacy against DBM. Efficacy of mevinphos and parathion, as well as the newly introduced quinalphos, were evaluated between 1969 and 1971 in the central region where good DBM control was obtained. A few years later, based on field studies, methamidophos, acephate, and cartap gave better DBM control while quinalphos and mevinphos still retained effectiveness. The first field test of methomyl was carried out in the early 1970s. The product failed to give adequate control. Excellent control of DBM by triazophos and prothiophos was first obtained in 1974 in the northern area (Table 1). These two chemicals were also excellent in DBM control in the central region for a number of years (1975-1978). Recent field evaluation (1982-1984) has indicated that the efficacy of prothiophos was reduced in the central area but it still gave satisfactory control of DBM infesting annual crucifer crops.

Insecticidal control of DBM in Thailand entered the new era of synthetic pyrethroids in 1976 when fenvalerate and permethrin gave impressive control of the pest in Bangkok suburban areas. Cypermethrin and deltamethrin were among other pyrethroids that were introduced later. These four insecticides were used extensivety for two to three years before DBM showed resistance to them. From recent field tests (1982-1984) it appears that those four synthetic pyrethroids are no longer effective in the central area but still give fair control in areas where crucifers are grown once a year. Profenofos, another new insecticide introduced in the late 1970s, showed excellent effectiveness in the central area during 1977-1978 tests but gave rather poor control in the same area in 1983. Insecticide control of DBM in the central area during 1978-1982 mostly involved the spraying of mixtures of pyrethroid and other chemicals. At this time the latest generation of chemical insecticides, insect growth regulators (IGRs), were introduced to vegetable growers. Diflubenzuron was the first to be released directly to growers, followed by triflumuron. The efficacy of the four insect growth regulators diflubenzuron, trifluron, triflumuron and chlorfluazuron was therefore evaluated in the field in 1983. Two newer products, tefluron and chlorfluazuron, were very effective in DBM control at much lower rates as compared to triflumuron and diflubenzuron. Tefluron became a leading IGR for DBM control in the central plain.

The microbial insecticide *Bacillus thuringiensis* (*Bt*), has been used in DBM control since 1972. Most commercial *Bt* products available belong to strain HD-1, variety *Kurstaki*, serotype 3a 3b. Field evaluation of these products in 1982 (Table 1) showed most promising results in the northern area while in the central plain the efficacy was rather erratic. Among the major factors that could contribute to the successful utilization of this microbial insecticide in Thailand, as pointed out by Rushtapakornchai et al (1984), are loss of efficacy prior to application and irrigation practices, as well as extreme climatic conditions after the treatment. Rustapakornchai et al (1982) have developed action thresholds for DBM on cabbage in the north by using *Bt*. It was found that if a decision

to spray is made at three larvae per plant before heading, and 10 larvae per plant from heading to harvest, the number of treatments can be reduced without loss of marketable yield.

Table 1. Summary of results of field screening of various insecticides in Thailand during 1965-1984

Insecticides	Year of introduction and use[a]																		
	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
Malathion	3C	3N	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mevinphoos	4C	4N	—	—	—	—	4C	4N	—	2N	3N	—	—	—	—	—	—	—	—	1C
Naled		3N	—	—	—	—	—	2N	—	—	—	—	—	—	—	—	—	—	—	—
Quinalphos					4C	—	—	—	—	4C	—	—	—	—	—	—	—	—	—	—
Parathion							2C	—	—	—	—	—	—	—	—	—	—	—	—	—
Methomyl								2N	—	—	—	—	—	—	—	—	—	—	—	—
Methamidophos								3N	—	3N	2N	—	—	—	—	—	—	—	—	—
Acephate								3N	—	—	2N	—	—	—	—	—	—	—	—	—
										3N	—	—	—	—	—	—	—	—	—	—
Biotrol								3N	3N	2C+	—	—	—	—	—	—	—	—	—	—
Disidrin									2N	2C	—	—	—	—	—	—	—	—	—	—
										2N+	—	—	—	—	—	—	—	—	—	—
Dipel									2N	2N	—	—	—	—	—	—	—	—	—	—
										1C	—	—	—	—	—	—	—	—	—	—
Cartap										3N	—	—	—	—	—	—	—	—	—	—
										3C	—	1C	—	—	—	—	—	—	—	—
Triazophos										3N	3N	3C	4C	4N	—	—	—	—	—	—
Prothiophos											4C	4N	—	4C	—	—	—	4N	—	1C
Monocrotophos											1N	—	—	—	—	—	—	—	—	—
Fenvalerate												4C	3C	4N	—	—	—	3N	—	—
														2C	—	—	—	—	—	—
Permethrin												4C	—	2C	—	—	—	—	—	—
Cyanofenphos													3C	3C+	—	—	—	—	—	—
Profenofos													3C	3C	—	—	—	—	2C	—
Cypermethrin														2C	—	—	—	—	1C	—
Deltamethrin														2C	—	—	—	—	2C	1C
Thuricide															2C	—	—	3N	2C	—
Bactospeine																		3N	2N	2C
Agrona																		2N	2C	—
Diflubenzuron																		3N	3C	—
																			1C+	—
Triflumuron																		3N	2C	1C
Tefluron																			3C	4C
Chlorfluazuron																			4C	—

[a] 1 = poor control, 2 = fair control, 3 = good control, 4 = excellent contorl. C = central region including Bangkok suburbs, N = northern region. + Mixed with other insecticides.

Present and Future Trends in Insecticide Use for DBM Control

Results of the field test in 1984 in the central vegetable area involving 11 insecticides belonging to six chemical groups emphasised the present and future status of insecticide use for the control of insecticide-resistant DBM strains. Data in Tables 2 and 3 shows that IGRs give excellent DBM control. Tefluron, at the rate of 0.05 kg AI/ha and Triflumuron, at 0.375 kg AI/ha performed well. Triflumuron was excellent at one location but did not do well at another. The synthetic pyrethroid deltamathrin

Table 2. Evaluation of insecticides for control of DBM on Chinese cabbage at Kumpangsan Campus, Kasetsart University, Nakornpathom Province[a-f]

Insecticides	Rate kg AI/ha	No. DBM larvae/10 plants at DAT[g]				Yield t/ha
		13	22	31	40	
Rotenone	5.00	102.00	41.60abc	26.30ab	31.00ab	15.61
Tobacco (extract)	84.00	100.60	49.60bcd	48.00bc	43.00abc	18.68
Nevinphos 24EC	1.00	102.30	88.30def	61.00cd	58.30bcd	15.24
Prothiophos 50EC	1.00	99.60	122.30f	101.00e	101.30f	15.12
Carbaryl 43.4SC	2.00	111.30	96.30ef	102.00e	185.00g	12.17
Methomyl 90SP	0.50	119.30	120.60f	87.60de	98.30ef	12.78
Deltamethrin 3EC	0.025	70.60	104.60ef	94.00de	86.00def	14.50
Tefluron 5EC	0.05	108.60	6.66a	1.30a	5.30a	19.42
Bactospeine[h] SC	1.50	108.30	12.60ab	6.30a	6.00a	13.28
Triflumuron 25WP	0.375	96.30	4.00a	7.00a	8.30a	17.33
ENZ#1 50EC[i]	1.00	102.30	43.30abc	26.00ab	40.60abc	16.47
Control	—	130.30	63.00cde	50.00bc	59.60bcd	14.87

[a] Cultivar: Local. [b] Transplanting date: 15 May 1985. [c] Insecticides applied: 30 May, 4, 8, 12, 16, 20, 24, 28 June and 2 July 1984. [d] Harvested: 7 July 1984. [e] Data are mean of three replicates. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test. [f] Plot size: 17.50 sq m. [g] Days after transplanting. [h] *Bacillus thuringiensis*. [i] Code number given by Entomology and Zoology Division, Department of Agriculture, Thailand.

Table 3. Evaluation of insecticides for control of DBM on Chinese cabbage at Paseejaroen District, Bangkok[a-f]

Insecticides	Rate kg AI/ha	No. of DBM larvae/10 plants at DAT[g]			Yield t/ha
		24	35	46	
Rotenone	5.00	0.00	8.25h	43.75e	12.47
Tobacco (extract)	84.00	0.00	7.25ef	24.00cd	12.60
Mevinphos 24EC	1.00	0.50	8.50h	29.25d	12.75
Prothiophos 50EC	1.00	0.00	7.50g	26.75d	14.06
Carbaryl 43.4SC	2.00	0.25	7.75g	22.25cd	11.92
Methomyl 90SP	0.50	0.75	7.75g	31.75d	11.09
Deltamethrin 3EC	0.05	0.00	7.50g	30.25d	12.91
Tefluron 5EC	0.05	0.00	0.00a	1.50a	13.69
Bactospeine[h] SC	3.00	0.00	6.25e	17.50bc	14.34
Triflumuron 25WP	0.373	0.00	5.50d	22.50cd	14.50
ENZ#1 50EC[i]	1.00	0.00	6.75f	12.50b	14.15
ENZ#1 50WP[i]	1.00	0.00	0.75b	3.25a	14.61
ENZ#1 1.8LC[i]	0.18	0.00	4.50cd	25.50cd	12.46
ENZ#1 1.8LC[i]	0.36	0.00	2.00bc	16.00bc	12.34
Control	—	0.00	8.50gh	26.25d	11.77

[a] Cultivar: Local. [b] Sowing date: 25 June 1984. [c] Insecticides applied: 20, 24, 28 July, 1, 5, 9 and 13 August. [d] Harvested: 84/8/17. [e] Data are mean of four replicates. Means in each vertical column followed by same letter are not significantly different at the 5% level according to Duncan's multiple range test. [f] Plot size: 10 sq m. [g] Days after transplanting. [h] *Bacillus thuringiensis* Berliner. [i] Code number given by Entomology and Zoology Division, Department of Agriculture, Thailand.

when applied at 0.025 kg AI/ha gave poor DBM control at both locations. Two organohposphorus products, mevinphos and prothiophos, which in the past were used extensively, afforded poor control. Carbamates such as methomyl and cabaryl also

gave poor control. ENZ -1, an organophosphorus insecticide, gave fair control when applied at the rate of 1 kg AI/ha. The two botanical insecticides, rotenone and nicotine sulphate (tobacco leaf extract), when applied at high rates gave fair control in one location but failed at another. The only bacterial product, Bactospeine, when applied at the rate 1.50 and 3.0 kg product/ha gave good DBM control in both tests. For the present and near future, in the highlands and in the areas where crucifers are grown once a year and where insecticide pressure is generally lower, the DBM control by insecticides is less complicated as certain commonly used insecticides still give good control. This trend can be observed from 1982 field reports described in Table 1. A number of chemicals that failed to control DBM in the central area performed better at other areas. In areas of continuous crucifer cultivation, however, only IGRs show promise in DBM control.

Present Research to Tackle the Pesticide Use Problem in Thailand

Since the tropical climate and the continuous cultivation of crucifers in Thailand is conducive to DBM infestation and rapid multiplication, this pest has been a serious problem for the past several years. Because of the rapid turnover of generations, DBM develops resistance to chemical insecticides rather quickly. In order to combat the DBM pest problem, the following long range research projects are presently being under taken by the Department of Agriculture.

1. Studies of control thresholds for DBM on major cruciferous crops. 2. Studies of the dynamics of DBM and its parasite populations on cabbage in the highlands. 3. Studies of the effect of insecticides on the parasites of DBM in the field. 4. Studies into improving the potential of commercial products of *B. thuringiensis* in the field. 5. Studies into the potential use of sex pheromones for mass trapping of DBM adults. 6. Studies of the potential of insect growth regulators for integrated control of DBM.

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Effect of Insecticides on Various Field Strains of Diamondback Moth and Its Parasitoid in Indonesia

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Abstract

The susceptibility of four field strains (Tawangmangu, Pacet, Kopeng and Lembang) of diamondback moth to the synthetic pyrethroids, carbaryl and *Bacillus thuringiensis* was assessed in the laboratory as well as in the field. Results indicated that there were differences in insect susceptibility depending upon their origin. In general, Lembang and Kopeng strains were more resistant than Pacet and Tawangmangu strains to all insecticides tested except *B. thuringiensis*. The susceptibility of the diamondback moth parasitoid, *Diadegma eucerophaga*, from two major cabbage centers (Lembang and Pacet) was also tested. Results indicated that Lembang strain has developed resistance to fenvalerate. The efficacy of *B. thuringiensis* was lower compared to the synthetic pyrethroids and carbaryl. However, field assessment in West Sumatra indicated that *B. thuringiensis* applied singly or in combination with synthetic pyrethroids gave significantly higher yields than quinalphos as a standard insecticide. *B. thuringiensis* was less toxic to *D. eucerophaga*.

Introduction

Cruciferous vegetables are economically very important to farmers in the highlands and in specialized production areas of Indonesia. These farmers use input intensive agronomic practices because the sale of these vegetables provides an important source of ready cash income. However, crucifer production in recent years has been seriously affected by a steady increase in the incidence of insect pests.

Two major insect pests, diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Yponomeutidae), and *Crocidolomia binotalis* Zell (Lepidoptera: Pyralidae) feed on the leaves of cruciferous plants from seedling stage to harvest and greatly reduce both yield and quality of the produce. During the dry season, heavy infestation of DBM can cause 100% yield loss if no insecticides are used (Sudarwohadi 1975). During the wet season, the yield loss still can be 30% (Sudarwohadi and Eveleens 1977). Oka (1976) reported that the yield loss from this insect ranged from 46 to 90%.

Insecticides are considered the most effective means of protecting crops against insect damage as they provide rapid control of whole pest complexes of major cruciferous pests. Usually farmers use large quantities of chemicals, often spraying a 'cocktail' of compounds. Woodford et al (1981) reported that the farmers of West Java used about 16 kinds of insecticides to control pests of cruciferous vegetables. The most popular insecticides now are the synthetic pyrethroids fenvalerate, permethrin, and deltamethrin.

In North Sumatra, the most popular insecticides are permethrin and chlorpyrifos. As a consequence of frequent insecticide use, DBM has developed resistance to practically all categories of insecticides, and minor insect pests have become major problems in some areas.

In 1953, the development of insecticide resistance to DDT was first noted in Lembang by Ankersmit (1953). In the 1960s, organophosphorus insecticides were used intensively in the Lembang area. Since then, resistance to most of the commonly used insecticides has been observed in this insect. In 1977, farmers started to use synthetic pyrethroids such as permethrin and deltamethrin. Permethrin at a rate of 7.5 to 15 g AI/ha could then effectively control DBM at Pujon in East Java and Kabanjahe in North Sumatra (Sitanggang 1977). But in 1982, the DBM population from West Sumatra and West Java could only be controlled when the dosage of permethrin was increased to 40 g AI/ha. Likewise, deltamethrin at a rate of 7.5 to 12.5 g AI/ha could initially control DBM at Margahayu and Segunung, however, since 1982 a dose of at least 30 g AI/ha has been required to control DBM at these locations (Sudarwohadi 1983).

These observations suggested that the DBM population is becoming resistant to this new group of compounds. Studies were initiated in 1982 to determine DBM's response to pyrethroids, carbamates, and microbial insecticides. The results reported here represent the data obtained in 1982 and 1983.

Materials and Methods

Two laboratory studies and three field experiments were conducted in 1982 and 1983.

Laboratory Study I (1982)

This experiment was conducted at Segunung, in West Java.

Insecticides Permethrin 2EC, cypermethrin 5EC, fenvalerate 5EC, and deltamethrin 2.5EC were obtained locally.

Insects Pupae of the DBM were collected from three locations and reared on cabbage in the laboratory. A population from Selo in Central Java was identified as a susceptible (S) strain. Populations from the other two locations, Kopeng in Central Java and Lembang in West Java, were reported to be resistant (R) to the synthetic pyrethroids.

Bioassay procedure The standard test for determining LD_{50} values by topical application of insecticides was used (ESA 1970, and Heinrichs et al 1981). Insecticide in 0.05 μl acetone was applied to the dorsal thoracic surface of 3rd instar larvae. The larvae were then transferred to 9 cm diam petri dishes containing cabbage leaves and maintained in rearing room at 25°C, 70% RH, and at a photoperiod of L:D 12:12. Ten untreated larvae were placed in a petri dish containing cabbage leaves. Each of three replicates had at least 10 larvae per insecticide concentration. A minimum of six concentrations, together with a control, were used for each bioassay. Mortality was recorded after 24 h and analyzed by probit analysis (Finney 1971).

Laboratory Study II (1983)

This experiment was conducted at Pacet in West Java.

Insecticides Permethrin 2EC, cypermethrin 5EC, fenvalerate 5EC, carbaryl 85WP, and *Bacillus thuringiensis* strain HD 1 were obtained locally.

Insects Third and/or fourth instar larvae of DBM were collected from four locations and reared on cabbage. A population from Tawangmangu in Central Java was identified as a susceptible (S) strain, and populations from Lembang and Pacet in West Java and Kopeng in Central Java were reported to be resistant (R) to the synthetic pyrethroids. Pupae of *Diadegma eucerophaga* Horstm, one of the most promising biological control agents of DBM, were also collected from Lembang and Pacet and reared separately on DBM larvae.

Bioassay procedure Toxicity measurements for synthetic pyrethroids and carbamate insecticides were made by using the procedure of Plapp and Vinson (1977).

DBM

Twenty 2nd or 3rd instar larvae were exposed to residues of insecticides on the inner surfaces of 9 cm diam petri dishes. These dishes were treated with acetone solutions of each insecticide. Acetone only was used for the control. One hour after the exposure, the larvae were transferred to untreated petri dishes containing cabbage leaves.

Diadegma eucerophaga

Ten three to five day-old adult females of *D. eucerophaga* were exposed to residues of insecticides on the inner surfaces of 25 mm od x 20 cm test tubes. These tubes were treated with acetone solutions of each insecticide. Acetone only was used in the control. One hour after exposure, the insects were transferred to untreated test tubes containing a cotton plug soaked in a 10% honey in water solution, and they were maintained in a rearing room.

All petri dishes and test tubes were maintained at 25°C, 70% RH and at a photoperiod of L:D 12:12 during the observation period.

Mortality determinations were made 48 h after initial exposure.

Toxicity measurement for *B. thuringiensis* was made by the procedure of Busvine (1971). Five week-old cabbage plants were sprayed with water solutions of *B. thuringiensis*. Water only was used for the control. Twenty 2nd or 3rd instar DBM larvae were confined on the treated plants. Mortality determinations were made 72 h after exposure. LC_{50} and LC_{90} and slope values for each insecticide against all field strains were calculated with maximum likelihood probit analysis (Finney 1971).

Field Experiment I, West Java (1982)

Two field experiments were conducted at Lembang and Segunung. Cabbage cultivar Gloria Osena was used at Lembang and K K Cross at Segunung. Six treatment plots including standard insecticide and control replicated four times were arranged in a randomized complete block design. The cabbage plants were transplanted at 80 x 50 cm apart in 8 x 5 m plots which contained 100 plants. Insecticidal dosage and treatments were as follows: fenvalerate 5EC (0.08 kg AI/ha), permethrin 2EC (0.04 kg AI/ha), cypermethrin 5EC (0.08 kg AI/ha), deltamethrin 2.5EC (0.03 kg AI/ha), and diethquinalphion 25EC (0.5 kg AI/ha) used as a standard check. Sprays were applied with a semi-automatic knapsack sprayer and depending on the age of the crops a spray volume of 500 to 1100 l/ha (average 800 l/ha) was used. The first application started at 14 days after planting (DAP) and was repeated once every week thereafter when the population reached the economic injury level (action threshold or control threshold). The threshold level at Lembang was 0.1 larvae/plant starting 13 DAP up to 69 DAP (Chalfant et al 1979). At Segunung the threshold level was 0.1 larvae/plant, starting 13 DAP up to 34 DAP (Chalfant et al 1979) and intermediate injury level was P = 41-60%, starting

41 DAP up to 62 DAP (Sastrosiswojo et al 1981). Standard check insecticide was applied at weekly intervals starting at 14 DAP up to 70 DAP at Lembang and 63 DAP at Segunung.

Ten plants within each plot were selected systematically. The numbers of DBM and *C. binotalis* larvae on each plant were recorded at weekly intervals starting 13 and 15 DAP up to 71 DAP of Lembang and 64 DAP at Segunung.

Percentage injury level was calculated as follows:

$$P = \frac{\Sigma (n \times v)}{5N} \times 100$$

P = percentage injury level; n = total number of leaves in an infestation class; v = numerical value of infestation class (0 to 5); where 0 = no leaf damage; 1 = 20% of the total leaf area damaged; 2 = 40% of the total leaf area damaged; 3 = 60% of the total leaf area damaged; 4 = 80% of the total leaf area damaged; and 5 = all of the leaf area damaged, and N = total number of leaves observed.

Counting was conducted every week starting 41 DAP up to 69 DAP for Lembang and 43 DAP up to 64 DAP for Segunung.

In each plot, 10 3rd or 4th instar larvae of DBM were collected at random and reared in the rearing room to determine the percentage of parasitism by *D. eucerophaga*. The insects were collected starting 16 DAP up to 65 DAP for Segunung and 37 DAP up to 72 DAP for Lembang.

Yields and ability to develop heads were observed at harvest time.

Field Experiment II, West Sumatra (1982)

The experiment was conducted at Air Anget, Tanah Datar, West Sumatra. The statistical design, plot size, planting distance, insecticidal treatments and so on were similar to those in Field Experiment I.

Field Experiment III, West Sumatra (1983)

The location of the experiment was the same as Field Experiment II. The insecticidal treatments were: *B. thuringiensis* HP 32 kg AI/ha; *B. thuringiensis* WP 32 kg AI/ha; fenvalerate 5EC 0.08 kg AI/ha; cypermethrin 5EC 0.08 kg AI/ha; *B. thuringiensis* HP 16 kg product + fenvalerate 5EC 0.04 kg AI/ha; *B. thuringiensis* WP 16 kg product + cypermethrin 5EC 0.04 kg AI/ha; *B. thuringiensis* HP 16 kg product + cypermethrin 5EC 0.04 kg AI/ha; *B. thuringiensis* WP 16 kg product + fenvalerate 5EC 0.04 kg AI/ha; quinalphos 25EC 0.5 kg AI/ha; and control.

The observations and insecticidal applications were conducted in the same way as in Field Experiments I and II.

Results and Discussion

Laboratory Study I (1982)

Among the four synthetic pyrethroid insecticides tested against the three field strains of DBM, LD_{50} values of permethrin for the Kopeng and Lembang strains were 3 and 11 times higher compared to the Selo strain. These data indicated the possibility of development of resistance to permethrin in the Kopeng and Lembang strains. Therefore it appears wise not to use synthetic pyrethroids in Lembang area, though in Kopeng these insecticides can still be used in combination with other control practices.

Laboratory Study II (1983)

This study indicated that most of the field strains of DBM had already developed resistance to all three synthetic pyrethroids (Table 1). Resistance levels to cypermethrin were much lower than those to permethrin and fenvalerate. Tawangmangu strain was more susceptible to permethrin and cypermethrin than the other strains, but it was more resistant to fenvalerate than Pacet strain. This was at least partly due to the fact that the farmers from the Pacet area prefer to use carbamate insecticides rather than synthetic pyrethroids.

Table 1. Resistance ratios of DBM strains from four locations to selected insecticides

Location	Resistance ratios				
	Permethrin	Cypermethrin	Fenvalerate	Carbaryl	*B.thuringiensis*
Kopeng	7.5	2.5	10.4	2.5	1.7
Pacet	3.1	1.5	1.0	1.0	1.7
Lembang	3.8	2.5	18.1	1.7	1.0
Tawangmangu	1.0	1.0	5.9	1.0	1.9

Fenvalerate has been used in Kopeng, Lembang and Tawangmangu since 1981, whereas the other compounds were introduced more recently. However, levels of resistance appeared in most field strains. This finding coincided with a general observation that the effectiveness of synthetic pyrethroids in controlling DBM has declined significantly in the field. The LC_{50} values of fenvalerate for Kopeng and Lembang strains were 10 and 18 times those of to Pacet strain. The resistance ratio of Kopeng strain has increased 10 fold compared with the 1982 value.

Since 1977, the microbial insecticide *B. thuringiensis*, has been introduced into Lembang (Sudarwohadi and Said 1977). This insecticide is still effective in controlling DBM and there is no indication of development of resistance (Table 1).

D. eucerophaga did not show any development of resistance except in the case of Lembang strain to fenvalerate, which exhibited a resistance ratio of 3 compared to Pacet Strain (Table 2). This indicated that fenvalerate has been used intensively in the Lembang area. Data on the selectivity of four insecticides to DBM vs the parasitoid are presented in Table 3. The data show that, in general, synthetic pyrethroids are more toxic to the parasite than to DBM.

The results of this study suggest that DBM has become resistant in varying degrees to synthetic pyrethroids. The LC_{50} values obtained indicate that failure in DBM control is possible if the present insecticide application practices continue. Ten to 15 insecticide

Table 2. Toxicity of four insecticides to female adult of *Diadegma eucerophaga*

Insecticide	Strain	LC_{50}[a]	RR[b]
Permethrin 2EC	Pacet	1.58	—
	Lembang	2.15	1.4
Cypermethrin 5EC	Pacet	2.83	—
	Lembang	3.64	1.1
Fenvalerate 5EC	Pacet	0.81	—
	Lembang	2.39	3.0
Carbaryl 85WP	Pacet	65.44	1.2
	Lembang	53.35	—

[a] LC_{50} value, based on ug of insecticide per test tube.
[b] RR = resistance ratio.

Table 3. Selectivity of four insecticides against *D. eucerophaga*

Insecticide	Selectivity ratio[a]	
	Pacet	Lembang
Permethrin	13.5	12.2
Cypermethrin	11.9	19.7
Fenvalerate	6.4	39.2
Carbaryl	4.3	8.7

[a] LC_{50} to DBM/LC_{50} to parasite.

sprays are not uncommon for DBM control on cabbage in these areas. Most of the applications contain pyrethroid insecticide.

Field Experiment I, West Java (1982)

At Lembang, even at the first observation, the population of DBM had reached the threshold level of 0.1 larvae/plant except in the cypermethrin plot (13 DAP) and deltamethrin plot (20 DAP). Nine sprays of fenvalerate and diethquinalphion and eight of permethrin, cypermethrin and deltamethrin provided excellent insect control (Table 4). The synthetic pyrethroids were more or as effective as the standard check.

All synthetic pyrethroids tested were also effective in controlling the population of *C. binotalis*.

Table 4. Effectiveness of selected insecticides against DBM at Lembang 1982[a]

Insecticide	Number of larvae/plant sample at DAP[b]							
	13	15	34	36	48	50	69	71
Fenvalerate 5EC	0.13a	0.08a	2.18a	1.68b	2.40abc	0.92bc	0.30a	0.20a
Permethrin 2EC	0.14a	0.00a	2.30a	0.73a	1.25a	0.36a	0.20a	0.08a
Cypermethrin 5EC	0.00a	0.00a	3.03a	1.48ab	1.55ab	0.50ab	0.30a	0.13a
Deltamethrin 2.5EC	0.10a	0.03a	2.35a	1.00ab	1.47ab	0.37a	0.35a	0.15a
Diethquinalphion 25EC	0.08a	0.08a	2.75a	1.78b	2.78bc	1.23c	0.73a	0.28a
Control	0.05a	0.30b	6.13b	7.24c	3.52c	3.18d	2.82b	2.99b

[a] Insecticide was applied when the larval population reached 0.1 larvae/plant sample. [b] Average of 40 plant samples; DAP = days after planting. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

At Segunung, the DBM population was low, and only one spray per week of each of fenvalerate, cypermethrin and deltamethrin was needed up to 36 DAP. Starting at 41 DAP, however, the percent injury level had reached at intermediate stage (above 40%), which necessitated two to three more sprays (Table 5). Synthetic pyrethroids were as effective as the standard check.

Table 5. Percentage injury level of the plant samples one day before spraying, Segunung, 1982

Insecticide	Percent injury level at DAP[a]			
	41	48	55	62
Fenvalerate 5EC	17.19a	44.92b	32.81b	45.31b
Permethrin 2EC	43.75cd	38.28b	48.05bc	43.00b
Cypermethrin 5EC	32.03bc	41.80b	40.23bc	49.22b
Deltamethrin 2.5EC	46.09cd	39.45b	39.45bc	43.36b
Diethquinalphion 25EC	8.20a	9.38a	9.77a	10.16a
Control	51.56d	53.91b	55.86c	57.03b

[a] Average of 40 plant samples; insecticide was applied when percentage injury level had reached at an intermediate stage (41-64 dap); DAP = days after planting. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Percent injury level In general the percent injury levels were significantly lower in insecticide-treated plots compared to the standard check and control plots. However, they were still at an intermediate stage (30-40%). This suggested that the synthetic pyrethroids had intermediate toxicity to Lembang and Segunung strains (Table 6).

Table 6. Percentage injury level of the plant samples one day before spraying

Insecticide	Injury level (%) at DAP[a]				
	Lembang			Segunung	
	41	55	69	43	57
Fenvalerate 5EC	30.84a	42.66ab	45.00a	18.75a	32.81b
Permethrin 2EC	30.89a	39.65a	39.76a	39.06b	42.19bc
Cypermethrin 5EC	31.44a	42.15a	39.82a	41.41b	40.23bc
Deltamethrin 2.5EC	31.76a	38.23a	43.09a	43.36b	43.36bc
Diethquinalphion 25EC	40.82a	51.19ab	56.00b	8.20a	10.16a
Control	65.68b	81.54c	84.19c	52.73b	55.86c

[a] Average of 40 plant samples; DAP = days after planting. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Laboratory tests had earlier shown that DBM had developed resistance to these synthetic pyrethroids.

***D. eucerophaga* parasitism of DBM larvae** In general, insecticide application did not affect the parasitism of DBM by *D. eucerophaga*, except at 44 DAP in the fenvalerate, permethrin, deltamethrin, and diethquinalphion plots (Table 7). The data also showed that cypermethrin was slightly safer for the parasite than the other synthetic pyrethroids. This finding agrees with those reported by Tonny (1982) and Pardede (1980).

Table 7. Parasitism of DBM larvae by *D. eucerophaga* in insecticide treated plots. Lembang 1982

Insecticides	Parasitism (%) at DAP[a]					
	37	44	51	58	65	72
Fenvalerate 5EC	40a	32bc	25a	23a	26a	29a
Permethrin 2EC	45a	22a	22a	30a	33a	15a
Cypermethrin 5EC	55a	35cd	22a	37a	19a	33a
Deltamethrin 2.5EC	55a	30bc	18a	37a	27a	20a
Diethquinalphion 25EC	35a	12a	18a	21a	27a	31a
Control	67a	45d	30a	35a	43a	49a

[a] DAP = days after planting. Means in each vertical column followed by the same letter are not significantly different at te 5% level by Duncan's multiple range test.

Field Experiment II, West Sumatra (1982)

DBM populations From the first observation (8 DAP), the larval population of DBM always exceeded the threshold level of 0.1 larvae/plant in all the experimental plots (Table 8). Therefore, insecticides were applied at weekly intervals. A total of 11 sprays were applied. The first application did not show any effect on DBM (11 DAP). At the subsequent applications, all the insecticides could effectively control the pest. All synthetic pyrethroids were more or as effective as the standard check quinalphos. These results were similar to the results at Lembang and Segunung. Fenvalerate was the most effective in controlling DBM. *C. binotalis* population was very low throughout the test.

Percent injury level All insecticides tested reduced the percent injury levels (Table 8). The synthetic pyrethroids provided excellent DBM control. The percent injury levels were lower compared to the standard check quinalphos at 49 DAP.

***D. eucerophaga* parasitism of DBM larvae** In contrast to the Lembang and Segunung experiments, in West Sumatra, only during the first three observations (35, 39 and 43 DAP) did insecticides fail to adversely affect the parasitoids. However,

Table 8. Effect of insecticide spray at one day before and three days after spraying on DBM population, injury level, and yield at Air Angat, West Sumatra, 1982[a]

Insecticides[b]	Number of larva/plant sample at DAP[c]								Percent injury[d] level	Yield t/ha
	7	11	31	35	47	51	63	67		
Fenvalerate	0.38a	0.38a	0.15b	0.43b	0.43c	1.05c	0.68c	1.28c	8.61c	36.8a
Permethrin	0.28a	0.25a	0.55b	0.88b	0.68c	2.45c	1.80c	3.18c	16.10c	26.1b
Cypermethrin	0.48a	0.40a	0.73b	0.48b	0.78c	2.95c	1.83c	2.63c	12.70c	25.7b
Deltamethrin	0.45a	0.43a	0.93b	1.05b	2.75bc	6.93b	3.80c	4.93c	16.69c	33.4a
Quinalphos	0.45a	0.35a	0.83b	1.28b	3.33b	7.98b	9.78b	12.15b	33.63b	11.3c
Control	0.30a	0.35a	1.85a	3.03a	5.58a	12.63a	17.40a	17.80a	50.63a	8.4c

[a] Insecticide was applied when the larval population reached 0.1 larvae/plant sample. [b] See text for insecticide formulation and AI used. [c] Average of 40 plant samples: DAP = days after planting. [d] At 40 DAP. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

beginning at 47 DAP, the insecticide application did have some adverse affect on the parasitism of DBM larvae (Table 9). Only the standard check, quinalphos, showed no significant difference in the percent parasitism compare to insecticide-free control plots.

Head development and yields The numbers of heads developed in the synthetic pyrethroid plots were higher than in the standard check quinalphos and control plots. Consequently the yields in pyrethroid-treated plots were significantly higher than in the standard check and control plots. The highest yield of 36.8 t/ha was obtained in the fenvalerate plot (Table 8).

Table 9. Parasitism of DBM larvae by *D. eucerophaga* in insecticide treated plots at Air Angat, West Sumatra, 1982[a]

Insecticides[b]	Parasitism (%) at DAP[c]						
	47	51	55	59	63	67	71
Fenvalerate 5EC	17bc	15bc	23ab	25bc	18b	18d	20c
Permethrin 2EC	19bc	33abc	13b	18c	30c	25b	60a
Cypermethrin 5EC	24bc	38ab	28a	15c	20d	13b	38bc
Deltamethrin 2.5EC	10c	15bc	25ab	23bc	13d	25b	33bc
Quinalphos 25EC	45a	50a	33a	38a	48a	45a	63a
Control	33ab	33abc	35a	30ab	38b	48a	50ab

[a] Observations were conducted at two days after spraying. [b] See text for AI used. [c] DAP = days after planting. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Field Experiment III, West Sumatra (1983)

Based on the previous laboratory and field experiments, the results suggested that DBM had developed resistance to synthetic pyrethroids and that these chemicals had an adverse affect on the parasitoid of DBM. However, synthetic pyrethroids were still preferred by farmers for controlling DBM. Therefore, in this experiment, we looked for alternative control method by using a microbial insecticide and mixing it with synthetic pyrethroids.

DBM population From the first observation (13 DAP), the larval population of DBM was already above the threshold level of 0.1 larvae/sample plant in all the plots (Table 10). The insecticides were sprayed at weekly intervals, because each individual insecticide spray failed to reduce the larval population to below the threshold level. Microbial

Table 10. Effect of insecticide mixtures on DBM larval population at one day before and two days after application, on injury level, and yield of cabbage at Air Angat, West Sumatra. 1983[a]

Insecticide[b]	No. of larvae/plant at DAP[c]						Injury % at 48 DAP[d]	Yield t/ha
	13	16	34	37	55	58		
Bt[e] HP	5.57ab	1.80b	1.33c	1.30c	4.53cd	2.47b	27.78c	36.78ab
Bt WP	3.63b	1.73b	0.57c	0.53c	2.03cd	1.07b	26.15c	37.78ab
Fenvalerate	5.10ab	1.90ab	1.70c	0.90c	4.27cd	3.60b	29.61bc	29.31b
Cypermethrin	7.37a	2.13ab	1.80c	1.40c	3.37cd	4.33b	33.21ab	30.46b
Bt HP + Fen[f]	3.42b	1.53b	1.13c	1.13c	4.50cd	3.77b	27.46c	37.78ab
Bt WP + Cyper[g]	4.23ab	1.80b	1.20c	1.27c	2.30cd	2.00b	26.32c	34.87ab
Bt HP + Cyper	4.27ab	1.97ab	1.93bc	1.23c	4.90bc	4.07b	27.09c	37.21ab
Bt WP + Fen	6.33ab	1.73b	0.60c	0.80c	1.53d	1.67b	26.95c	42.76a
Quinalphos	5.20ab	2.43ab	3.17ab	3.80a	14.87a	10.40a	35.91a	16.30c
Control	5.50ab	4.47a	3.43a	2.63b	7.73b	8.83a	34.98a	15.97c

[a] Insecticide was applied when the larval population reached 0.1 larva/plant. [b] See text for insecticide formulation and AI used. [c] Average of 40 plants. [d] Average of 30 plants. DAP = days after planting. [e] *Bt* = *Bacillus thuringiensis*. [f] Fen = Fenvalerate. [g] Cyper = Cypermethrin. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test. See text for the formulation and rate of application of the insecticides.

insecticides applied alone or as mixtures with fenvalerate or cypermethrin gave a better control than either fenvalerate or cypermethrin alone or the standard check, quinalphos. A mixture of *B. thuringiensis* WP with fenvalerate or cypermethrin performed better than a mixture of *B. thuringiensis* HP with fenvalerate or cypermethrin. The synthetic pyrethroids alone were less effective.

Percent injury level The microbial insecticide applied alone or as a mixture could reduce the percent injury level of DBM. Of the two synthetic pyrethroids tested, cypermethrin was less effective.

Parasitism DBM larvae by *D. eucerophaga* The parasitism level of DBM in the microbial insecticide-treated plots was similar to the parasitism level in the control plot. In contrast to the second field experiment, the synthetic pyrethroid applied alone or as a mixture did not show adverse effects on the parasitoid (Table 11).

Head development and yields The head development in all the insecticidal plots was higher than the control plot. The total number of plants which did not develop

Table 11. Parasitism of DBM larvae by *D. eucerophaga* in insecticide treated plots. Air Angat, West Sumatra. 1983[a]

Insecticides[b]	Parasitism (%) at DAP[c]						
	16	23	30	37	44	51	58
Bt[d] HP	10a	0d	25a	13b	12a	0b	27a
Bt WP	17a	33abcd	17a	36ab	13a	19ab	17a
Fenvalerate	25a	60ab	32a	30ab	20a	10ab	22a
Cypermethrin	50a	43abc	26a	38a	17a	23a	30a
Bt HP + fenvalerate	29a	31abcd	7a	21ab	21a	3ab	23a
Bt WP + cypermethrin	43a	67ab	8a	10b	19a	10ab	17a
Bt HP + cypermethrin	22a	54ab	22a	26ab	17a	4ab	35a
Bt WP + fenvalerate	19a	17cd	18a	33ab	11a	9ab	32a
Quinalpos	32a	58ab	25a	39a	21a	4ab	23a
Control	21a	71a	19a	24ab	24a	14ab	37a

[a] Observations were conducted at two days after spraying. [b] See text for formulation and AI applied. [c] DAP = days after planting. Means in each vertical column followed by the same letter are ot significantly different at the 5% level according to Duncan's Multiple Range Test. [d] *Bt*: *Bacillus thuringiensis*.

heads in the cypermethrin plot was quite high. However, it was still significantly lower than in the standard check quinalphos plots and in control plots. The yields when microbial insecticide was applied alone or as a mixture with synthetic pyrethroids were better than when pyrethroids were applied alone and in the standard check quinalphos plots (Table 10). The highest yield of 42.76 t/ha was obtained with a mixture of *B. thuringiensis* WP with fenvalerate.

The results obtained in these three field experiments indicated that synthetic pyrethroids had intermediate to low toxicity to the various field strains of DBM. These insecticides are toxic to the parasitoid. Mixture with a microbial insecticide gave better control and a less adverse effect on parasitoid. However, our studies show that there can be a wide variation in the toxicity of individual insecticides or their mixtures, to both DBM and to the parasitoid. Therefore, comparative field evaluation of the possible candidate insecticides within the class and their mixtures with microbial insecticides or other kinds of chemicals may be necessary to ascertain their effects on the whole natural enemy complex and to evaluate their relative usefulness in integrated pest management programs.

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Discussion

G. S. LIM: You have previously identified 82 plant species toxic to insects. You now have six more. Are there plant species among the 82 already identified which are promising enough to justify more intensive research so that practical use could be made of these species. What is the point in identifying additional species?
B. MORALLO-REJESUS: The 82 plant species listed in the table were gathered from the literature, reports of farmers, and surveys of rural folk. Most of these claims are not substantiated by entomological assay. My purpose is to verify if indeed the plant materials are toxic to the reported insect species and to determine their toxicity to other major insect pests. After the basic toxicity studies, we are going to evaluate the possibility of using them in the field.

C. J. W. MAA: Your data show that all plant oils are volatile, so is malathion. Did you check how much active ingredient was still left in these extracts after such a long exposure — 24, 48, and 72 hours.
B. MORALLO-REJESUS: No, I did not study this.

A. SIVAPRAGASM: Have you tried using whole botanical - insecticidal plants together with cabbage to elucidate the repellent effect on DBM as opposed to using extracts from such plants?
B. MORALLO-REJESUS: No, I might do that experiment.

A. SIVAPRAGASM: In some of your slides you mentioned that 'the number of larvae visiting cabbage'. Can you explain what you mean by 'visiting'?
B. MORALLO-REJESUS: To determine the repellent effect, the number of larvae that went on to or 'visited' the treated leaves and left the leaves without feeding was noted.

M. SAKAI: What is the concentration of essential oil in raw plant material?
B. MORALLO-REJESUS: The essential oil recovered varied with the plant species and parts. For example, in *Lantana* the recovery from the flowers and leaves ranges from 0.10 to 0.30 ml and 0.10 to 0.15 ml/100 g dried material, respectively. The recovery from *Caesalpinia* flowers ranges from 0.20 to 0.50 ml and from the leaves it ranges from 0.10 to 0.20 ml per 100 g dried material.

M. P. FERINO: How much active ingredient could be extracted from one kilogram of plant material such as leaves or roots?
B. MORALLO-REJESUS: The active ingredients of the plants mentioned to be insecticidal are not isolated yet except for *Tagetes erecta*. The percent recovery from the roots of *T. erecta* was 0.04% for 5(3-buten-1-ynl)2,2 bithienyl and 0.02% for alpha-terthienyl.

R. F. HOU: Can teflubenzuron be used safely in combination with microbial control agents, especially fungal insecticides?
C. P. DALEBOUT: Yes, the teflubenzuron and microbial insecticides are compatible.

P. WEBER: You mentioned that CME 134 has contact action against *Spodoptera littoralis*. Could similar action also be observed with DBM?

P. BECKER: A distinct contact activity of CME 134 has not been observed with DBM. If there is any such activity with DBM we expect it to be of negligible importance under field conditions.

C. N. SUN: In 1982 biochemists were unable to confirm the inhibition of chitin synthetase *in vitro* by diflubenzuron. Therefore, there might be other mechanisms for IGR's mode of action. Any comment?
P. BECKER: The effects that can be seen in the test insects after treatment with benzoyl urea compounds strongly support the hypothesis that insect growth regulators interfere with chitin synthesis indicating that chitin inhibition might be the major mode of action of IGR, although chitin synthetase was not inhibited in *in vitro* experiments by diflubenzuron.

K. SCHLUTER: Did you ever observe high efficacy of CME 134 against any insect species within 24 h after application which could indicate a second mode of action besides the chitin synthesis inhibition?
P. BECKER: Some results are available indicating that even one day after treatment high mortality rates can be obtained with CME 134 in field trials but since normally full activity is only visible about seven days after treatment we do not suspect any other major modes of action besides chitin synthesis inhibition and those activities reported in the paper. In such cases with rapid initial kill rates, weather conditions might have influenced metabolism and thus molting sequence.

D. S. LEWIEWICZ: What is the efficacy of CME 134 against sucking pests such as aphids?
SAGENMUELLER: It is not effective against sucking pests.

J. L. LIM: You stated that there is no residue of Hoe 522 on cabbage in your experiment. How long is the period between sampling and residue analysis?
A. SAGENMUELLER: My statement was referring to a trial in the Philippines on cabbage. The last application of Hoe 522 was made on 3 May, the sample was taken on 13 May, and the analysis was made on 8 June 1984.

J. HOFFMANN: Thailand is the first country in southeast Asia to introduce insect growth regulators (IGR) which may be used in IPM. Is there any chance to forcing farmers in heavily DBM infested areas to apply IGRs in conjunction with IPM?
VATTANATANGUM: No, but Thai authorities are trying to educate farmers by demonstration trials and by allowing them to choose their own method of pest control.

P. A. C. OOI: I observed that the economic threshold used in the trial was 0.01 larvae/plant. Could you please elaborate as to how this level was achieved?
M. IMAN: The economic threshold used in the trial was 0.1 larvae/plant, not 0.01 larva/plant. To achieve this level, we took 10 sampled plants/plot at random. If we found one larva or more within these sampled plants, then we had to apply the insecticidal treatment. At the most susceptible growth stage, one larva/plant will cause serious damage, the head will not develop, or head formation will be delayed for at least two to three weeks.

The Resistance, Cross Resistance, and Chemical Control of Diamondback Moth in Taiwan

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Abstract

In order to improve the chemical control of diamondback moth, *Plutella xylostella* (L), in Taiwan, the Taiwan Agricultural Research Institute organized in 1980 a program aimed at analyzing the insecticide resistance and mode of action. After almost five years of study, we have gathered information on the sampling method, resistance, cross resistance, the mode of insecticide action, and the efficacy of the newest experimental insecticides. Over an area of five thousand hectares, a mixture of five populations from separate fields is needed to test insecticide resistance accurately. The insect develops resistance quickly to almost all insecticides, and of eight tested insecticides the quickest response was recorded to carbofuran, profenofos, and fenvalerate. Cross resistance between organophosphorus compounds and synthetic pyrethroids was detected; carbofuran resistance was independent of that of other insecticides. The resistance impact not only demonstrated the initial but also the residual effectiveness of all insecticides. Several insecticides with minimal resistance problem (mevinphos, phenthoate, cyanofenphos, methamidophos and cartap) were identified and were very helpful in adjusting the diamondback moth control scheme.

Introduction

From the initial five insecticides that were recommended in Taiwan for control of diamondback moth (DBM), *Plutella xylostella* (Lepidoptera: Yponomeutidae), in 1966, the number of chemicals registered for this purpose rose to 27 in 1982. Despite the availability of a large number of control agents, satisfactory control of this pest has become difficult due to its development of resistance to different insecticides. Meanwhile the demand for good quality vegetables is constantly increasing. Good quality means both pest free and residues free, two things which are hard to come by for crops protected by intensive insecticide sprays. From all signs and indications, DBM has continuously developed higher levels of insecticide resistance, and the threat of this pest to cruciferous vegetable production will certainly push farmers to use even more insecticides unless reliable alternate control measures are developed.

Since DBM control has become an urgent matter, the Taiwan Agricultural Research Institute (TARI) initiated a long term research program aimed at resolving the resistance problem and making the necessary adjustments in chemical control practices. The program started in 1980 and after almost five years of study, we can now roughly shape out a new control scheme according to the information gathered.

The program started with a preliminary probe into the sampling method for resistance surveys, followed by a general survey to identify the troubled areas (Cheng 1981a, 1981b). Laboratory simulation of resistance induction was carried out in the hope of establishing the resistance development pattern and the laboratory-bred resistant

strains were compared to field resistant strains for the analysis of cross resistance characters.

Finally, the initial and residual effects of different insecticides were compared, as this information will be useful in selecting a proper agent to fit chemical control needs.

Sampling

To start with, there was no adequate information on the distribution pattern of resistance intensity within the DBM population in any designated area. We aimed at developing a sampling method for large vegetable growing districts, since the resistance problem in these areas was more severe than in areas where vegetables are grown sporadically in patches scattered over vast area of paddy. The hypothesis was that if the resistance of DBM in an open area was homogeneous in intensity, then we could save a lot of time and labor by sampling only a fraction of the population. On the other hand, if the resistance intensity varied widely from one vegetable field to another, a general survey of resistance would not carry much meaning in practical terms.

Research into a proper sampling method for monitoring resistance was carried out in 1980 at Hsihu and Yungchien, two of the largest and most important vegetable producing districts in Taiwan. The whole area was divided into four regions from northwest to southeast with a distance of 4-5 km between adjacent regions. At the center of each region, we sampled four spots, each sampling spot an independent cruciferous field. The distance between sampling spots was 100 to 200 m. A detailed map of regions and sampling spots is shown in Figure 1.

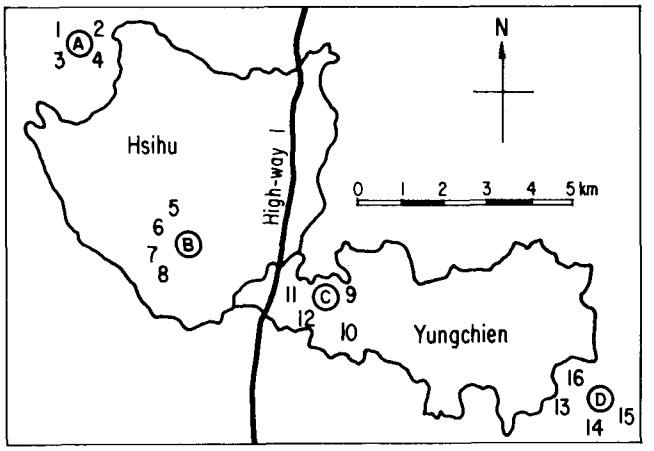

Figure 1.
Map of Hsihu-Yungchien area showing sampling locations

In each sampling spot, we collected 200 to 300 DBM larvae or pupae. Insects were brought back to the laboratory and reared on insecticide free cabbage to the adult stage; the adults were fed on a honey-water mixture. After mating, insects were maintained on potted cabbage plants in screen cages for oviposition. Third instar larvae of the first generation were used for the LC_{50} test. Cartap and permethrin were chosen to test the resistance of all sixteen samples. The LC_{50} data for all samples are listed in Table 1 and were subjected to the F-test for examining the possible differences between regions.

Since the chemical spray frequency in a sampling spot may influence the density of natural enemies, the rate of parasitism was also examined (Table 2), and the information was subjected to the same analysis procedure to obtain toxicity data.

Table 1. Susceptibility of DBM from Hsihu-Yungchien area to permethrin and cartap

Insecticide	Sampling spot	LC_{50} for regions			
		A	B	C	D
Permethrin	1	3,820	[a]	5,830	2,415
	2	2,653	7,662	4,560	4,854
	3	6,207	5,223	4,837	3,590
	4	6,533	7,646	4,836	3,143
	Average[b]	4,803	6,844	5,016	3,501
Cartap	1	520	649	796	623
	2	560	506	547	687
	3	336	299	503	320
	4	503	421	703	704
	Average[c]	480	469	637	583

[a] Inadequate insects for LC_{50} test. [b] Laboratory strain $LC_{50} = 93$ ppm. [c] Laboratory strain $LC_{50} = 345$ ppm.

Table 2. Rate of parasitism of DBM by *Apanteles plutellae* in Hsihu-Yungchien area

Field	Parasitism (%) at regions			
	A	B	C	D
1	19.2	1.8	6.7	31.0
2	10.0	5.8	1.6	16.5
3	19.2	5.6	4.0	39.1
4	6.1	4.0	13.8	19.1
Average	13.6	4.3	6.5	26.4

The F-test results indicated that DBM from regions A to C were homogeneous in both insecticide susceptibility and rate of parasitism. The region D was surrounded by rice paddy and was not similar to the three other regions in terms of cropping pattern. The test results confirmed that DBM from region D were less resistant to permethrin than those from the three other regions. This indicated an area of five thousand hectares can have a homogeneous insecticide-resistant DBM population.

To minimize the sample size without reducing the accuracy of information, we grouped the permethrin susceptibility data from regions A to C and the cartap susceptibility data of the whole area in two separate information pools. The coefficient of variation was tested against the sample size by sampling the information pool. The results are presented in Figure 2. The coefficient of variation of sample mean was close to or lower than 10% as the sample size reach 5. Regions A-C cover about five thousand hectares and sampling five cruciferous fields was adequate to measure the insecticide susceptibility of a supposed homogeneous DBM population. This sampling method was generally adopted in our further investigations.

Insecticide Resistance

After the five-year study, we gained some knowledge about DBM resistance and felt it would be helpful to outline the general situation before presenting detailed studies. Two important aspects of resistance investigation, the geographic distribution pattern as well as the profile of different insecticides, are discussed.

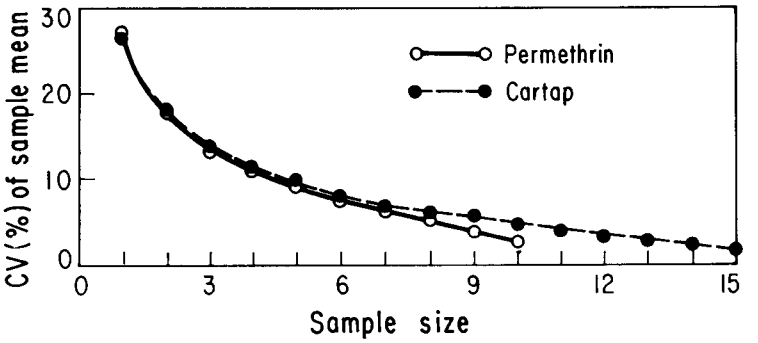

Figure 2. The relationship of the coefficient of variation (cv) and the sample size from pooled data of insecticidal susceptibility of DBM

Geographic distribution pattern of resistance

Theoretically the DBM can become resistant to almost all registered insecticides in Taiwan. The highest levels of resistance are usually found in intensive vegetable cultivation districts, where vegetables are cropped year round. DBM in vegetable fields which are scattered among rice paddy fields or upland crops have lower levels of resistance. At present no susceptible DBM population exists in open field conditions on the west coast of Taiwan, and even in the east coast where vegetable production is much lower, DBM populations have developed high levels of resistance to many insecticides. The only exception is I-lan County, located in the northeastern corner of the island (Figure 3), which is isolated from both east and west coasts by mountains. Although the farmers in this district use insecticides to control DBM, the DBM strain there is very susceptible to all registered insecticides. We have no explanation for this fact, except that the area is geographically isolated and has high annual precipitation. The frequency and quantity of rain would certainly reduce pesticide effectiveness and slow down the pace of microevolution for resistance, while the mountains prevent the flying in of insecticide-resistant populations from other areas.

The toxicity of 22 registered insecticides to the I-lan strain of DBM is presented in Table 3 (Chou and Cheng 1983). Of all the insecticides, deltamethrin and carbaryl were the most and the least effective compounds with the LC_{50} at 3.58 ppm and 2.7 x 10^4 ppm respectively. The five most effective insecticides on the list are synthetic pyrethroids; mevinphos and carbofuran were the most effective compounds from the organophosphorus and carbamate groups, respectively.

The results were further compared and calibrated to the results of Liu et al (1982). The response of I-lan (IL) strain to four common synthetic pyrethroids tested in both studies matched perfectly with that of FS-strain, a susceptible strain introduced from France in Liu et al's study (Table 4). However, the sensitivity of IL-strain to organophosphorus insecticides was much lower than that of FS-strain. The PH-strain, the native susceptible strain in Liu et al's study, responded differently to synthetic pyrethroids than either FS-strain and our IL-strain. The most effective insecticide to PH-strain was permethrin, the same insecticide that was also most effective against BC-strain, a native resistant strain.

Based on these findings, we adapted the I-lan strain as our standard susceptible strain in the laboratory study. We also double-checked this fact by going back to I-lan in 1983 and collecting DBM from separate vegetable fields and testing susceptibility in laboratory. The insecticide sensitivity had not changed significantly in three years. A

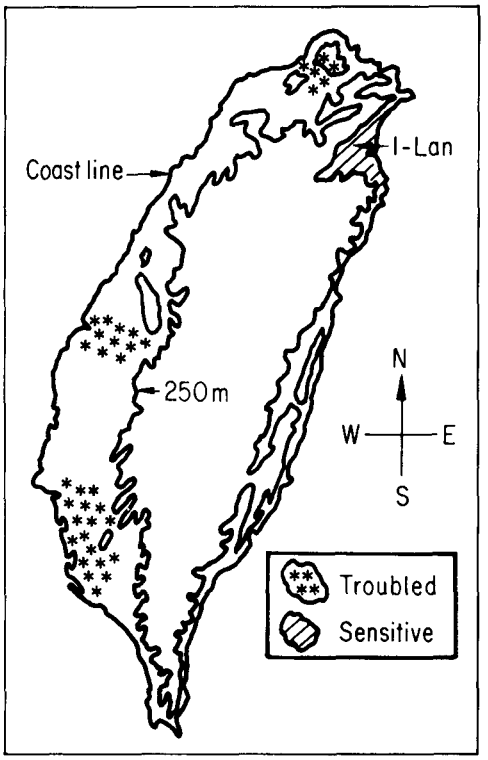

Figure 3.
General view of geographic distribution of insecticide resistance of DBM in Taiwan

Table 3. The toxicity of several insecti cides to the I-lan strain of DBM

Insecticides	LC_{50} (ppm)	Insecticides	LC_{50} (ppm)
Deltamethrin 2.8EC	3.58	Fenvalerate 20EC	8.28
Permethrin 10EC	1.4×10^1	Cypermethrin 5EC	1.9×10^1
UCX-33 34EC[a]	6.3×10^1	Mevinphos 25.3EC	7.3×10^1
Profenofos 43EC	1.0×10^2	Carbofuran 40.6WP	1.2×10^2
Prophos 70.6EC	1.7×10^2	Cyanophenphos 25EC	1.9×10^2
Diethquinalphion 25EC	2.3×10^2	Methidathion 40EC	2.7×10^2
Cartap 98SP	2.9×10^2	Prothiophos 50EC	3.1×10^2
Mephosfolan 25EC	3.6×10^2	Methamidophos 50EC	5.6×10^2
Phenthoate 50EC	6.7×10^2	Chlorpyrifos 40.8EC	7.7×10^2
Methomyl 24SP	3.4×10^3	Fenitrothion 50EC	8.7×10^3
Malathion 50EC	1.6×10^4	Carbaryl 85WP	2.7×10^4

[a] Permethrin formulated by Union Carbide.

general view of geographic distribution of resistance intensity of DBM in various parts of Taiwan is illustrated in Figure 3. The most troubled areas are usually the intensive vegetable production districts, a view also shared by Chang (1975).

Resistance profile of different insecticides

Insecticides registered for DBM control in Taiwan belong to four major chemical groups: synthetic pyrethroids, organophosphorus compounds, carbamates, and tertuary amines. Our survey in 1980 revealed that of all groups, DBM has developed the greatest level of resistance to synthetic pyrethroids, a conclusion also shared by Liu et al (1980).

Table 4. Comparison of insecticide sensitivity of I-lan (IL) strain with other DBM strains[a]

Insecticide	Relative LC_{50} (ppm)[b] to strains			
	IL	FS	PH	BC
Deltamethrin	1.0[c]	1 0[d]	1.0[e]	1.0[f]
Fenvalerate	2.3	2.0	1.1	2.5
Prothiophos	86.6	2.0	14.8	5.4
Permethrin	3.8	4.0	0.3	0.2
Cypermethrin	5.5	5.0	2.0	2.1
Cyanofenphos	53.1	10.0	13.1	220
Mevinphos	20.4	—	—	—
Methyl parathion	—	23.5	4469	220
Profenofos	27.9	—	—	—
Carbofuran	33.5	—	—	—
Prophos	47.5	—	—	—
Dichlorvos	—	84.0	65.2	11.3
Cartap	81.0	125.0	36.0	11.1
Malathion	4469	137.0	1396	220
Diazinon	—	146.5	114.4	27.1
DDT	—	174.0	1991	220
Methomyl	949.7	253.0	316.2	119.0
Propoxur	—	1690	10000	220
Carbaryl	7542	2160	910.0	220

[a] LC_{50} data for FS, PH, and BC strains are from Liu et al (1983). Deltamethrin was a common insecticide in both studies, hence was used as common reference standard. [b] Relative to LC_{50} 1.0 of deltamethrin. [c] 1.0 = 3.58 ppm, [d] 1.0 = 0.2 ppm, [e] 1.0 = 11.1 ppm, and [f] 1.0 = 447 ppm. Testing method of IL-strain was different from that used for other strains.

Organophosphorus resistance is much more complicated than synthetic pyrethroid resistance, since organophosphorus insecticides have very diverse molecular structures which have diverse modes of toxic action and metabolism, and thus induce different resistance responses in the DBM. The resistance ratios for organophosphorus insecticides can vary from 5 to 30 from compound to compound, which makes the generalization of their resistance mechanism very difficult.

None of our field-collected DBM populations was susceptible to either carbaryl or methomyl. It has been reported that methomyl was extremely effective against DBM when it was first introduced in Taiwan (Wen 1984). Nowadays, most vegetable growers still believe that methomyl is a special cure for DBM, and they mix it in their insecticide 'cocktail'. We are rather skeptical about whether methomyl has ever been effective for DBM control in Taiwan. Hirano (1981) reported that methomyl is not effective against DBM in Japan, and erratic results were reported in Singapore. In our test, carbofuran is the only carbamate which showed promising insecticidal action against DBM. Unfortunately, DBM can develop resistance to carbofuran in just a few generations; besides, the extremely high toxicity of carbofuran to mammals and other non-target organisms has made the use of carbofuran on vegetables an undesirable choice.

Possibly, tertiary amines form the only insecticide group that presents minimal resistance problem in use against DBM. As far as we have observed, all the DBM collected in Taiwan are still sensitive to cartap. We also tested thiocyclam hydrogenoxalate another compound in this group, against a few DBM samples and have not found significant resistance.

Resistance Induction

DBM from I-lan was used as starting material in the resistance induction study. Under fixed LC_{75} selection pressure in the laboratory, the resistance response of DBM

to various insecticides was carefully recorded from generation to generation. We intended to observe three important aspects of DBM resistance: (A) speed of resistance induction, (B) resultant resistance intensity, and (C) the cross resistance characters of insecticide-selected strains.

The speed of resistance induction

For all insecticides tested, the LC_{75} was adjusted from generation to generation according to the change in susceptibility. The number of selecting generations ranged from 8 to 20 depending upon the response induced. In the past four years, we have obtained information on eight insecticides and the summary is presented in Table 5.

Table 5. Resistance characteristics of DBM population specially selected under different insecticide pressure from native susceptible strain[a]

Insecticides	No. of generations	LC_{75} (ppm)		Resistance Ratio
		Original	After press	
Profenofos	12	230	7,290	31.60
Prothiophos	14	560	2,555	4.56
Mevinphos	20	180	1,440	8.00
Permethrin	11	28	176	6.30
Cypermethrin	11	53	249	4.70
Fenvalerate	12	23	330	14.34
Cartap	12	580	5,600	9.66
Carboturan	8	690	25,000	36.23

[a] I-lan strain.

The quickest resistance response was recorded for carbofuran. Of the three organophosphorus insecticides, profenofos induced resistance rapidly. For synthetic pyrethroids, fenvalerate induced faster and higher levels of resistance than permethrin and cypermethrin. We have successfully induced cartap resistance but the level seems rather low.

The stability of resistance for each insecticide was quite different; for example, the resistance to mevinphos and prothiophos was somewhat unstable. Mevinphos resistance varied from five to eight fold after twenty generations of selection and a similar unstable pattern was also characteristic of prothiophos resistance. On the other hand, resistance to profenofos, carbofuran, and fenvalerate was very stable.

Intensity of induced resistance

Different insecticides induced varying levels of resistance (Table 5). Among organophosphorus insecticides, profenofos resistance can easily reach 30 fold, but in prothiophos and mevinphos the resistance ratios reached only five and eight respectively, even though the selection was made over a longer period. Mevinphos appeared not resistance-inducing since it had failed to generate high resistance in field strains, and this suspicion was tentatively confirmed in our laboratory simulation.

In general, the resistance induced by synthetic pyrethroids in the laboratory studies was much lower than that observed in field strains. After 12 generations of selection, fenvalerate induced 14.3 fold resistance and could be considered as a good resistance inducer. Similar observations were not recorded for either permethrin or cypermethrin selections; the resistance ratios rose to only 6.3 and 4.7, respectively, after 11 generations.

Carbofuran induced a very strong resistance response, as the resistance ratio reached 36 in LC_{75} or 66 in LC_{50} and should be labelled as a good inducer for resistance. Although cartap induced 6 to 10 fold resistance following 12 generations of selection, the resistance was rather unstable and it is hard to determine the resistance-inducing characters of cartap (Table 6).

Table 6. Cross resistance of two laboratory-bred insecticide resistant DBM to other insecticides

Insecticides	Carbofuran resistant		Cartap resistant	
	LC_{50} (ppm)	R. R[a]	LC_{50} (ppm)	R. R.
Cartap	1,120	3.86	1,945	6.70
Carbofuran	7,953	66.28	574	4.78
Carbaryl	48,984	1.81	28,308	1.05
Methomyl	2,793	0.82	2,672	0.79
Chlorpyrifos	1,467	1,91	2,619	3.40
Cyanofenphos	68	0.37	378	2.00
Diethquinalphion	102	0.44	199	0.86
Fenitrothion	9,808	1.13	7,413	0.85
Malathion	9,125	0.57	4,991	0.31
Mephosfolan	362	1.01	166	0.46
Methamidophos	249	0.44	624	1.11
Methidathion	289	1.07	401	1.48
Mevinphos	291	3.98	263	3.60
Phenthoate	542	0.81	574	0.86
Profenofos	45	0.45	257	2.57
Prophos	67	0.39	171	1.00
Prothiophos	146	0.47	476	1.54
Deltamethrin	9.2	2.57	17.5	4.89
Fenvalerate	21	2.54	53.6	6.47
Permethrin	43	3.07	20.4	1.46

[a] R. R.: resistance ratio.

During the study, the hardest decision was to decide what kind of resistance intensity was needed to evaluate DBM response. We have posed an arbitrary and simple answer to that question by judging the whole matter in economic terms. When the resistance ratio reaches over 10 it usually makes the continuing use of that insecticide uneconomical. We therefore used 10 fold as the criterion for judging DBM resistance.

When the laboratory simulation did not provide a satisfactory explanation for the field observation, as with the synthetic pyrethroid resistance, we were ready to look for an alternative answer.

Cross resistance characters

The measurement of cross resistance of laboratory-bred resistant strains may not always clarify the interrelationships of various insecticides tested, but there is enough published information to distinguish the following cross resistance relationships: (1) no relation at all, (2) compounds with strong cross resistance, and (3) compounds with only moderate cross resistance. For example, DBM can develop carbofuran resistance to a very high level but show no cross effect to any other insecticide. This resistance does not even affect the sensitivity of DBM to two other carbamates, carbaryl and methomyl (Table 6). In the fenvalerate-selected strain, the cross resistance between fenvalerate and deltamethrin was obvious (Table 7). While cartap resistance showed some signs of cross resistance to fenvalerate and deltamethrin, the relation is not so clear, as the resistance

Table 7. Susceptibility of different DBM strains to various organophosphorus insecticides

Insecticides	LC_{50} (ppm) in strains							
	Suscep-tible	Seven wild	OP pressed[a]			Pyr pressed[b]		
			Prof	Prot	Mev	Fev	Per	Cyp
Mevinphos	70-100	270- 500	334	326	409	459	276	253
Diethquinalphion	230-440	8140-9010	8021	11366	1290	254	694	—
Cyanofenphos	100-190	770-3360	3825	2200	686	551	1881	—
Phenthoate	280-670	630-4200	2140	337	590	1574	416	—
Prophos	170-320	420-3040	1182	763	826	537	354	—
Methidathion	270-560	640-1380	600	425	—	689	1044	980
Mephosfolan	360-370	790-1920	1313	1560	608	395	432	—
Profenofos	100-120	580-1450	3330	1938	444	225	753	957
Prothiophos	310-420	1250-3120	1124	1130	643	745	1387	—
Permethrin	14- 16	50- 740	71	327	38	60	101	77
Cypermethrin	19- 41	100- 370	89	156	31	115	138	160
Fenvalerate	9- 41	90-1260	90	67	15	136	240	340
Deltamethrin	4- 12	50- 600	51	88	13	49	52	81

[a] Organophosphorus insecticide pressed strains; Prof: profenofos, Prot: prothiophos, Mev: mevinphos.
[b] Synthetic pyrethroids pressed strains; Fev: fenvalerate, Per: permethrin, Cyp: cypermethrin.

to cartap itself is not particularly high and can be considered as belonging to the third group.

Results of cross resistance determination of both organophosphorus-and synthetic pyrethroid-selected strains are presented in Table 7.

Organophosphorus-selected DBM usually developed resistance to other organophosphorus compounds. For instance, profenofos-selected DBM became resistant to diethquinalphion, cyanophenphos, and phenthoate; prothiophos-selected strains had cross resistance to diethquinalphion, cyanophenphos and mephosfolan. Comparatively, mevinphos, which is most widely used, again had the least effect in inducing cross resistance. We have stated that DBM is slow to become resistant to mevinphos and this was confirmed as neither profenofos-nor prothiophos-selected DBM showed high levels of cross resistance to mevinphos, despite their high cross resistance to other organophosphorus insecticides. Some exceptions were noticed: the prothiophos-resistant strain did not have cross resistance to either phenthoate and methidathion and the profenofos-resistant one was not resistant to methidathion.

Among synthetic pyrethroids, cross resistance between the four compounds was conspicuous. Although the synthetic pyrethroid-induced resistance had not yet reached the high levels of field strains, the cross resistance of the organophosphorus-resistant strain was confirmed in our study (Table 7). We suspect the high level of resistance to synthetic pyrethroids in field strains is due to additive cross resistance. Synthetic pyrethroids also induced cross resistance to the organophosphorus group but the magnitude was not comparable to that induced within the organophosphorus insecticide group itself.

The cross examination of permethrin- and cypermethrin-selected strains by permethrin and cypermethrin (Table 8) showed that the response of both strains was similar, which indicated that the extra α-cyano group in the cypermethrin molecule is not involved in the resistance mechanism.

The analysis of cross resistances

The cross resistance pattern in DBM is so complicated that only a few conclusions can be drawn and discussed. However, some distinct relationships have been recognized which are helpful for the decision makers in plant protection.

Table 8. Cross resistance of two synthetic pyrethroid-selected DBM strains to permethrin and cypermethrin

DBM strain	Permethrin		Cypermethrin	
	LC_{50}[a]	R. R[b].	LC_{50}	R. R.
I-lan	14	1.0	19	1.0
Permethrin-selected	101	7.2	138	7.3
Cypermethrin-selected	77	5.5	160	8.4

[a] ppm. [b] R.R: Resistance ratio.

(1) There is a common mechanism for synthetic pyrethroid resistance which affects fenvalerate and deltamethrin more than permethrin and cypermethrin. The extra α-cyano group in the synthetic pyrethroid molecule does not make any difference to resistance.

(2) Synthetic pyrethroid-selected DBM also becomes less sensitive to organophosphorus insecticides. This cross resistance is evident, but is rather mild.

(3) Cross resistance within the organophosphorus insecticides group is common and diverse. Some organophosphorus-resistant strains have cross resistance to synthetic pyrethroids as well.

(4) Carbofuran resistance is independent and is not linked to any other insecticide.

(5) Cartap resistance is independent and has only a minor effect on both fenvalerate and deltamethrin, and this effect becomes evident only when cartap resistance reaches a very high level.

The interrelationship of resistance to different insecticides is generalized in Figure 4.

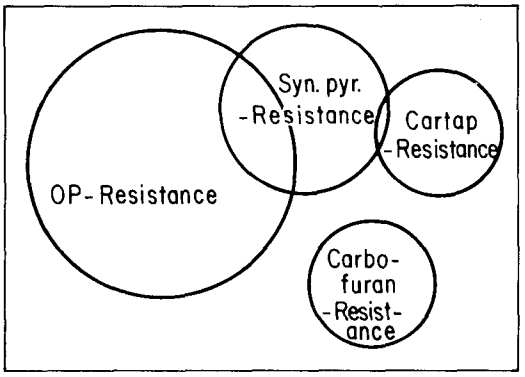

Figure 4.
A scheme showing the relationship of four major insecticide resistance groups in DBM

Investigation with Field Strains

In 1953, Ankersmit reported that DBM had become resistant to DDT in Java (Ankersmit 1953). In Taiwan too DBM has developed resistance to insecticides (Chang 1975, Cheng 1981a, 1981b, Chi and Sun 1976, Lee and Lee 1979, Tao 1976). Every report has its merits in evaluating selected chemicals. The details of different studies may conflict with one another from certain points of view, but there are common salient features among these reports. An in-depth review of DBM resistance is still not appropriate due to the incompleteness of information.

For 20 years, DDT had been intensively used for DBM control in Taiwan (Tao and Chen 1951, Tao et al 1952). Following the ban in 1970, the application of all organochlorine insecticides became rare in agriculture. DBM resistance investigation

began only in 1970 and the situation concerning chlorinated hydrocarbon insecticide resistance remains unknown and it may never be possible to investigate this in detail. Investigations into DBM resistance to other synthetic insecticides have been reported only recently.

TARI launched a general survey of DBM resistance in 1980 with only five commonly used insecticides but we expanded the monitoring program to most insecticides registered for DBM control. The work was spread out from 1983 to 1985. During the first year of this project, 1983, we completed a study on seven DBM populations collected in the southern part of Taiwan together with a freshly collected susceptible DBM population from I-lan. The salient features of the results of this project are as follows:

The intensity of resistance development

Of the five insecticides tested in 1980-81, the strongest resistance was recorded for fenvalerate and permethrin where the resistance ratios ranged from quite low to more than 50 in some cases. The next highest response was recorded for carbofuran. Except for one sample with ratio of 32, the rest of the populations have resistance ratios of 5 to 25. In the tests of cartap and mevinphos, very mild and narrow resistance was observed (Cheng 1981a, 1981b). The laboratory study showed that DBM can only develop moderate levels of resistance to either cartap or mevinphos. It seems that it was not a good choice to select mevinphos to represent the organophosphorus insecticides in our 1980-81 survey. However, the resistance varies so much within the organophosphorus group that it is hard to select a compound which can properly represent the whole group.

Of eight organophosphorus insecticides tested in 1983, diethquinalphion encountered the highest resistance (RR = 40). Although diethquinalphion was reported to be effective in 1977, the results of our study showed that DBM developed a high level of resistance to this in the field. Profenofos and cyanofenphos had 10 fold resistance. One population sample had 10 fold resistance to prophos and prothiophos. The former was never recommended or formulated for DBM control so that the detected resistance has definitely resulted from cross resistance from other insecticides. Most prothiophos resistance was far below a ratio of 10 and can still be considered mild. In the field, DBM exhibited mild resistance to mephosfolan, mevinphos, methidathion, and phenthoate.

In 1983, four synthetic pyrethroids were tested and the results again demonstrated that DBM had retained high levels of resistance to this group; the resistance ratios ranged from 4 to 165. It is interesting that the resistance of field strains was much higher for fenvalerate and deltamethrin than for permethrin and cypermethrin. A similar pattern was also observed in the laboratory simulation study. The carbofuran resistance level was lower than in the 1980-81 survey. As in 1980-81, the cartap resistance level was again low in 1983.

Re-examining native susceptible DBM, we have found that in the I-lan area DBM has gradually developed resistance to synthetic pyrethroids during the past three years. The resistance level ranged from one to two fold for permethrin and cypermethrin and from three to five fold for fenvalerate and deltamethrin. The insect still retained similar susceptibilities to other insecticides. It would be interesting to study DBM resistance to synthetic pyrethroids in that region.

Stability of resistance

Two important aspects need to be considered when considering the resistance stability of field strains. Firstly whether resistance intensity will continually increase or reach a steady state under the normal frequency of insecticide spraying. This is hard to measure specifically because farmers use a variety of insecticides and the addition

or withdrawal of an insecticide is very hard to trace. Tentative information can only be obtained through a chronological monitoring program on both the resistance levels and insecticides used in a region. Secondly whether resistance will or will not disappear following the withdrawal of insecticidal pressure. Although the matter can be investigated in the laboratory, the result will not carry much meaning in practice. As long as a variety of chemicals are used for DBM control, the intricate cross resistance relationship will still interfere any insecticide which is withdrawn from use.

Correlation of Field and Laboratory Studies

Having established the resistance of specially bred laboratory strains resistant to several insecticides, it would be interesting to compare their resistance to the resistance of field strains. This comparison may provide clues as to what will happen next if chemical control is to be continuously used.

Synthetic pyrethroids

The laboratory simulation cannot match the level of resistance detected in the field. An insufficient number of insecticide selection generations and the cross resistance-free environment in the laboratory were presumably the reasons.

Organophosphorus compounds

After 10 to 20 generations of selection, the offsprings have gained the same level of organophosphorus resistance as the field strains. The laboratory simulation experiment for organophosphorus resistance has successfully converted susceptible DBM to strains with strong resemblance to the field strains in terms of resistance. A few cross resistance relationships were detected within organophosphorus insecticides in the laboratory study. These results cannot be obtained simply by testing the field strains.

Carbamates

Our studies were successful in identifying high levels of resistance to the only effective compound in this group—carbofuran. High resistance was detected after just a few generations but it had no cross resistance to any other insecticide. No effort was made to induce carbaryl and methomyl resistances because DBM is not sensitive to them. The I-lan strain is 28 and 225 times more sensitive to carbofuran than to methomyl and carbaryl respectively. The toxic action of most carbamates is similar but the mode of entry and metabolism vary. Interestingly, the large difference in sensitivity between carbofuran and the two other carbamates disappeared after resistance selection. This indicates the development of an important factor which is responsible for eliminating carbofuran before it hits the target site within the insect's body.

Cartap and related compounds

In the laboratory, cartap resistance can be bred to a level higher than was actually found in the field. We have not yet detected any high level of cartap resistance in DBM populations in Taiwan. DBM resistance to cartap is unique, possibly due to the fact that there is no cross resistance effect from other insecticides. Since cartap alone is not used extensively in vegetable growing areas for control of DBM, cartap resistance does not build up in the field.

Influence of Resistance on Insecticidal Mode of Action

After investigating many details of the resistance and cross resistance, we considered to what extent the action of insecticides was affected by resistance. The actual measurements of the mode of action should give clues to the adjustments necessary for the existing control measures to become more effective. No two insecticides will behave exactly the same way in terms of their toxic action to DBM. For example, organophosphorus insecticides in the field are sprayed at 250-500 ppm concentrations. This range may be too high for some compounds and only marginal for others. The effectiveness of insecticides can last from several hours to more than ten days. Obviously, the insecticides registered for DBM control in Taiwan are diverse in their insecticidal actions. Knowledge of their action patterns would enable us to select the right compound for a particular purpose.

The action pattern of an insecticide includes both the initial and the residual effects, both of which may be adversely influenced by resistance. In this regard, we adapted the method used by Hirano (1981) in his fenvalerate and cyanofenphos study and completed an action pattern study of every registered insecticide. Both the initial and the residual effects on susceptible and resistant DBM were carefully measured as we hoped the result would reflect what the farmer will get when he follows the spray instructions printed in the Plant Protection Manual (1982).

The results of the initial effects study are listed in Table 9 and that the residual effects study in Figure 5.

Table 9. The initial effect of different insecticide sprays on both susceptible (S) and resistant (R) strains of DBM[a]

Insecticide	Mortality (%)[b]		Insecticide	Mortality (%)	
	S	R		S	R
Pirimiphos-methyl	96.8	85.7	Methidathion	100.0	98.3
Diethquinalphion	72.7	48.3	Cyanofenphos	91.1	100.0
Mephosfolan	88.5	94.3	Methamidophos	89.8	62.5
Dichlorvos	60.6	55.0	Prothiophos	100.0	100.0
Diazinon	64.6	28.1	Cypermethrin	100.0	32.8
Naled	47.3	53.7	Deltamethrin	100.0	41.4
Phenthoate	100.0	83.6	Fenvalerate	94.0	59.7
Mevinphos	100.0	100.0	Flucythrinate	100.0	57.4
Pyridaphenthion	55.7	26.4	Permethrin	100.0	65.5
Acephate	23.3	20.8	Carbofuran	77.7	85.0
Sannate[d]	95.0	77.1	Methomyl	6.9	15.3
Salithion	68.3	40.0	Thiocyclam	100.0	100.0
Profenofos	100.0	77.4	Cartap	100.0	100.0

[a] At the registered concentration of each chemical. [b] S = susceptible, I-lan strain; R = resistant, Lu-chu strain. [d] Phenthoate (30%) + dimethoate (15%)

The influence of resistance on the action patterns of insecticides is very clear, in that resistance not only reduced the initial effect but also shortened the residual action of almost every insecticide. Generally, the action pattern of any insecticide on both susceptible and resistant strains was similar except that the effectiveness was reduced in the resistant strain.

Some insecticides were effective in initial contact action but poor in residual effect, while some others were good in both initial and residual action. Synthetic pyrethroids were persistent in the field, but when applied at recommended dosages the residues did not have appreciable toxicity to DBM. Some organophosphorus compounds such as

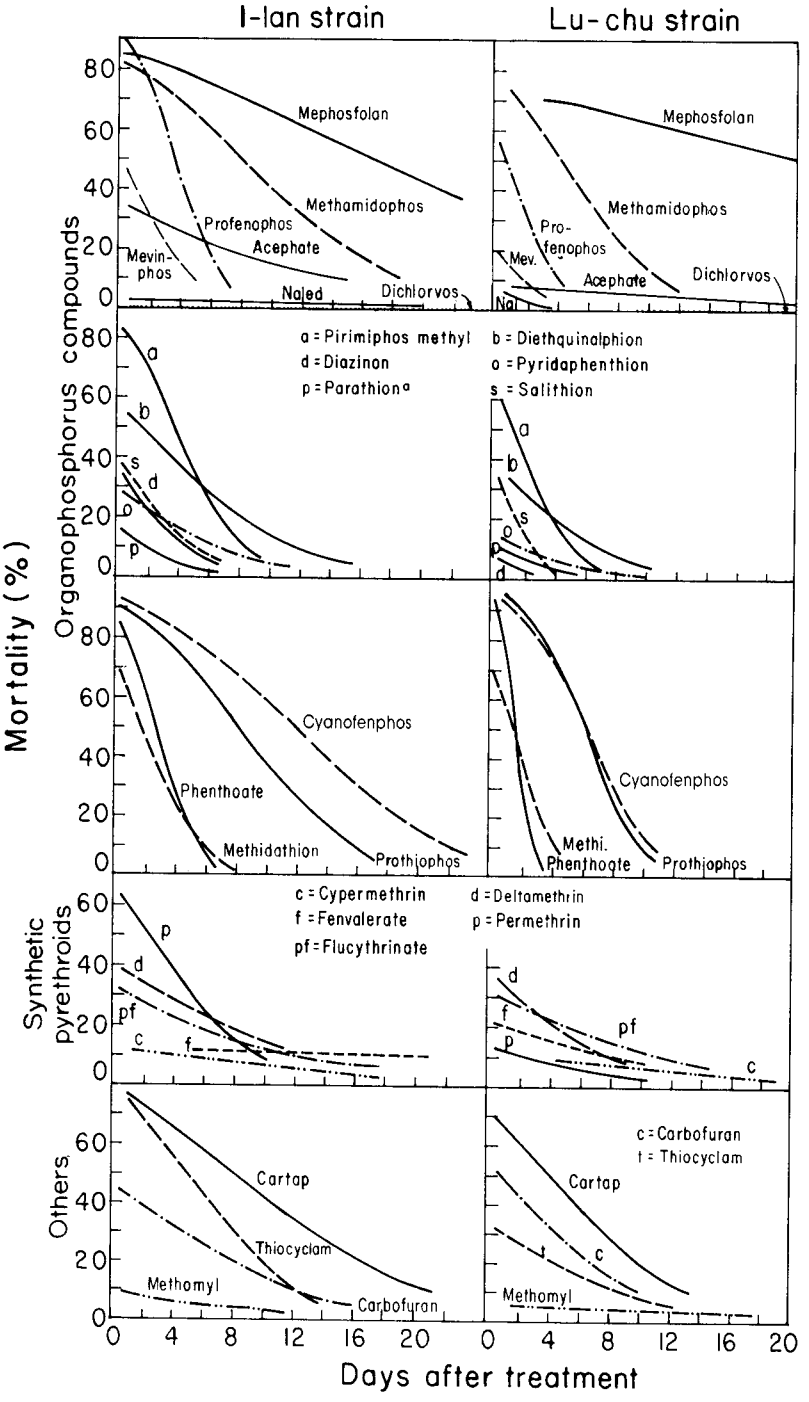

Figure 5. The residual effects of 26 insecticides to two strains of DBM. I-lan, susceptible strain; Lu-chu, resistant strain. [a]Parathion was used as a reference insecticide; it is not registered for DBM control

prothiophos, are effective in both initial and residual action. The action pattern of other important insecticides used in DBM control can be easily judged from Figure 5. The information is a useful reference for pest management strategists, extension workers, and even some knowledgeable farmers.

Adjustments in the Chemical Control of DBM

After the toxicological information from both field and laboratory studies became available, it was necessary to correlate that knowledge with other known biological and ecological parameters of DBM to redesign the control strategy. Our information can provide clues to the selection of proper insecticides to avoid possible cross resistance, to select insecticides with both initial and residual effect for application especially during the active growing stage, to select insecticides with only short residual action when the vegetable is approaching harvest, to select good contact insecticides for loose-structured vegetables as the DBM larvae are accessible for contact action, and to select insecticides with good residual effect for dense-structured vegetables where the insects are not easily accessible for direct contact action.

New Insecticides to Combat DBM Resistance

Although the traditional insecticides have become obsolete due to the development of resistance, we do have many alternative such as the newly developed insect growth regulators (IGR), microbial insecticides, and insecticides with new modes of actions. A new insecticide with the ability to combat DBM resistance should meet two requirements. First, it must not produce cross resistance with existing insecticides and should not induce resistance of its own in DBM, or do so only very slowly. An experimental insecticide, SN72129, currently being tested in our laboratory, is very effective for DBM control and is not affected by any resistance to other chemicals (Table 10). We are also surprised to find that both susceptible and resistant DBM strains were slow in developing resistance after more than 10 generations of selection. We are continuing with selection and hope to determine whether or not DBM develops resistance to SN72129.

Table 10. Effective dosages of SN72129 against susceptible and resistant strains of DBM

Insects used	LC_{50} (ppm)	LC_{75} (ppm)	Slope
Field collected strains from			
Chia-li	48.2	115.7	0.77
Feng-shan	87.4	255.1	0.63
Hua-lien	177.5	476.8	0.68
Lu-chu	104.6	299.5	0.64
Ma-tou	121.2	258.6	0.89
Ping-tung	127.8	287.3	0.83
Ta-hu	103.5	201.9	1.01
Lab-bred resistant strains			
Carbofuran resistant	127.1	312.3	0.75
Fenvalerate resistant	50.8	155.0	0.60
Mevinphos resistant	65.4	178.3	0.67
Profenofos resistant	120.9	359.3	0.62
Prothiophos resistant	65.1	130.9	0.96
Susceptible strains			
I-lan, collected in 1980	59.5	124.8	0.91
I-lan, collected in 1983	101.5	197.8	1.01

A new insecticide with a unique mode of action should be considered as a precious asset and be used more rationally than in the past. We do not like to see the limited resources of pest control agents to be spent in a wasteful way

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Studies on the Mechanism of Diamondback Moth Resistance to Insecticides

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Abstract

Since the first report of insecticide resistance in diamondback moth, *Plutella xylostella* L, to DDT in 1953, the number of cases of insecticide resistance in *P. xylostella* has increased. Currently this insect shows resistance to more than 46 insecticides, including some synthetic pyrethroids. The cross resistance spectrum is different between populations and insecticide resistance selections. DDT resistance is considered to be controlled by a non-metabolic mechanism. Synthetic pyrethroids resistance seems to be mediated partly by metabolic and partly by non-metabolic mechanisms. Organophosphorus insecticide resistance also seemed to be mediated in part by metabolic (increased metabolism by carboxylesterase and glutathione-S-transferase) and non-metabolic (reduced susceptibility of cholinesterase) mechanisms. It is important not only to control resistant *P. xylostella* strains but also to retard the development of resistance.

Introduction

Resistance to insecticides is an evolutionary phenomenon brought about by intensive 'natural selection' of the insect pest after continuous massive applications of insecticides. Resistance is not limited to insects and insecticides. A range of other organisms, including rodents, fungi, and weeds develop resistance to chemicals intended to control them. The number of species of arthropoda resistant to insecticides has incresed almost linearly from 1 in 1908, 5 in 1928, 14 in 1948, 76 in 1957, 224 in 1967, 364 in 1975 and 432 in 1980 (Georghiou and Taylor 1977, Georghiou and Mellon 1980).

The diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), is a cosmopolitan species of considerable importance as a pest of cruciferous plants. DBM has 14 to 28 generations in Malaysia (Ho 1965), 15 to 20 generations in Taiwan (Sun et al 1978) and 5 to 12 generations in Japan (Umeya and Yamada 1973) each year with overlapping of all developmental stages. DBM damage has become serious in Japan since 1960. Yamada (1977) pointed to the following reasons for this increase in damage: (1) year-round cultivation of crucifers, especially cabbage, which is an excellent host plant; (2) increase of the cabbage cultivation area; and (3) insecticide resistance caused by frequent application of insecticides. Recently Nemoto et al (1984) reported that methomyl might cause a resurgence in DBM populations through the stimulation of the reproductive potential. These factors will also explain the increasing problem of DBM in other countries.

Development of Insecticide Resistance in DBM

The first well documented case of insecticide resistance in DBM was demonstrated in Java, Indonesia, in 1953 by Ankersmit (1953). He observed that insects have developed

over time as much as seven times the level of resistance to DDT as they had exhibited when the compound was first used. Since then numerous cases of resistance to various kinds of insecticides have been reported from the Philippines (Barroga and Morallo-Rejesus 1974, 1981, Morallo-Rejesus and Eroles 1976), Japan (Asakawa 1975, Tokairin and Nomura 1975, Miyata et al 1982, Noppun et al 1983, Hama 1984), Malaysia (Lim 1974, Sudderudin and Kok 1978, Teh et al 1982), Taiwan (Sun et al 1978, Lee and Lee 1978, Liu et al 1981, 1982b, Chou and Cheng 1983), Thailand (Sinchaisri et al 1980), Singapore (Georghiou 1984) and so on. Some of the resistance patterns of DBM are shown in Tables 1 and 2. All these reports have indicated that DBM has developed resistance to various types of insecticides, including recently introduced synthetic pyrethroids.

Table 1. Susceptibility to some insecticides of susceptible, slightly resistant (Peng-hu), and highly resistant (Ban-chau) strains of DBM in Taiwan[a]

Insecticide	Susceptible	Peng-hu	Ban-chau
	LC_{50} (mg/ml)	R.R[b].	R.R.
Malathion	0.0274	536	>3,650
Diazinon	0.0293	43	413
Methyl parathion	0.00472	10,508	>21,000
Dichlorvos	0.0168	43	300
Cyanofenphos	0.00196	74	>50,000
Prothiophos	0.00041	400	5,854
Carbaryl	0.432	23	>230
Propoxur	0.338	>44	>300
Methomyl	0.0507	69	1,049
Permethrin	0.000776	4	110
Cypermethrin	0.00104	21	894
Deltamethrin	0.0002	56	2,235
Fenvalerate	0.000382	33	2,880
DDT	0.0348	635	>2,870
Cartap	0.025	16	199

[a] Source: Liu et al 1982b. Insecticides were sprayed on 4th instar larvae. [b] R.R.: resistance ratio.

According to Georghiou (1981), the cases of DBM resistance to insecticides had increased to 36 insecticides and 14 countries by 1980 (Table 3). Hama (1983) compared the susceptibility of the field-collected Miinohara strain and the susceptible strain (a strain reared in laboratory without exposure to insecticides) against 26 insecticides. Fifteen insecticides showed more than 20 fold resistance (Table 2).

Resistance stability and selection for resistance

Noppun et al (1984b) reported a decrease of insecticide resistance in DBM after withdrawal of chemicals. Strains collected in Okinawa and Aichi showed high levels of resistance to phenthoate, prothiophos, and cyanophenphos, and a moderate level of resistance to acephate, methomyl, and cartap when tested after 12 months and 5 months of laboratory rearing following field collection, respectively (Noppun et al 1983). However, there were no significant differences between resistance levels among field-collected strains and the susceptible strain after another 12 months laboratory rearing without insecticide selection (Noppun et al 1984c). A similar phenomenon was also observed by Ankermit (1953). The susceptibility of a DDT-resistant DBM strain to DDT increased at the eighth generation of laboratory rearing. Sun et al (1978) observed that the susceptibility of field-collected DBM to diazinon increased about three fold after

Table 2. Toxicity of various insecticides to susceptible and resistant (Miinohara) strains of DBM in Japan

Insecticides	LD_{50} (ug/larva)		Resistance ratio
	Susceptible	Resistant	
Fenvalerate	0.0073	0.0093	1.3
Phenothrin	0.030	0.034	1.1
Cyanofenphos	0.031	29.0	936.0
Dimethylvinphos	0.046	1.9	41.0
Methidathion	0.068	1.6	24.0
Profenofos	0.073	5.6	77.0
Prothiophos	0.089	24.0	270.0
Cyanophos	0.10	9.6	96.0
Phenthoate	0.13	8.3	64.0
Isoxanthion	0.14	>45.0	>321.0
Cartap	0.16	1.2	7.5
Thiocyclam	0.19	0.39	2.1
Salithion	0.43	11.0	26.0
Pirimiphos-methyl	0.48	8.7	18.0
Dialifor	0.71	>45.0	>63.0
Dichlorvos	0.73	9.6	13.0
Methomyl	0.86	>45.0	>52.0
Chlorvinphos	1.1	7.7	7.0
Chlorpyrifos-methyl	1.3	>45.0	>35.0
EPN	1.5	37.0	25.0
Diazinon	1.6	>45.0	>26.0
Fenitrothion	1.6	>45.0	>28.0
Acephate	1.7	>4.5	>2.6
Chlorpyrifos	2.3	>4.5	>2.0
Dimethoate	2.4	—	—
Trichlorfon	13.0	>45.0	>3.5
Malathion	20.0	>45.0	>2.3
BPMC	4.5	—	—
Carbaryl	10.0	—	—
Oxyphinofos	45.0	—	—

[a] Source: Hama 1983. Insecticides were topically applied to 4th instar larvae.

having been reared for 14 generations in the laboratory without insecticides. Lee and Lee (1979) also reported that susceptibility levels of DBM to malathion, dichlorvos, diazinon, phenthoate, mevinphos, and endosulfan increased three to seven fold after laboratory rearing for 20 generations. The loss of insecticide resistance during laboratory rearing causes some difficulties in insecticide resistance studies of DBM. On the other hand, Hama (1983) mentioned that the Miinohara strain did not show any significant loss of resistance (except to a few insecticides) after laboratory rearing for more than 15 generations.

Noppun et al (1984c) selected the Osaka susceptible strain and the Okinawa strain which lost resistance to phenthoate. High levels of resistance to phenthoate were obtained after selection repeated eight times during nine generations (Figure 1). At LD_{50} and LD_{95} levels, the phenthoate-selected Okinawa strain exhibited 172 and 287 fold resistance, while the Osaka susceptible strain exhibited 194 and 289 fold resistance, respectively. No significant difference in the rate of development of phenthoate resistance between the two selected strains was observed.

Sun et al (1978) selected the field-collected DBM strain with diazinon and methomyl pressure. Strains with resistance ratios of 14.4 and 17.5 to diazinon and methomyl

Table 3. Geographical distribution of the occurrence of insecticide resistance in DBM[a]

Insecticide group	Country, area	Insecticide group	Country, area
DDT	Barbados, Indonesia, Malaysia, Philippines, Singapore, South Africa, Sri Lanka, Taiwan, Vietnam	Malathion	Antigua, Barbados, Jamaica Malaysia, Philippines, South Africa, Taiwan, Vietnam
		Mevinphos	Philippines, Singapore
BHC/cyclodienes	Venezuela	Monocrotophos	Vietnam
Aldrin/dieldrin	Vietnam	Naled	Vietnam
Endosulfan	South Africa	Parathion	Sri Lanka, Taiwan
Endrin	Sri Lanka, Vietnam	Phenthoate	Japan, Vietnam
Isobenzan	Malaysia	Phosphamidon	Vietnam
Lindane/BHC	Malaysia, Singapore, Sri Lanka	Prothiophos	Taiwan
Acephate	Japan	Trichlorfon	Japan, Malaysia
Chlorpyrifos-methyl	Malaysia	Carbaryl	Barbados, Malaysia, Taiwan, Vietnam
Cyanophos	Taiwan	Isoprocarb	Taiwan
Diazinon	Japan, Philippines, Taiwan, Vietnam	Methomyl	Barbados, Japan, Malaysia, Taiwan
Dichlorvos	Japan, Malaysia, Philippines, Taiwan, Vietnam	Propoxur	Taiwan
		Pyrethroids	Malaysia, Thailand
Dimethoate	Barbados	Cypermethrin	Taiwan
EPN	Japan	Deltamethrin	Taiwan
Fenitrothion	Vietnam	Fenvalerate	Taiwan
Leptophos	Malaysia, Vietnam	Permethrin	Taiwan
Methamidophos	Malaysia	Resmethrin	Malaysia
Methyl parathion	Philippines, Taiwan, Vietnam	Cartap	Malaysia, Taiwan

[a] Source: Georghiou 1981.

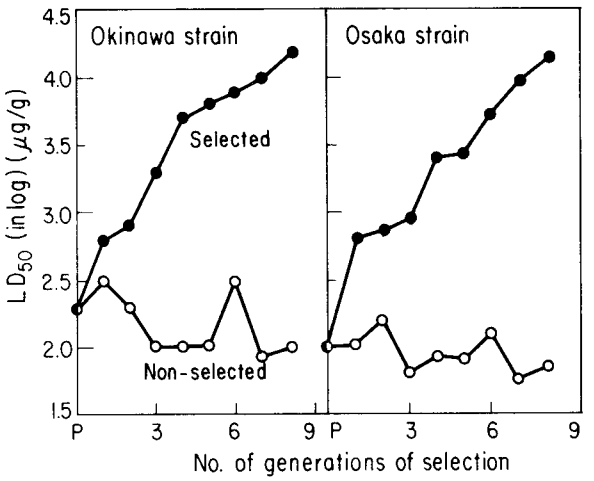

Figure 1.
Changes in LD_{50} values of phenthoate in the phenthoate-selected and non-selected strains from Okinawa and Osaka

respectively were developed in the laboratory by continuous selection for 14 and 19 generations, respectively. Chou and Cheng (1983) also selected the field-collected susceptible IL strain of DBM with carbofuran, fenvalerate, and cartap. The resistance to carbofuran developed 36 fold in eight generations. The other two insecticides showed smaller levels of resistance: 15 fold for fenvalerate in 12 generations and 10 fold for cartap in 10 generations. Noppun et al (1983) selected the field-collected Okinawa strain with fenvalerate 15 times during 22 generations and recorded an 8.7 fold resistance. However, Liu et al (1981, 1982b) reported higher levels of resistance in Taiwan strains of DBM.

Cross Resistance

The term cross resistance denotes the resistance of a strain of insects to compounds other than those they were selected against. The term multiple resistance denotes the resistance of a strain of an insect developed during the simultaneous or consecutive use of several insecticides (Yamasaki 1972). However, Oppenoorth and Welling (1976) state that the term cross ressistance denotes the resistance of a strain of insects to compounds other than those they were selected against, when resistance is due to the same mechanisms. In contrast, they assert that multiple resistance is the resistance of a single strain to several different compounds but resulting from different mechanisms. Multiple resistance often results from the simultaneous or consecutive use of several insecticides. However, it is sometimes difficult to discriminate between cross resistance and multiple resistance, since genetic linkage may result in different cross resistances, particularly during selection in the laboratory. If selection with an insecticide favors a rare gene A, it will simultaneously select the gene-alleles that are linked with it. If another resistance gene B already occurs in the strain, either this gene or its S-allele may be linked with gene A. Selection for gene A can thus increase or decrease gene B, depending on its accidental occurrence, whereas in actuality multiple resistance is present. Therefore, in this paper, we follow Yamasaki's definition (1972).

Sasaki (1982) selected the Osaka susceptible strain of DBM with dichlorvos, prothiophos, and cyanophos for more than 15 generations. He also conducted negative selection and obtained highly susceptible strains for each insecticide selection. Kuwahara (1983) reported that the Osaka susceptible strain was 2.5 to 4.1 times less sensitive than a strain from Uruguay to some insecticides. Cross resistance spectra of each selected

Table 4. Pattern of cross resistance to insecticides in dichlorvos-, prothiophos-, and cyanophos-selected DBM strains[a]

Insecticides	RR[b] of strains selected for resistance to		
	Dichlorvos	Prothiophos	Cyanophos
Dichlorvos	37.0	17.0	11.0
Cyanophos	7.0	158.0	381.0
Dimethylvinphos	1.7	2.3	5.0
Phenthoate	2.4	3.9	2.0
Prothiophos	2.5	98.0	29.0
Cyanofenphos	0.5	57.0	—
Diazinon	0.6	44.0	66.0
Dibrom	26.0	—	—
Isoxanthion	1.5	32.0	37.0
Salithion	12.0	12.0	6.0
Mecabram	13.0	8.0	—
Dialifor	1.3	1.5	0.7
Dimethoate	2.7	6.0	13.0
Fenitrothion	10.0	40.0	—
Tetrachlorvinphos	7.0	6.0	—
Acephate	3.1	1.6	—
Phosalone	1.4	3.9	—
EPN	2.8	4.2	—
Pyridaphenthion	2.5	1.2	—
BPMC	4.1	2.5	—
Pyrethrins	2.1	2.9	—
Fenvalerate	1.4	—	—
Pirimiphos-methyl	—	54.0	53.0

[a] Source: Sasaki 1982. [b] RR: resistance ratio.

strain are shown in Table 4. Each selected strain showed cross resistance to a wide range of insecticides. But cross resistance was lowest in the dichlorvos selected strain.

Liu et al (1981) demonstrated obvious cross resistance to synthetic pyrethroids (permethrin, cypermethrin, deltamethrin and fenvalerate). The methomyl-selected strain showed 3.8 fold resistance to fenvalerate, while this strain showed only 0.5 to 0.2 fold resistance to the other three synthetic pyrethroids. Hama (1983) reported more than 28 fold resistance to diazinon in the Miinohara strain, but this strain showed no resistance to fenvalerate and phenothrin (Table 2).

Chou and Cheng (1983) reported that the carbofuran-selected IL strain of DBM showed very little cross resistance to another 19 insecticides. On the other hand, stronger cross resistance was observed in both cartap-and fenvalerate-selected strains. Cheng et al (1984) also selected the susceptible IL strain with mevinphos for 20 generations and obtained only five to eight fold resistance. The mevinphos-selected strain showed a broad cross resistance to other organophosphorus insecticides and cartap, but this resistance was not extended to most of the synthetic pyrethroids.

On the other hand, Noppun et al (1984a) compared the cross resistance spectra of two DBM strains selected with phenthoate (Table 5). The phenthoate-selected Okinawa

Table 5. Cross resistance spectra of phenthoate-selected DBM strains[a]

Insecticide	Strain	RR[b] based on	
		LD_{50}	LD_{95}
Phenthoate	Selected Okinawa	109.0	116.0
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	166.0	178.0
	Non-selected Osaka	1.0	1.0
Dichlorvos	Selected Okinawa	7.7	9.0
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	7.5	8.3
	Non-selected Osaka	1.0	1.0
Prothiophos	Selected Okinawa	120.0	839.0
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	7.6	8.8
	Non-selected Osaka	1.0	1.0
Cyanophos	Selected Okinawa	95.0	680.0
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	10.9	11.7
	Non-selected Osaka	1.0	1.0
Acephate	Selected Okinawa	3.4	3.8
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	4.5	4.6
	Non-selected Osaka	1.0	1.0
Methomyl	Selected Okinawa	318.0	1380.0
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	130.0	274.0
	Non-selected Osaka	1.0	1.0
Cartap	Selected Okinawa	3.7	14.8
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	2.5	9.3
	Non-selected Osaka	1.0	1.0
Fenvalerate	Selected Okinawa	1.5	1.9
	Non-selected Okinawa	1.0	1.0
	Selected Osaka	1.2	1.7
	Non-selected Osaka	1.0	1.0

[a] Source: Noppun et al 1984a. [b] RR: resistance ratio.

strain showed high cross resistance to prothiophos, cyanophos, and methomyl and showed low cross resistance to dichlorvos and cartap. The phenthoate-selected Osaka strain also showed high cross resistance to methomyl, however, it showed low cross-resistance to dichlorvos, prothiophos, cyanophos, and cartap. This result indicates that even if the selection starts at the same insecticide susceptibility levels, when the strains are different the resultant selected strains do not necessarily show the same cross resistance spectra.

Resistance Mechanism

Susceptible and multiple resistant (Banchou, resistance factor for DDT = 200) strains of DBM were used to determine the effect of a microsomal oxidation inhibitor, piperonyl butoxide (PB), and a DDT-dehydrochlorinase inhibitor, 1,1-bis (p-chlorophenyl) ethanol (DMC). The absence of synergism by PB and DMC raised the possibility of the existence of a non-metabolic mechanism of DDT (Liu et al 1982a). However, against the multiple resistant strains (with high resistance to synthetic pyrethroids) collected from Banchou, synergism of synthetic pyrethroid toxicity by PB, but not by DEF (S,S,S-tributyl phosphorothioate), was observed (Table 6). The results seemed to indicate that oxidative metabolism mediated by microsomal oxidases contributed, at least in part, to synthetic pyrethroid resistance in DBM, whereas hydrolytic metabolism might not be involved. But, among synthetic pyrethroids, PB synergism was the lowest against permethrin (Liu et al 1981). Teh et al (1982) reported only a slight synergism with PB against permethrin in DBM from the Cameron Highlands (resistance ratio against permethrin >700).

Table 6. Effect of piperonyl butoxide (PB) and DEF on the susceptibility to several synthetic pyrethroids of Ban-chou (resistant) strain of DBM[a]

Insecticide		LC_{50} (mg/ml)				LC_{50} (mg/ml)		
	RR[b]	No PB	+PB[c]	SR[d]	RR	No DEF	+DEF[c]	SR
Permethrin	14.1	0.48	0.18	2.7	77.6	2.64	1.24	2.1
Cypermethrin	87.3	2.88	0.17	16.7	316.4	10.44	6.71	1.6
Deltamethrin	67.1	0.94	0.02	47.0	714.3	2.22	2.04	1.1
Fenvalerate	207.7	2.70	0.09	30.0	701.5	9.12	8.15	1.1

[a] Source: Liu et al 1981. [b] RR: resistance ratio. [c] Larvae were sprayed with 1.0 mg of PB/ml one hour prior to insecticide treatment. [d] SR: synergistic ratio.

From genetic analysis, it was demonstrated that fenvalerate resistance in DBM was partially recessive and was due to more than one gene (Liu et al 1981).

In some organophosphorus insecticide resistant species, resistance correlates with esterase activities (Motoyama and Dauterman (1974). Sun et al (1978) demonstrated a qualitative difference in esterase activity between susceptible and methomyl- or diazinon-resistant DBM strains in Taiwan. However, Miyata et al (1984) could not demonstrate a qualitative difference in esterase between Japanese strains of DBM.

Noppun et al (1984a) studied the effect of PB, triphenyl phosphate (TPP), and fenvalerate on the toxicity of phenthoate to phenthoate-selected and non-selected DBM strains (Table 7). High co-toxicity coefficient values were obtained by the mixture of phenthoate and TPP combinations against phenthoate-selected strains, but not against non-selected strains. This suggests that an enhanced carboxyl-esterase degrading phenthoate might be involved as one of phenthoate resistance factors. However, the mixture of TPP and phenthoate could not completely suppress phenthoate resistance, suggesting that other resistance mechanism(s) could be involved. *In vitro* acetylcholin-

Table 7. Joint toxicity of phenthoate to non-selected and phenthoate selected DBM strains[a]

Strain	LD50 or CC[b] of LD50 of phenthoate							
	+ PB[c]	CC	+ TPP[d]	CC	+ TPP[e]	CC	+ Fenval[f]	CC
Sel[g] Okinawa	12800	112.0	3270	713	3570.0	664	0.721	189
Non-sel Okinawa	452	92.5	165	129	96.3	222	0.477	190
Sel Osaka	12600	107.0	2610	759	2980.0	664	0.633	170
Non-sel Osaka	400	58.4	97	123	55.8	213	0.330	263

[a] Source: Noppun et al 1984a. [b] Co-toxicity coefficient, [c] Pineronyl butoxide. [d] Phenthoate + TPP (simultaneous treatment). [e] Phenthoate + TPP (pretreatment). [f] Fenvalerate. [g] Selected.

esterase inhibition by phenthoate-oxon indicated that acetylcholinesterase of phenthoate-selected DBM strains is less sensitive to phenthoate-oxon than non-selected strains. Sun et al (1978) also mentioned that acetylcholinesterase of the diazinon-resistant strain was less sensitive to diazinon than that of a susceptible strain.

The role of glutathion-S-transferase as an organophosphorus insecticide detoxification mechanism was investigated by Cheng et al (1983, 1984). The results indicated that glutathione-S-transferase activities in the organophosphorus-resistant strains were three to four times higher than in the susceptible IL strain.

Liu et al (1981) mentioned that several mechanisms, including differential penetration, metabolism by microsomal oxidases and soluble enzymes, and possibly acetylcholin-esterase insensitivity, were involved in DBM resistance to diazinon and methomyl. However, this could not provide an explanation for the observed cross resistance patterns of diazinon-resistant and methomyl-resistant strains to some synthetic pyrethroids.

Measures to Overcome Insecticide Resistance

It has become increasingly difficult to develop new insecticides. In the United States 1800 compounds were screened to develop one new compound in 1956; 3600 in 1965; and 10,000 in 1972. The cost of $20 million to develop each marketable compound, estimated in 1977, was almost 17 times the cost estimated in 1956 ($1,196,000). The conclusion is that it will become increasingly difficult and expensive to discover and develop new pesticides (Metcalf 1980).

Therefore, it has become more difficult to introduce alternative insecticides which have no cross resistance when insects show resistance to certain insecticides. The use of synergists is a common measure to overcome insecticide resistance. As far as we know at this stage, we have no effective synergist to overcome insecticide resistance in DBM (Liu et al 1981, Noppun et al 1984a).

Certain combinations of insecticide mixtures and insecticide rotation are promising approaches for retarding insecticide resistance (Georghiou et al 1983). Miyata and Saito (1984) reviewed many successfull cases of suppression of resistance by a combination of synergistic insecticides and alternative use of chemical combinations with negatively correlated cross resistance in the green rice leafhopper, *Nephotettix cincticeps* Uhler (Hemiptera: Deltocephalidae), the brown planthopper, *Nilaparvata lugens* Stal (Hemiptera: Delcephalidae) and the smaller brown planthopper, *Laodelphax striatellus* Fallen (Hemiptera: Delphacidae).

El-Guindy et al (1983) studied cross resistance patterns to certain insecticides and insect growth regulators in the diflubenzuron-resistant strain of *Spodoptera littoralis* F (Lepidoptera: Noctuidae). The diflubenzuron resistant strain showed slight cross resistance to synthetic pyrethroids (fenvalerate and cypermethrin) and endrin, but

extremely low cross resistance to insect growth regulators (resistance ratio for methoprene 0.006 and for tripren 0.05).

However, no good combination of insecticides has yet been found against insecticide-resistant DBM (Sasaki 1982). Even though the insecticide resistance problem in DBM has become a worldwide phenomenon, the study of resistance mechanisms is not yet complete. The promotion of basic studies will result in progress in monitoring for the development of insecticide resistance and the development of new countermeasure, to control resistant DBM, or at least to retard the development of insecticide resistance.

As mentioned previously, insecticide resistance is caused by insecticide selection. Therefore the establishment of integrated pest management programs is also very important for the control of DBM.

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Insecticide Resistance in Diamondback Moth

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Abstract

High levels of resistance to the major categories of insecticides, ie, organophosphorus, carbamates, pyrethroids, and DDT, have been detected in the diamondback moth in Taiwan. Synergist studies have provided insufficient evidence to show significant involvement of known metabolic systems, such as microsomal oxidation, esterase hydrolysis, and glutathione conjugation in organophosphorus and carbamate resistance. Meanwhile, moderate levels of reduction of acetyl cholinesterase sensitivity to these compounds have been observed. This, however, could not account for all the resistance detected. In addition, the relationship between carbofuran and carbosulfan resistance is discussed. While pyrethroid resistance is closely associated with microsomal oxidation, indirect evidence indicates nerve insensitivity may also be a contributing factor. Synergist piperonyl butoxide may temporarily obliterate pyrethroid resistance. But this effect disappears quite quickly, probably because of the development of resistance to this specific compound by the insect. Diamondback moth larvae selected with fenvalerate or fenvalerate/piperonyl butoxide seem to be more susceptible to some organophosphorus insecticides including mevinphos, profenofos, and prothiophos. Recommendations are suggested regarding the use of synergists, pyrethroids, and organophosphorus insecticides.

Introduction

In 1984, 30 insecticides including 17 organophosphorus compounds, 2 carbamates, 6 pyrethroids, 2 mixtures of organophosphorus compounds and pyrethroid, 2 organonitrogen compounds and *Bacillus thuringiensis* were officially recommended for the control of diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), in Taiwan (Table 1). Different levels of resistance to these insecticides have been detected

Table 1. Insecticides recommended for DBM control in Taiwan in 1984[a]

1. Organophosphorus compounds (17)			
Acephate	Cyanofenphos	Cyanophos	Diazinon
Dichlorvos	Mephosfolan	Methamidophos	Methidathion
Mevinphos	Naled	Phenthoate	Pirimiphos-methyl
Profenofos	Prothiophos	Pyridaphenthion	Quinalphos
Salithion			
2. Carbamates (2)			
Carbofuran	Methomyl		
3. Pyrethroids (6)			
Cypermethrin	Deltamethrin	Fenvalerate	
Fenpropathrin	Flucythrinate	Permethrin	
4. Mixtures (2)			
Dimethoate + Phenthoate (1:2)			
Chlorpyrifos + Cypermethrin (9:1)			
5. Others (3)			
Cartap	Thiocyclam	*Bacillus thuringiensis*	

[a] Source: PDAF 1984.

in a multiple-resistant (BC) strain from the field (Table 2). Despite the resistance, some insecticides, including dichlorvos, mevinphos, profenofos, permethrin, cypermethrin, deltamethrin, and fenvalerate still possess much higher potency than the rest against this highly resistant strain. Cartap and *B. thuringiensis* are also effective. No resistance to the latter is detected in the BC strain.

In the following, the resistance to each group of compounds, with special reference to the pyrethroids, will be discussed.

Table 2. Toxicity of some insecticides to susceptible (FS) and multiresistant (BC) strains of DBM

Insecticide	FS LC_{50} (μg/ml)	BC LC_{50} (mg/ml)	RR[a]
Organophosphorus[b,c]			
Cyanofenphos	1.96	>100.00	>50,000
Diazinon	29.30	12.10	413
Dichlorvos	34.00	3.20	94
Malathion	34.00	>100.00	>2,941
Methyl parathion	9.40	>100.00	>10,638
Mevinphos	16.00	2.40	150
Profenofos	0.14	0.94	6,714
Prothiophos	0.41	2.40	5,854
Carbamates[b]			
Carbaryl	820.00	>100.00	>122
Carbofuran	270.00	8.90	33
Methomyl	420.00	46.50	111
Pyrethroids[d]			
Cypermethrin	1.29	0.67	519
Deltamethrin	0.40	0.74	1,850
Fenpropathrin	9.07	13.30	1,466
Fenvalerate	1.13	2.22	1,965
Flucythrinate	2.14	23.60	11,028
Fluvalinate	44.70	104.00	2,327
Permethrin	2.58	0.40	155
Phenothrin	24.00	14.30	596
Tetramethrin	61.9	17.40	281
Tralomethrin	1.64	11.10	6,768
Organochlorines[d]			
DDT	84.60	>100.00	>1,182
Others			
Cartap[c]	25.00	4.97	199
Bacillus thuringiensis[e]	1,859.00	3.58	2

[a] Resistance ratio: LC_{50} of BC strain/LC_{50} of FS strain. [b] Wu, T. K. and C. N. Sun. Unpublished data. [c] Liu et al (1982). [d] Chen, J. S. and C. N. Sun. Unpublished data. [e] *Bacillus thuringiensis*. Cheng, Y. P. and C. N. Sun. Unpublished data based on feeding and 36 h mortality.

Organophosphorus and Carbamate Resistance

Metabolic mechanism

In view of the high resistance levels observed, the synergistic action of piperonyl butoxide (PB) and *S,S,S*-tributyl phosphorotrithioate (TBPT), inhibitors of microsomal oxidases and esterases associated with the metabolism of organophosphorus and carbamate insecticides, was rather insignificant (Table 3). This might imply that

Table 3. Synergism of several insecticides by *S,S,S*-tributyl phosphorotrithioate (TBPT) and piperonyl butoxide (PB) in a susceptible (FS) and a resistant (BC) strains of DBM

Treatment	FS		BC		
	LC_{50} (μg/ml)	SR[a]	LC_{50} (mg/ml)	SR	RR[b]
Dichlorvos	34		4.50		132
+ TBPT[c]	30	1.1	5.69	0.8	
+ PB	27	1.3	4.53	1.0	
Mevinphos	16		2.24		140
+ TBPT	12	1.3	2.19	1.0	
+ PB	17	0.9	2.03	1.1	
Profenofos	14		0.68		6,714
+ TBPT	—	—	1.00	0.7	
+ PB	—	—	1.97	0.4	
Methomyl	420		46.70		111
+ TBPT	470	0.9	45.30	1.0	
+ PB	140	3.0	13.30	3.5	
Carbofuran	270		12.30		46
+ TBPT	250	1.1	9.62	1.3	
+ PB	170	1.6	4.76	2.6	

[a] Synergism ratio: LC_{50} unsynergized/LC_{50} synergized. [b] Resistance ratio: LC_{50} of BC strain/LC_{50} of FS strain. [c] Larvae were sprayed with TBPT or PB at maximal sublethal concentrations one hour prior to insecticide treatment. For FS strain: TBPT μg/ml, PB 0.1 mg/ml; for BC strain: TBPT 0.25 mg/ml, PB 1.0 mg/ml.

microsomal oxidation was only slightly involved in the resistance to methomyl and carbofuran. The slight antagonistic action of PB on profenofos might be due to the blockage by this synergist of its activation pathway. Another synergist, *O,O*-diisopropyl-*S*-benzylthiophosphate (IBP), which was reported to inhibit both carboxylesterases and glutathione-transferase in insects (Miyata et al 1981, Yeoh et al 1982), gave only a two fold increase of the toxicity of mevinphos and had practically no synergistic action on dichlorvos and profenofos (Table 4). These results prompted us to investigate whether reduced sensitivity of acetylcholinesterase to these insecticides might be a resistance factor.

Table 4. Synergism of several insecticides by *O,O*-diisopropyl-*S*-benzylthiophosphate (IBP) in a resistant (BC) strain of DBM

Treatment	LC_{50} (mg/ml)	SR[a]
Dichlorvos	5.17	
+ IBP	4.11	1.3
Mevinphos	1.75	
+ IBP	0.85	2.0
Profenofos	0.46	
+ IBP	0.42	1.1

[a] Synergism ratio: LC_{50} unsynergized/LC_{50} synergized.

Reduced sensitivity of acetylcholinesterase

We adopted the method of Main and Dauterman (1963) to determine the bimolecular rate constants for the inhibition by some insecticides of acetylcholinesterases of a susceptible (FS) and a resistant (BC) strains of DBM. Table 5 shows clearly that the acetylcholinesterase of the BC strain was indeed less sensitive to several organophosphorus and carbamate insecticides. Our subsequent studies revealed that this reduced

Table 5. Bimolecular rate constants for the inhibition by several insecticides of acetylcholinesterases of a susceptible (FS) and a resistant (BC) strains of DBM

Insecticide	Ki $M^{-1}min^{-1}$		FS/BC	RR[a]
	FS	BC		
Dichlorvos	$0.380x10^6$	$1.00x10^4$	38	94
Mevinphos	$1.400x10^6$	$3.40x10^4$	41	150
Malaoxon	$10.400x10^6$	$19.70x10^4$	53	2,941[b]
Methyl paraoxon	$1.800x10^6$	$7.50x10^4$	24	10,638[b]
Profenofos	$0.098x10^4$	$0.68x10^4$	0.14	6,714
Methomyl	$0.210x10^6$	$0.58x10^4$	36	111
Carbofuran	$1.800x10^6$	$8.20x10^4$	22	33
Carbaryl	$0.140x10^6$	$1.30x10^4$	11	122

[a] Resistance ratio. [b] Resistance ratio for malathion and methyl parathion, respectively.

sensitivity was mainly due to a lower affinity of this enzyme for these insecticides. Profenofos, an *O*-ethyl *S*-n-propyl phosphorothiolate, displays high levels of activity against both susceptible and resistant DBM (Table 2). Yet it is not a potent inhibitor of acetylcholineesterase *in vitro* (Table 5). Similar results were obtained in *Spodoptera littoralis* (Dittrich et al 1979). Recently, Kono et al (1983) suggested that profenophos, and other *O*-ethyl *S*-n-propyl phosphorothiolate insecticides were activated oxidatively in the central nervous system of the insects to inhibit acetylcholinesterase. This is also in accordance with the slight antagonism of profenofos by PB as shown in Table 3.

Nevertheless, this mechanism still could not account for the extremely high levels of resistance to methyl parathion and malathion.

Carbofuran vs carbosulfan resistance

Selection of the susceptible FS strain with carbofuran for seven generations resulted in about 170 fold resistance to the selection agent as well as approximately 50 fold resistance to the pro-insecticide carbosulfan (Table 6). Similar selection with carbosulfan resulted in 170 fold resistance to this pro-insecticide and about 1000 fold resistance to carbofuran. The reasons for this unique cross resistance between these two carbamates are being investigated. Meanwhile, attention is drawn to the cross resistance to organophosphorus compounds and pyrethroids.

Table 6. Toxicity of some insecticides to a susceptible (FS), a carbofuran-selected (CF), and a carbofusulfan-selected (CS) strains of DBM[a]

Insecticide	FS	CF		CS	
	LC_{50} (mg/ml)	LC_{50} (mg/ml)	RR[b]	LC_{50} (mg/ml)	RR
Carbofuran	0.11	18.4	167	106	964
Carbosulfan	0.12	5.55	46	20.5	171
Mevinphos	0.093	1.56	17	0.95	10
Prothiophos	0.084	1.70	20	0.84	10
Permethrin	0.0013	0.087	67	0.04	31
Cypermethrin	0.0034	0.33	97	0.13	38

[a] Source: Lee and Sun, unpublished data. [b] Resistance ratio: LC_{50} of CF or CS strain/LC_{50} of FS strain.

Carbofuran selection apparently made the DBM more resistant to both organophosphorus compounds and pyrethroids than carbosulfan selection did; and DBM selected by carbofuran was more resistant to pyrethroids than to organophosphorus compounds.

This could be due to overlapping of carbofuran resistance mechanisms and organophosphorus or pyrethroid resistance mechanisms. The overlapping of carbofuran and pyrethroid resistance was more extensive than that of resistance to carbofuran and organophosphorus compounds. Microsomal oxidation could be the common mechanism for carbofuran and pyrethroid resistance. Reduced sensitivity of acetylcholinesterase, on the other hand, could be the common mechanism for carbofuran and organophosphorus resistance.

Pyrethroid Resistance

Regression of susceptibility

Upon relaxation of the insecticide selection pressure, the mixed field (MD) strain still retained its resistance to the four major pyrethroids for about 10 generations (Table 7). By the 16th generation, its resistance to permethrin was reduced about nine fold and that to cypermethrin and fenvalerate about six fold, while resistance to deltamethrin remained practically the same. Pyrethroid resistance in DBM thus appears to be quite stable and lingers on for a period of time after the removal of selection pressure.

Table 7. Changes of susceptibility to four pyrethroids of the mixed field strain of DBM upon relaxation of insecticide selection pressure[a]

Generation	LC_{50} (μg/ml)			
	Cypermethrin	Deltamethrin	Fenvalerate	Permethrin
00	677	1017	5356	639
01	411	1091	3060	204
02	584	1719	4135	480
03	626	1428	2959	413
04	316	941	3418	273
05	471	949	2900	553
06	427	1417	3797	484
07	536	1100	3006	404
08	740	1097	1999	215
09	850	783	2153	307
10	498	848	1537	300
11	421	1587	1059	290
12	253	976	578	145
13	306	1056	816	67.7
14	214	1064	674	84.9
15	154	1338	973	49.5
16	107	922	830	70.2

[a] Modified from Chen and Sun (1986).

Table 8 shows the regression of susceptibility of the same strain to three organophosphorus insecticides over the same period of time. Organophosphorus resistance in DBM seems to be less persistent than pyrethroid resistance. A greater reduction of resistance, 32 fold for mevinphos, 5 fold for profenofos and 16 fold for prothiophos, was observed. The susceptibility to mevinphos of this regressed field strain was comparable to that of the susceptible FS strain (Table 2). In view of the great differences in susceptibility to many insecticides between the FS strain and the local BC strain (Table 2) (Liu et al 1982a), this is a truly unique phenomenon. Advantage should be taken of the instability of mevinphos resistance, and its rapid regression to the truly susceptible state for the control of DBM.

Although the regression of susceptibility to carbamates might also have occurred upon the relaxation of selection pressure from the mixed field strain of DBM, data were not available due to the limitations of the bioassay method (Table 9).

Table 8. Changes of susceptibility to three organophosphorus insecticides of the mixed field strain of DBM upon relaxation of insecticide selection pressure[a]

Generation	LC_{50} (μg/ml)		
	Mevinphos	Profenofos	Prothiophos
00	254.0	2760	7910
01	22.7	2174	—
02	12.9	2254	4719
03	10.9	1500	2003
04	14.8	1779	1049
05	10.7	1436	1067
06	12.3	1145	1297
07	9.0	1460	923
08	5.2	1113	988
09	8.7	1047	742
10	7.4	752	1152
11	6.3	646	534
12	7.2	872	914
13	3.6	618	813
14	7.3	514	529
15	9.3	598	603
16	8.0	507	493

[a] Modified from Chen and Sun (1986).

Table 9. Changes of susceptibility to three carbamates of the mixed field strain of DBM upon relaxation of insecticide selection pressure[a]

Generation	LC_{50} (mg/ml)		
	Carbofuran	Carbaryl	Methomyl
0	nd[b]	nd	nd
1–10	nd	nd	nd
11	294[c]	nd	nd
12	116[c]	nd	nd
13	117[c]	nd	nd
14	204[c]	nd	nd
15	92	nd	nd
16	101[c]	nd	nd

[a] Source: Chen and Sun 1986. [b] Not determinable. No mortality was recorded at 100 mg/ml. [c] Estimated values.

Non-metabolic mechanism

DDT and pyrethroid resistance High levels of resistance in DBM to the four major synthetic pyrethroids were found only three to four years after the introduction of these pyrethroids to Taiwan (Liu et al 1981). A similarly high level of DDT resistance also existed in the field (Liu et al 1982a). We suspected that this rapid onset of pyrethroid resistance was due to widespread application of DDT on vegetables during the 1950s and 1960s before DDT was banned. The absence of synergism of DDT by PB and 1,1-di-(4-chlorophenyl) ethanol, inhibitors of microsomal oxidases and DDT-dehydrochlorinase, which are involved in the degradation of DDT, raised the possibility of the existence

of a non-metabolic mechanism of DDT resistance in this insect (Table 10). This mechanism might also play an important role in DBM resistance to synthetic pyrethroids and may be similar to a previously observed non-metabolic mechanism for DDT-pyrethroid resistance in houseflies and mosquitoes (Liu et al 1982b).

Table 10. Synergism of DDT by piperonyl butoxide (PB) and 1,1-di-(4-chlorophenyl) ethanol (DMC) in a susceptible (FS) and a resistant (BC) strains of DBM[a]

Treatment	LC_{50} (mg/ml)	
	FS	BC[b]
DDT	0.140	28
DDT + PB[c]	0.075	25
DDT + DMC	0.190	35

[a] Source: Liu et al 1982b. [b] Estimated by graphic method. [c] Larvae were sprayed with 0.1 mg/ml of PB or DMC one hour before DDT treatment.

Pyrethroid resistance insuppressible by metabolic inhibitors Recent synergist studies revealed that esterase hydrolysis contributed only to a moderate extent to permethrin resistance in DBM (Figure 1). With PB to suppress the oxidative degradation, the residual resistance to fenvalerate, deltamethrin, and cypermethrin was still substantial (Table 11). This may be taken as further evidence, though indirect, for the possible existence of a non-metabolic mechanism for pyrethroid resistance in this insect pest.

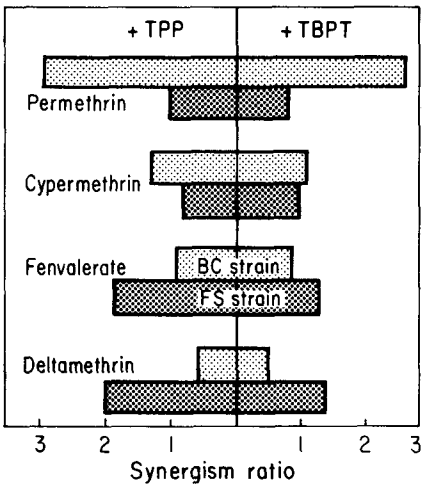

Figure 1.
Synergism of four pyrethroids by triphenyl phosphate (TPP) and *S,S,S*-tributyl phosphorotrithioate (TBPT) in a susceptible (FS) and a resistant (BC) strains of DBM

Metabolic mechanism

Cross-resistance to permethrin and cypermethrin (67 fold and 97 fold respectively) of carbofuran-selected DBM (Table 6) suggests that the high levels of pyrethroid resistance detected in the field shortly after their introduction to Taiwan could have arisen, in part, from previous uses of carbamate insecticides for the control of DBM and other insect pests on cruciferous vegetables.

Repeated synergist studies indicate that only permethrin could be synergized consistently and effectively in the resistant strain by the esterase inhibitors triphenyl phosphate (TPP) and TBPT (Figure 1) (Liu et al 1974, 1981). Meanwhile, PB has been found to synergize all four major pyrethroids, though to different degrees (Figure 2)

Table 11. Synergism of fenvalerate, deltamethrin, and cypermethrin by piperonyl butoxide (PB) in a susceptible (FS) and a resistant (BC) strains of DBM[a]

Treatment	FS	BC	
	LC_{50} (μg/ml)	LC_{50} (mg/ml)	RR[b]
Fenvalerate	0.94	3.39	3606
+ PB[c]	0.53	0.22	415
Deltamethrin	0.26	0.50	1923
+ PB	0.06	0.04	667
Cypermethrin	1.14	0.27	239
+ PB	0.79	0.10	127

[a] Source: Liu et al 1984. [b] Resistance ratio = LC_{50} of BC strain/LC_{50} of FS strain for each corresponding treatment. [c] Larvae were sprayed with 0.1 mg/ml PB one hour before insecticide treatment.

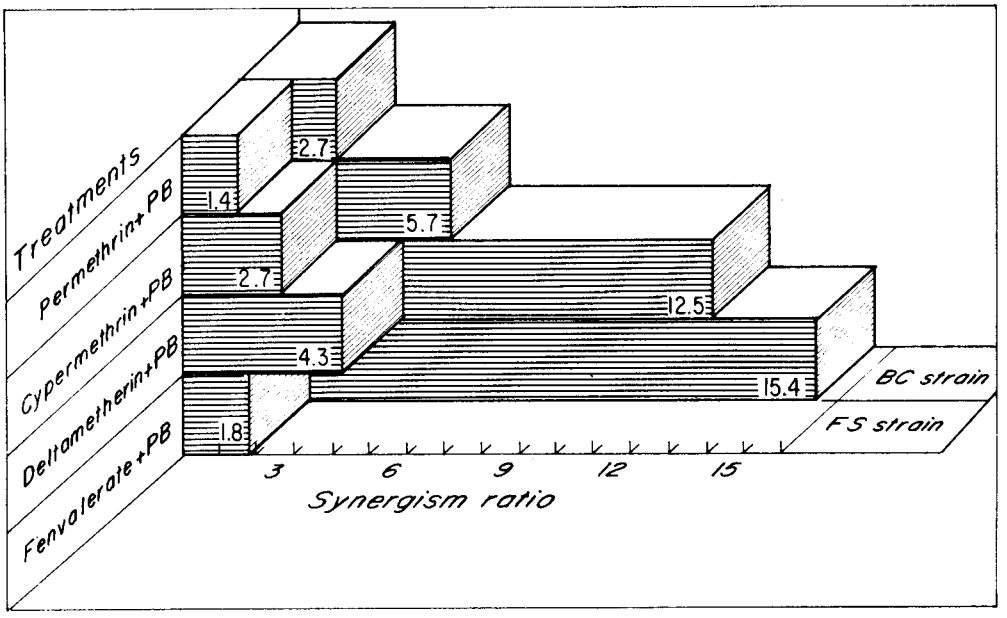

Figure 2. Synergism of four pyrethroids by piperonyl butoxide (PB) in a susceptible (FS) and a resistant (BC) strains of DBM

(Liu et al 1981, 1984). Fenvalerate, of the four pyrethroids tested, was most drastically synergized by Butacide, a tank-mix formulation of PB, mixed and applied simultaneously with these pyrethroids at varying ratios (Figure 3). These studies all imply that oxidative degradation is the most important metabolic mechanism in the pyrethroid resistance in this insect.

Use of PB to overcome pyrethroid resistance

The use of synergists which interfere with the detoxication of insecticides to cope with a resistance problem is expected to be more effective where one dominant metabolic mechanism exists for resistance to a number of insecticides. The optimal synergist may

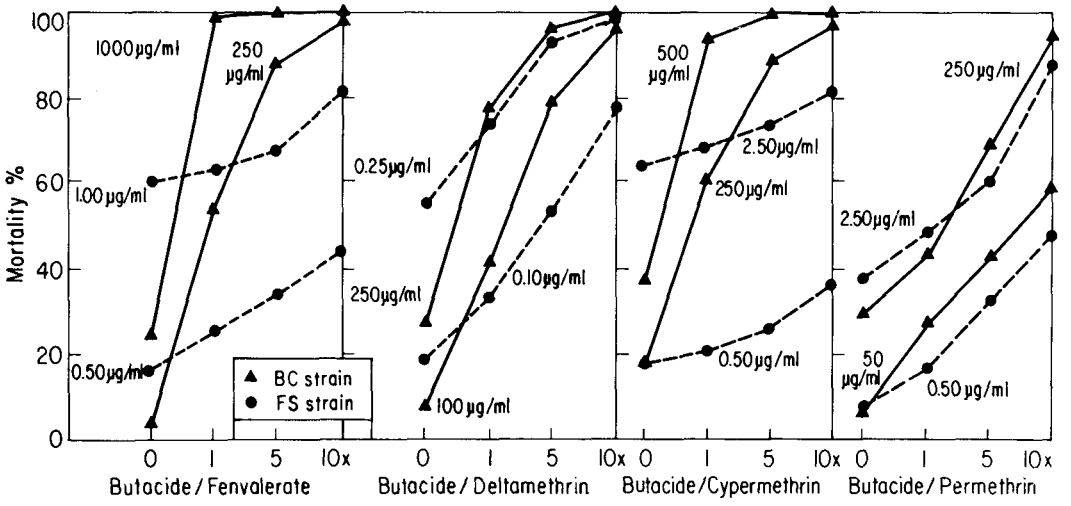

Figure 3. Synergism of four pyrethroids by Butacide in a susceptible (FS) and a resistant (BC) strains of DBM

vary with the insect species and the insecticides. A possible consequence of large scale application of synergists in the field for insect control may be the emergence and subsequent intensification of certain known or even unknown resistance mechanisms. In the case of DBM, the use of PB might eventually accelerate and intensify the suspected insensitive nerve resistance mechanism and the insensitive acetylcholinesterase resistance mechanism for pyrethroids and organophosphorus/carbamate insecticides (Liu et al 1984). In practice, farmers may choose to use the synergists indiscriminately with all their insecticides. The long term consequences of applying synergists at rates up to 10 times the dose of the insecticides should be carefully assessed.

Selection with fenvalerate and fenvalerate/PB Selection of the regressed field strain (MD strain at the 10th generation) with fenvalerate increased the LC_{50} from 1.24 mg/ml to more than 100 mg/ml in four generations, rendering this insecticide practically useless (Table 12). The persistence of resistance after removal of selection pressure mentioned earlier and the subsequent rapid recurrence of resistance constitute the major obstacles in the use of pyrethroids for DBM control.

Table 12. Changes of susceptibility to fenvalerate of regressed field strain (at 10th generation) upon selection with fenvalerate[a]

Generation	LC_{50} (mg/ml)	Slope
0	1.24	2.29
1	3.69	1.98
2	8.96	2.31
3	28.20	1.37
4	>100	nd[b]
5	>100	nd

[a] Modified from Chen and Sun (1986). [b] Not determinable.

The first eight generations of selection of the mixed field strain with fenvalerate/PB (PB at 1 mg/ml) caused only about three fold increase of LC_{50} (Table 13). After this

Table 13. Changes of susceptibility to fenvalerate + piperonyl butoxide (PB) of the mixed field mixed field strain of DBM upon selection with fenvalerate/PB[ab]

Generation	Fenvalerate + 1 mg/ml PB		Fenvalerate + 5 mg/ml PB	
	LC_{50} (μg/ml)	Slope	LC_{50} (mg/ml)	Slope
00	0.52	2.23	—	—
01	0.44	2.36	—	—
02	0.49	3.80	—	—
03	0.63	3.90	—	—
04	0.93	5.10	—	—
05	1.06	3.51	—	—
06	1.48	4.02	—	—
07	1.76	2.33	—	—
08	4.14	1.51	—	—
09	17.80	0.80	4.48	2.73
10	>100	nd[c]	6.41	1.48
11	>100	nd	48.90	1.13
12	>100	nd	>100	nd

[a] Modified from Chen and Sun (1986). [b] A concentration of 1 mg/ml of PB was used for selection until the 9th generation. Afterwards, 5 mg/ml of PB was used. [c] Not determinable.

stage of apparent adjustment, resistance to fenvalerate/PB started to increase rapidly and the LC_{50} jumped to more than 100 mg/ml in the 10th generation. Starting with the 10th generation, the concentration of PB used in selection was increased to 5 mg/ml. Within two generations of selection under these conditions, the LC_{50} again ran over 100 mg/ml. The synergist could no longer suppress the pyrethroid resistance in DBM.

Cross resistance patterns of fenvalerate and fenvalerate/PB-selected strains Selection of the mixed field strain with fenvalerate and fenvalerate/PB resulted in these two strains developing cross resistance to cypermethrin, deltamethrin, and permethrin (Table 14). At a concentration of 100 mg/ml, no mortality was observed for any one of these pyrethroids. However, compared to the original mixed field strain, the selected strains were generally more susceptible to the three organophosphorus insecticides tested, mevinphos, profenofos, and prothiophos. This suggests that there is probably no common mechanism between pyrethroid and organophosphorus resistance in DBM. It also offers the possibility of alternating organophosphorus insecticides with pyrethroids in the field for the control of this insect pest. Again, due to the limitation of the bioassay technique, it is not clear if carbamate susceptibility in these two strains was affected.

Synergism by several compounds in the fenvalerate and fenvalerate/PB-selected strains Synergists which block the esterases, such as IBP, TBPT, and TPP, enhanced the toxicity only of permethrin to any noticeable extent (Table 15). However PB, which inhibits microsomal oxidase, produced significant synergism of both fenvalerate and permethrin in the regressed field (MD) strain and the fenvalerate selected (FP) strain but not in the fenvalerate/PB selected strain. However another microsomal oxidase inhibitor, MGK 264, was less synergistic than PB in the regressed MD and fenvalerate selected FP strains. It definitely exhibited more synergism in the fenvalerate/PB selected FP/PB strain. A subsequent experiment designed to test the toxicity of PB to the four strains of DBM revealed that the strain selected with fenvalerate/PB was much less susceptible to this synergist (Table 16). Therefore, it seems that DBM selected with pyrethroid/PB has evolved a certain kind of tolerance to this synergist *per se* which would render it ineffective as a synergist. Like other methylenedioxyphenyl synergists, PB is an inhibitor as well as a substrate of microsomal oxidases (Casida 1970). Rapid excretion,

Table 14. Cross resistance patterns of a mixed field (PA), a regressed field (MD), a fenvalerate selected (FP) and a fenvalerate/PB selected (F/PB) strains of DBM[a]

Insecticide	PA	MD		FP		F/PB	
	LC_{50} (mg/ml)	LC_{50} (mg/ml)	RR[b]	LC_{50} (mg/ml)	RR	LC_{50} (mg/ml)	RR
Cypermethrin	0.68	0.107	0.16	>100	>147	>100	>147
Deltamethrin	1.02	0.922	0.90	>100	>98	>100	>98
Fenvalerate	5.36	0.830	0.16	>100	>19	>100	>19
Permethrin	0.64	0.070	0.11	>100	>156	>100	>156
Mevinphos	0.25	0.008	0.03	0.12	0.48	0.34	1.36
Profenofos	2.76	0.507	0.18	0.95	0.34	0.91	0.33
Prothiophos	7.91	0.493	0.06	1.80	0.23	2.54	0.32
Carbaryl	nd[c]	nd		nd		nd	
Carbofuran	nd	100		nd		nd	
Methomyl	nd	nd		nd		nd	

[a] Source: Chen and Sun (1986). [b] Resistance ratio = LC_{50} of MD, FP or F/PB strain/LC_{50} of PA strain. [c] Not determinable. No mortality was recorded at 100 mg/ml.

Table 15. Synergism of fenvalerate and permethrin by several compounds in a regressed field (MD), a fenvalerate selected (FP) and a fenvalerate/PB selected (F/PB) strains of DBM[a]

Treatment	MD		FP		F/PB	
	LC_{50} (μg/ml)	SR[b]	LC_{50} (mg/ml)	SR	LC_{50} (mg/ml)	SR
Fenvalerate	1294.0		>100		>100	
+ IBP[c]	794.0	1.63	>100	nc[d]	>100	nc
+ TBPT	914.0	1.42	>100	nc	>100	nc
+ TPP	1470.0	0.88	>100	nc	>100	nc
+ PB	108.0	11.98	5.43	>18.0	>100	nc
+ MGK 264	164.0	7.89	12.20	>8.2	9.21	>11.0
Permethrin	202.0		94.40		83.90	
+ IBP	111.0	1.82	77.20	1.2	75.10	1.1
+ TBPT	93.8	2.15	40.40	2.3	24.10	3.5
+ TPP	134.8	1.50	21.80	4.3	37.70	2.2
+ PB	15.9	12.70	6.63	14.2	58.60	1.4
+ MGK 264	32.6	6.20	9.65	9.8	7.30	11.5

[a] Source: Chen and Sun (1986). [b] Synergism ratio: LC_{50} unsynergized/LC_{50} synergized. [c] Larvae were sprayed with the synergist at maximal sublethal concentration one hour prior to insecticide treatment. The concentrations used are given in Table 17. [d] Not calculable.

Table 16. Toxicity of PB against a mixed field (PA), a regressed field (MD), a fenvalerate-selected (FP) and a fenvalerate /PB-selected (F/PB) strains of DBM[a]

Strain	LC_{50} (mg/ml)	RR[b]
PA	4.52	
MD	4.50	1.0
FP	11.7	2.6
F/PB	>100	>22

[a] Source: Chen and Sun (1986). [b] Resistance ratio = LC_{50} of each strain/LC_{50} of PA strain.

storage in certain tissues, and conjugation preceded by oxidation are possible causes for the tolerance to PB in this insect (Casida 1970, Yang 1976).

In addition, there is preliminary evidence indicating that DBM would gradually recover its susceptibility to the synergistic action of PB not long after the termination of its application.

Table 17. Concentrations of synergists used in bioassays for regressed field strain (MD), fenvalerate/PB selected strain(F/PB) and fenvalerate selected strain (FP)

Synergist	Concentration (mg/ml)		
	MD	F/PB	FP
PB	2.5	10.0	2.5
TBPT	1.0	2.5	2.5
TPP	10.0	10.0	10.0
IBP	5.0	10.0	10.0
MGK 264	5.0	5.0	5.0

Recommendations of the Use of Synergists, Pyrethroids, and Organophosphorus Insecticides

Our discussions may be summarized as follows:

1. Pyrethroid resistance would not decline rapidly after the application of this group of insecticides is terminated.
2. Organophosphorus resistance seems unstable and may be reduced quite rapidly and significantly once the selection pressure is removed.
3. Pyrethroid selected DBM does not seem to have cross resistance to some organophosphorus insecticides.
4. Synergist PB would temporarily arrest pyrethroid resistance.
5. DBM, to which PB has lost synergistic action on pyrethroids, may still respond to other synergists which block microsomal oxidases, such as MGK 264.
6. DBM seems gradually to regain its susceptibility to PB after the use of this synergist is terminated.
7. DBM resistance to conventional insecticides has little or no cross resistance to *B. thuringiensis* and to some chitin synthesis inhibitors such as IKI 7899 (Sun 1983, unpublished data).

In view of these findings, we make the following recommendations:

1. Use pyrethroids only when organophosphorus insecticides are no longer effective.
2. When pyrethroid resistance starts to show, shift to organophosphorus insecticides such as mevinphos, profenofos or prothiophos.
3. When these organophosphorus compounds begin to lose effectiveness, switch back to pyrethroids. Use piperonyl butoxide if necessary.
4. When piperonyl butoxide becomes ineffective, try to use organophosphorus compounds again.
5. Use pyrethroids to replace the organophosphorus compounds. Use other synergists such as MGK 264, if needed.
6. Try to use *B. thuringiensis* and some chitin synthesis inhibitiors such as IKI-7899, CME 134, or PH70-23, between the applications of organophosphorus compounds and

pyrethroids. Cartap, which has a mode of action different from that of phosphorus compounds or pyrethroids, may also be used.

We realize that these recommendations are based on only limited data, and thus we have reservations regarding their general applicability. The findings discussed above may also be used as the rationale in devising mixtures of insecticides for the control of DBM.

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Effects of Synergists on the Toxicity of Fenvalerate to Pyrethroid-Resistant Diamondback Moth

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Abstract

Synergism of fenvalerate with piperonyl butoxide (PB), NIA-16388 (NIA), S-421, and MGK-264 on both susceptible (S) and fenvalerate-selected (FS) strains of diamondback moth, *Plutella xylostella* L, were determined in laboratory tests. Further, combinations of fenvalerate and these synergists were tested for their efficacies against resistant strain under field conditions in the Cameron Highlands, Malaysia. Fenvalerate/PB showed higher synergism and efficacy than combinations of fenvalerate with other synergists against FS and pyrethroids-resistant strains in the field. A 1:3 ratio for fenvalerate and PB seemed to be optimal for the control of resistant diamondback moth. Combinations of fenvalerate with NIA, S-421 or MGK-264 showed slight synergism on the FS strain in the laboratory tests, whereas combinations with NIA and S-421 showed efficacy similar to that of combination with PB in the field test. S-strain of diamondback moth was selected by fenvalerate alone and in combination with PB. Selection by fenvalerate alone developed resistance, whereas selection by fenvalerate/PB resulted in a somewhat lower level of resistance. This suggests that fenvalerate/PB may be effective in preventing or retarding the diamondback moth from developing resistance.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), is an important pest of cruciferous crops in many parts of the world. This insect pest has been exposed mainly to organophosphorus insecticides over many years, and lately to pyrethroid insecticides. Recently, DBM strains resistant to pyrethroids have been found in some parts of the world, such as Malaysia (Ho et al 1983) and Taiwan (Liu et al 1981). As one of the countermeasures against the insecticide resistance problem, the use of synergists has been studied by Liu et al (1982, 1984) and Ho et al (1983). High efficacies of combinations of insecticides with synergists have been reported for the control of several insect species which have developed resistance to insecticides, such as *Musuca domestica* (Farnham 1973), *Culex pipiens fatigans* (Ranasinghe and Georghiou 1979), *Heliothis virescens* (Plapp 1979) and *Spodoptera littralis* (El-Sebae 1978, Riskallah 1984). *Heliothis virescens* (Plapp 1979) and *Spodoptera littralis* (El-Sebae et al 1978, Riskallah 1984).

The purpose of our studies was to evaluate the toxicity of fenvalerate with synergists to a susceptible strain, a fenvalerate-selected strain, and a multiple resistant strain of DBM which occurs in the field in Malaysia. Furthermore, the extent of resistance development was compared between selections using fenvalerate alone and in combination with piperonyl butoxicide.

Materials and Methods

Insects

Laboratory tests A susceptible (S) DBM strain reared in the laboratories of the Sumitomo Chemical Co Ltd was used. A fenvalerate-selected (FS) strain was obtained from the S-strain by selection at the 50% level of mortality with fenvalerate treatment over 30 consecutive generations. Insects were raised on radish seedlings. Third instar larvae were used for bioassay.

Field tests Testing was conducted in the field in the Cameron Highlands in Malaysia, where DBM has developed multiple resistance to organophosphorus and pyrethroid insecticides.

Fenvalerate and synergists Fenvalerate 10% EC was formulated by the Sumitomo Chemical Co Ltd. Technical grades of four synergists used were: piperonyl butoxcide (PB), NIA-16388 (NIA) (propylprop-2ynyl phenylphosphonate), MGK-264 (N-octyl bicycloheptene dicarboximide), and S-421 (octachlorodipropyl ether).

Bioassay

Laboratory tests Thirty 3rd instar larvae were dipped into a water solution of fenvalerate, alone or with a synergist (five times the amount of fenvalerate) for 20 seconds. After treatment the larvae were kept at $26 \pm 1°C$ in a plastic cup containing fresh radish seedlings. Mortality was recorded after 48 h. The results were analyzed by the probit method (Finney 1971) from the mortality adjusted by Abbott's formula (1925). LC_{50} values were obtained with a computer program.

Field tests Insecticide application: The tests were conducted at a cabbage farm in the Cameron Highlands in Malaysia in August 1984. Each plot consisted of 20 plants (10 sq m) and each treatment was duplicated. Sprays were made at the rate of 1000 l/ha with a knapsack sprayer. Insecticides were sprayed on 14, 16, and 18 August 1984.

Observations Five plants per plot were selected for the observation, and the numbers of living larvae were counted. Observations were recorded at two days after each spray.

The efficacy was calculated by the following equation

$$\% \text{ Efficacy} = \left(1 - \frac{Cb \times Ta}{Tb \times Ca}\right) \times 100$$

where Cb = number of larvae on untreated check before treatment, Ca = number of larvae on untreated check after treatment, Tb = number of larvae on treated plot before treatment, Ta = number of larvae on treated plot after treatment.

Selections Comparative development of insecticide resistance of DBM between selections made by fenvalerate alone and by fenvalerate in combination with PB were made during 40 consecutive generations. Each time, 1000 3rd instar larvae held in net sacks with radish seedlings were dipped into a 100 ppm concentration of PB for 20 seconds one hour prior to the application of the prescribed concentrations of fenvalerate. Concentrations of fenvalerate for each generation were determined by aiming at approximately 50% larval mortality. Bioassays were carried out once every two or three generations.

Results and Discussion

For the fenvalerate selected (FS) strain of DBM obvious synergistic effects were observed except with S-421 at a ratio of 1:5 (fenvalerate:synergist) (Table 1). PB was the most effective synergist. However, fenvalerate was poorly synergised by PB with the susceptible (S) strain.

Table 1. The effects of synergists on the toxicity of fenvalerate to susceptible (S) and fenvalerate-selected (FS) strains of DBM

Insecticide	LC_{50} (ppm)	S.R.[a]
S-strain		
fenvalerate alone	0.68	
+ PB (1:5)	0.09	7.6
FS-strain		
fenvalerate alone	26.6	
+ PB (1:5)	0.77	34.5
+ NIA (1:5)	2.8	9.5
+ S-421 (1:5)	12.4	2.1
+ MGK-264 (1:5)	4.8	5.5

[a] Synergistic ratio = LC_{50} value of fenvalerate alone/LC_{50} value of fenvalerate + synergist.

It is generally recognized that PB produces its synergistic effect by inhibition of mixed-function oxidases enzymes in the insect body (Casida 1970). Therefore, it is assumed that on increase of the enzyme may be a key factor as the mechanism of resistance in the FS-strain.

Further experiments were conducted to observe the efficacies of fenvalerate combined with each of four synergists for the field strain of DBM in the Cameron Highlands, Malaysia. In this area, vegetables are grown throughout the year, and insecticides have been applied extensively over the past several years. The insect has developed high levels of resistance to several insecticides. A 200 ppm fenvalerate spray gave only 54% control in the field test. However, a fenvalerate/PB combination (1:3) gave 90% control (Figure 1). Combinations of fenvalerate and each of NIA, S-421 or MGK-264, which had provided slight synergism to the FS-strain in laboratory tests (Table 1), showed greater efficacy in field tests, especially NIA and S-421 which gave nearly the same level of control as PB did. The fenvalerate/NIA combination was phytotoxic at a concentration of 200/600 ppm in this test. The high synergism of fenvalerate with S-421 may be caused by S-421 alone, because S-421 itself is toxic to insects. From the above results, PB and S-421 appear to be suitable for combination with fenvalerate for the control of pyrethroid-resistant DBM.

Figure 2 shows the prograession of development of resistance in DBM strains selected by fenvalerate alone and by fenvalerate/PB. Up to 10th generation of both selections, the mean LC_{50} values of fenvalerate were stable at levels of 0.7 ± 0.2 ppm in both strains. A 17-fold increase in fenvalerate resistance occurred in the strain selected by fenvalerate/PB after the 25th generation, whereas in the strain selected by fenvalerate alone the increase was 63-fold. From the 30th to 40th generation, the resistance levels in both strains did not change significantly, which indicated that the resistance had reached a maximum plateau. The strain selected by fenvalerate/PB attained a lower level of resistance compared to the strain selected by fenvalerate only. PB, which inhibits mixed-function oxidases enzymes, leads to the development of resistance at a much lower level than could be accomplished by fenvalerate alone.

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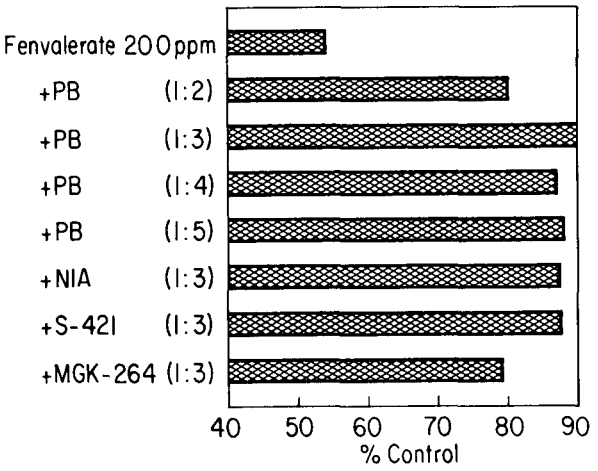

Figure 1.
The efficacies of fenvalerate alone and in combination with synergists to diamondback moth. (Cameron Highlands, Malaysia, 1984)

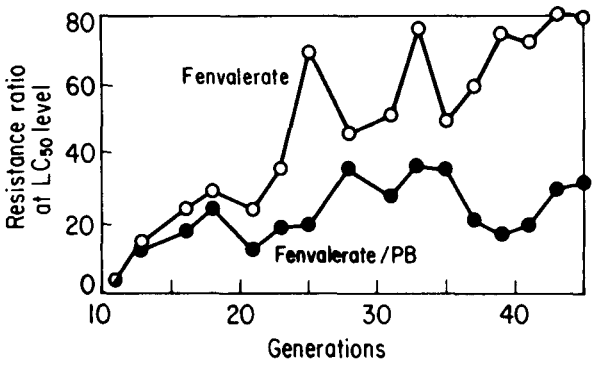

Figure 2.
Development of fenvalerate resistance to selected strains of diamondback moth by fenvalerate alone and in combination with PB

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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).

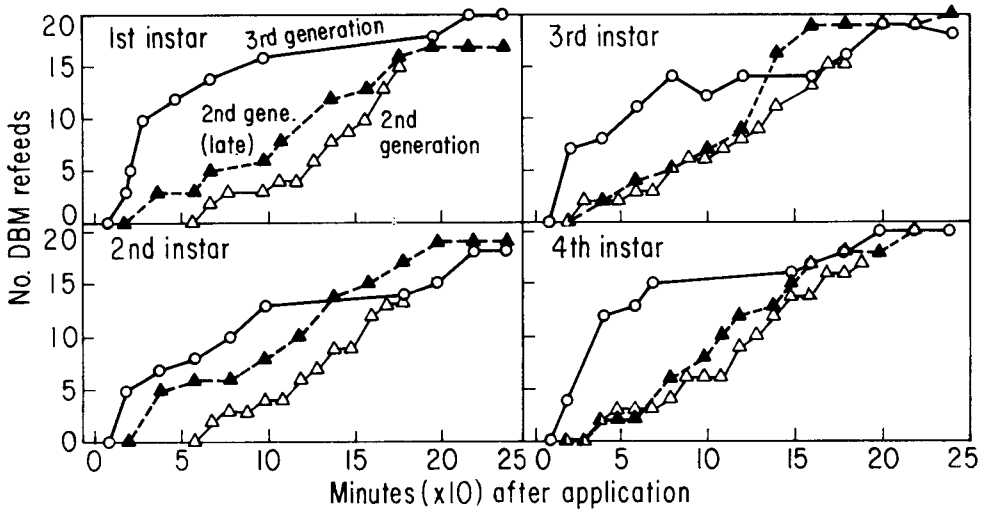

Figure 1. Feeding inhibition period of different larval instars in response to application of deltamethrin at 12.5 g AI/ha

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

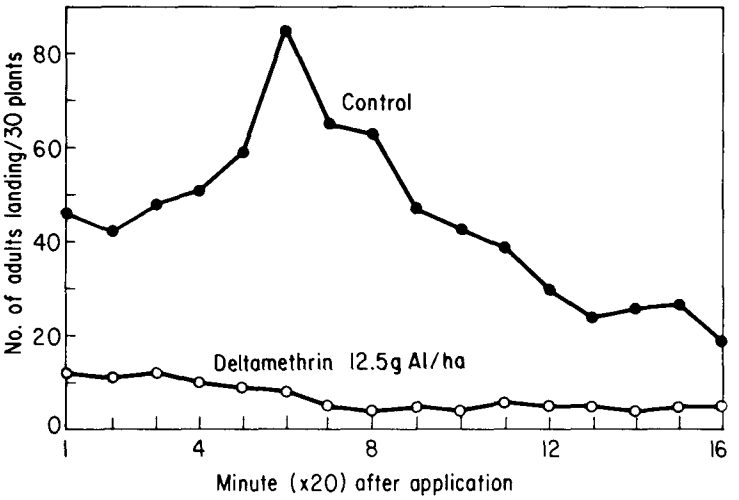

Figure 2. Influence of deltamethrin application on landing of DBM adults on treated and untreated plants

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).

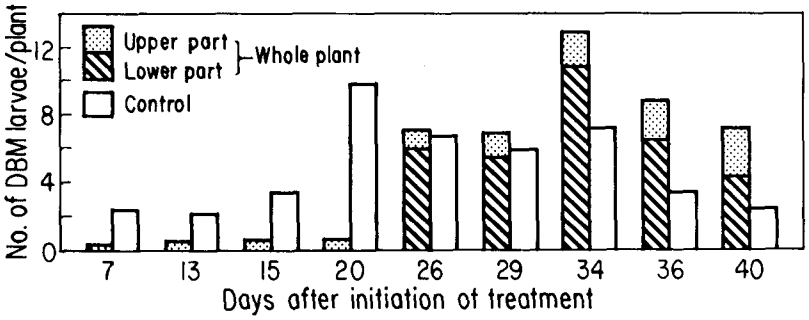

Figure 3. Distribution of DBM larvae in upper and lower parts of deltamethrin treated plants

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.

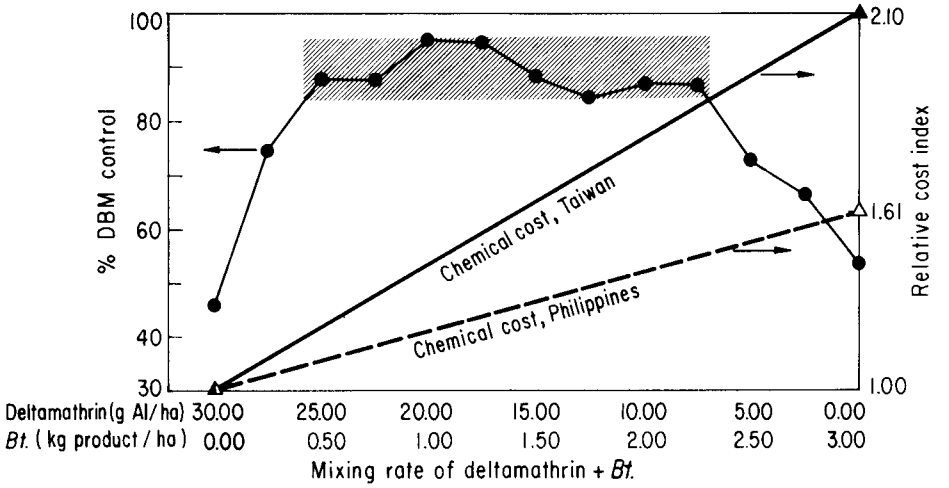

Figure 4. DBM control and relative insecticide cost at various combinations of deltamethrin and *Bt* in Taiwan and the Philippines. The percent DBM control points in shaded area are not significantly different at 5% level according to Duncan's multiple range test

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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Factors Inducing Resurgence in the Diamondback Moth After Application of Methomyl

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Abstract

Applications of sublethal concentrations of methomyl to 4th instar larvae and pupae of the diamondback moth resulted in increased fecundity of the adults which emerged. The adult females derived from the treated pupae laid more eggs with a higher rate of fertilization as compared with the untreated check. However, the adult females thus treated had a shorter life span than the untreated ones. These effects of methomyl enhanced the intrinsic rate of natural increase (r) or the finite rate of increase per month (λ). Applications of methomyl decreased lycosid spiders which were important predators of 3rd to 4th instar larvae of the diamondback moth in the cabbage fields. It is suggested that the application of methomyl might cause a resurgence of the moth population through the stimulation of the reproductive potential and differential mortality between predators and prey.

Introduction

The major caterpillar pests of crucifers in Japan are common cabbageworm, *Pieris rapae crucivora* Boisduval (Lepidoptera: Pieridae), diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), and beet semi-looper, *Autographa nigrisigna* (Walker) (Lepidoptera: Noctuidae). Insecticides are the most commonly used control agents against these pests in Japan.

In 1981, at Saitama Horticultural Experiment Station (SHES), DBM became abundant after applications of methomyl against common cabbageworm in the cauliflower field but not in the untreated field (Figure 1). Ripper (1956), who reviewed resurgences of pest populations after insecticide treatment, suggested the following as the causes for insect pest resurgence: (a) reduction of natural enemies along with the pest by pesticides, (b) favorable influence of pesticides on phytophagous arthropods (stimulating influence on the pest directly or via the plant), and (c) the removal of competitive species.

This paper describes results of two experiments conducted to analyze the process of DBM resurgence. In the first experiment direct stimulation of methomyl on the reproductive potential was examined and in the second, predators of DBM were identified and the toxicity of methomyl against on these predators evaluated.

Stimulation of Reproductive Potential

Larval treatment with methomyl

Effects of sublethal concentrations of methomyl applied to 4th instar larvae on the fecundity of DBM are shown in Table 1. The adult females derived from the treated larvae deposited more eggs than the control irrespective of concentrations of methomyl.

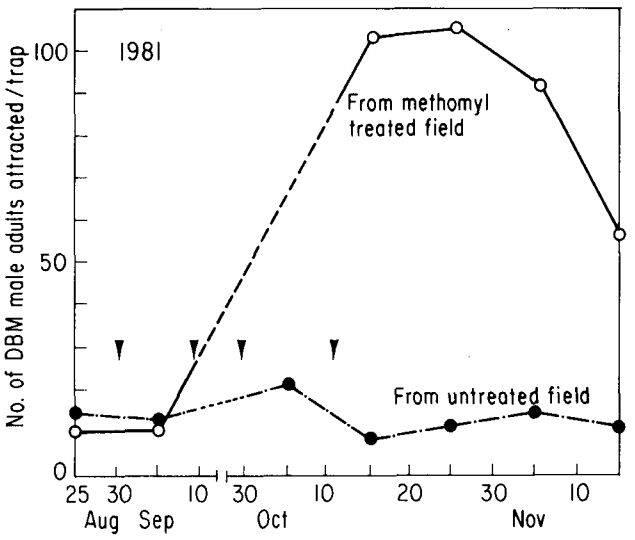

Figure 1.
Effects of methomyl treatments on the diamondback moth populations captured in pheromone traps from cauliflower fields of SHES. Three dry type traps (made by Takeda Chemical Ind Ltd) baited with "Px" (a synthetic sex pheromone for *P. xylostella*, which is a mixture of 0.05 mg of (Z)-11 hexadecenal with 0.05 mg of (Z)-11 hexadecenyl acetate and 0.001 mg of (Z)-11 hexadecenol) were arranged in each field. ▼: date of treatment

Table 1. Effects of the treatment of the fourth instar larvae with sublethal concentrations of methomyl on the fecundity of DBM

Methomyl concentrations (ppm)	No. eggs laid[ab]		No. examined
	per female	per mg of pupal weight[c]	
100	180.0 ± 44.8[d] (1.49)*	42.8 ± 8.0 (1.40)**	4
50	139.5 ± 16.7 (1.15)*	36.3 ± 2.1 (1.19)**	6
10	157.2 ± 18.4 (1.30)*	38.0 ± 3.3 (1.25)**	6
Control	121.2 ± 25.2	30.5 ± 6.4	6

[a] Figures in parentheses indicate the rate of relative increase as compared with control. [b] Figures with asterisks differ significantly from control at 5% level (*) and 1% level (**) by t-test. [c] No. eggs deposited per mg of fresh body weight of pupa. [d] Mean ± standard deviation.

In particular, at concentrations of 10 and 100 ppm, methomyl significantly increased reproduction. A 49% increase in the number of eggs per female was observed at 100 ppm followed by 30% at 10 ppm and 15% at 50 ppm. Based on pupal weight differences were highly significant.

Pupal treatment with methomyl

Dipping pupae (5.5 to 6.5 mg/each) in sublethal concentrations of methomyl resulted in increased fecundity of the adults. The adult females derived from these treated pupae laid more eggs with higher rates of fertilization, as compared with the untreated ones, irrespective of the concentrations of methomyl (Table 2). At 10 ppm, there was a 17% increase in number of eggs per female followed by a 12% increase at 100 ppm, a 10% increase at 500 ppm, and an 8% increase at 50 ppm. The number of fertilized eggs per female increased 1.3 times at 10 ppm and 1.15 times at 500 ppm compared to the untreated ones. The number of fertilized eggs per female per day increased 1.68 times at 10 ppm and 1.33 times at 500 ppm. The percentage of fertilized eggs also increased by methomyl treatment as compared to the untreated check. However, the adult females thus treated had a shorter life span than the untreated ones (Table 2).

Table 2. Longevity and fecundity of female DBM adults treated with methomyl in pupal stage

	Control	Methomyl concentrations (ppm)			
		10	50	100	500
No. of pairs examined	10	7	13	13	11
Adult emergence (%)	98.3	100	95.5	98.5	97.0
Longevity of female adults (days)	7.7 ± 1.1[a]	6.1 ± 0.7	6.5 ± 0.7	6.7 ± 1.2	7.1 ± 2.0
Oviposition period (days)	5.1 ± 0.9	4.4 ± 1.0	4.6 ± 0.7	4.6 ± 1.0	5.6 ± 2.0
Fecundity (eggs/female)	164.2 ± 37.9	191.9 ± 44.4 (1.17)[b]	176.9 ± 28.4 (1.08)	183.2 ± 40.2 (1.12)	180.6 ± 41.4 (1.10)
No. of eggs/female/day	24.9 ± 6.6	37.5 ± 8.3	32.3 ± 6.1	33.0 ± 8.1	31.9 ± 11.7
No. of fertilized eggs/female	139.3 ± 37.0	182.0 ± 43.3 (1.31)	170.1 ± 28.2 (1.22)	175.1 ± 35.3 (1.26)	160.6 ± 37.2 (1.15)
No. of fertilized eggs/female/day	21.2 ± 6.5	35.7 ± 8.4 (1.68)	31.1 ± 6.1 (1.47)	31.6 ± 7.4 (1.49)	28.3 ± 9.9 (1.33)
Fertilized eggs (%)	84.4	94.7	96.2	95.6	88.9

[a] Mean ± standard deviation. [b] Figures in the parentheses indicate the rate of relative increase as compared to the control.

Figure 2 shows survivorship and oviposition curves of female adults treated with methomyl in the pupal stage. The adults derived from the treated pupae deposited greater numbers of eggs for the first two days than the untreated ones. Figure 3 shows a typical comparison of cumulative oviposition curves between control and treated individuals at 10 ppm of methomyl in the pupal stage. The treated females laid not only more eggs but also a greater proportion of fertilized eggs as compared with the check.

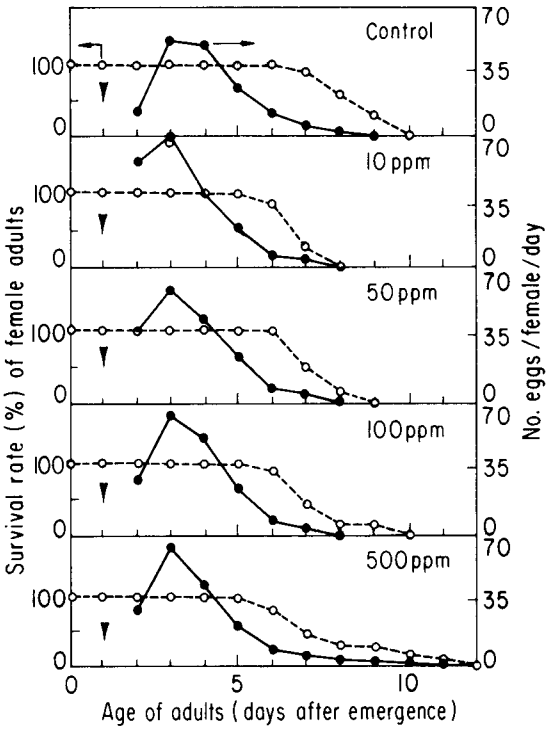

Figure 2.
Survival and oviposition curves of female adults treated with different concentrations of methomyl in the pupal stage. ▼: pairing

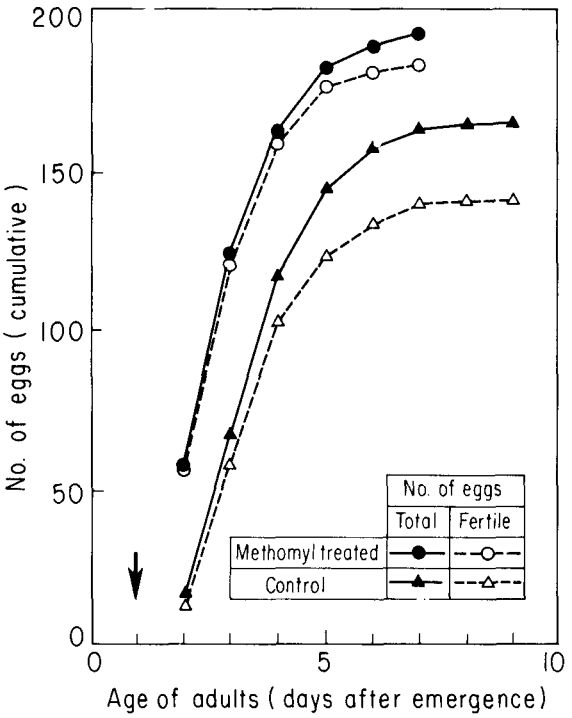

Figure 3.
Comparison of cumulative oviposition curves between untreated and methomyl treated individuals. ▼: pairing

Rate of population increase

We obtained a survival rate (lx (E-L)) value of 0.45 from egg to pupa by rearing the insects on radish *Raphanus sativus* (L) seedlings in the laboratory. Substituting the values of 0.5 for sex ratio, age-specific survival rate (lx) is expressed by the following equation (Nemoto et al 1984):

$$lx = lx(\text{E-L}) \times (\text{sex ratio}) \times lx(\text{P}) \times lx(\text{A})$$
$$= 0.225 \times lx(\text{P}) \times lx(\text{A})$$

where lx(P) is the rate of adult emergence and lx(A) is the age-specific survival rate of female adults.

The value of r (intrinsic rate of natural increase) was estimated by using the age-specific survival rate and fecundity tables based on the equation given by Birch (1948):

$$R_0 \simeq \Sigma (l_x\ m_x)$$
$$T \simeq \frac{\Sigma x\ l_x\ m_x}{\Sigma l_x\ m_x}$$
$$r \simeq \text{Ln}\ R_0 / T$$
$$\lambda = e^{30r}$$

where R_0 is net reproductive rate, m_x is age-specific fecundity, x is age (days), T is mean generation time and λ is finite rate of natural increase after 30 days.

The population doubling time under given conditions can be calculated as:

$$\text{doubling time} = \frac{\log_e 2}{r}$$

The population parameters of DBM treated with methomyl in the pupal stage were calculated by using the number of fertilized eggs shown in Table 2. The values of T for the treated ones were smaller than in the untreated check (Table 3). Also, the values of R_o increased as compared with the untreated check. As a result there was an increase in the value of r by 6% to 13% in the treated one. Consequently the values of λ (after 30 days) increased 2.03, 1.59, 1.63, and 1.37 times for 10, 50, 100, and 500 ppm methomyl, respectively.

Table 3. Population parameters of DBM treated with different concentrations of methomyl in the pupal stage

	Control	Methomyl concentrations (ppm)[a]			
		10	50	100	500
Mean length of one generation (T) (days)	18.42	17.71	17.85	17.95	18.10
Net reproductive rate (R_o)/female	30.81	40.95 (1.33)	36.55 (1.19)	37.78 (1.23)	35.06 (1.14)
Intrinsic rate of natural increase (r)/female/day	0.186	0.210 (1.13)	0.202 (1.08)	0.202 (1.09)	0.197 (1.06)
Finite rate of increase (λ)/month	265.75	538.46 (2.03)	423.39 (1.59)	432.38 (1.63)	364.02 (1.37)
Doubling time (days)	3.73	3.31	3.44	3.43	3.53

[a] Figures in the parentheses indicate the rate of relative increase as compared with control.

Effectiveness of Predators as Biotic Mortality Agents

Identification of DBM predators

Many species of predatory arthropods are collected by pitfall traps in the cabbage field in SHES (Table 4). In order to identify the predators of DBM, we used an immunological test. This method was sensitive enough to detect the whole-body extracts of 3rd to 4th instar larvae, pupae, and adults of DBM (Nemoto et al 1985). Field-collected lycosid spiders exhibited a positive reaction in the test, as did some *Misumenops tricuspidatus* (Feb) (Aranea: Thomisidae) (Figure 4). But few of *Labidura riparia japonica* (de Hann) (Dermaptera: Labiduridae) reacted positively and neither did any other suspected predators.

Around 10% of the lycosids collected in July showed a positive reaction. No individuals showed a positive reaction in August when the density of DBM larvae was low (Table 5).

Effect of methomyl on predator population

The effect of methomyl on predator populations was studied in the cabbage field. The numbers of lycosid spiders, particularly *Pardosa astrigera* L Koch and *Lycosa pseudannulata* (Bos et Str), were reduced by the applications of methomyl but certain predatory insects were not affected (Figure 5).

Table 4. Predatory arthropods captured from the cabbage fields at SHES

Family	Species
ARANEA	
Atypidae	*Atypus karschi* Donitz
Micryphantidae	*Gnathnarium deutatum* (Wider)
Tetragnathidae	*Dyschiriognatha quadrimaculata* Bos et Str
Hahniidae	*Hahnia corticicola* Bos et Str
Lycosidae	*Arctosa subamylacea* (Bos et Str)
	Lycosa pseudoannulata (Bos et Str)
	Pardosa laura Karsch
	Pardosa astrigera L Koch
Thomisidae	*Misumenops tricuspidatus* (Feb)
Salticidae	Gen et sp
Gnaphosidae	*Gnaphosa kompirensis* (Bos et Str)
Ctenidae	*Anahita fauna* Karsch
DERMAPTERA	
Labiduridae	*Labidura riparia japonica* (de Hann)
COLEOPTERA	
Harpalidae	*Epomis nigricans* Wiedemann
	Chlaenius sp Gen et sp
Cicindelidae	*Cicindela japana* Thunberg

Table 5. Record of lycosid spiders captured in pitfall traps in the cabbage field at SHES and level of their predation[a]

Date of collection	July 1983		Aug. 1983	
	8 to 12	22 to 26	5 to 9	19 to 23
No. of individuals tested[b, c]	25	27	28	6
Positive reaction (%)	8.0	11.1	0	0

[a] Micro-Ouchterlony precipitation test. [b] No. of spiders/30 pitfall traps. [c] Traped spiders were collected every day.

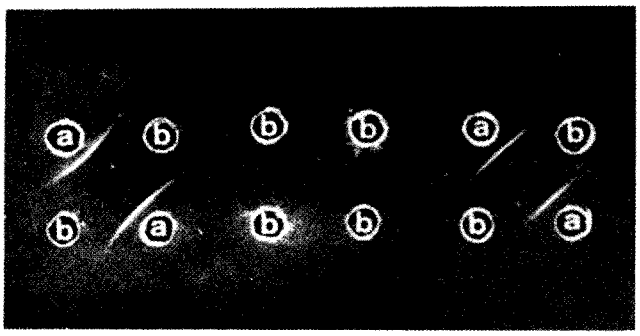

Figure 4. Precipitation test (Micro-Ouchterlony method) with anti-DBM serum against extract of *Pardosa astrigera* L Koch. The anti-DBM serum was placed in the central well and the extracts of *P. astrigera* diluted with saline was placed in the wells around the center. a: feeding on DBM, b: control

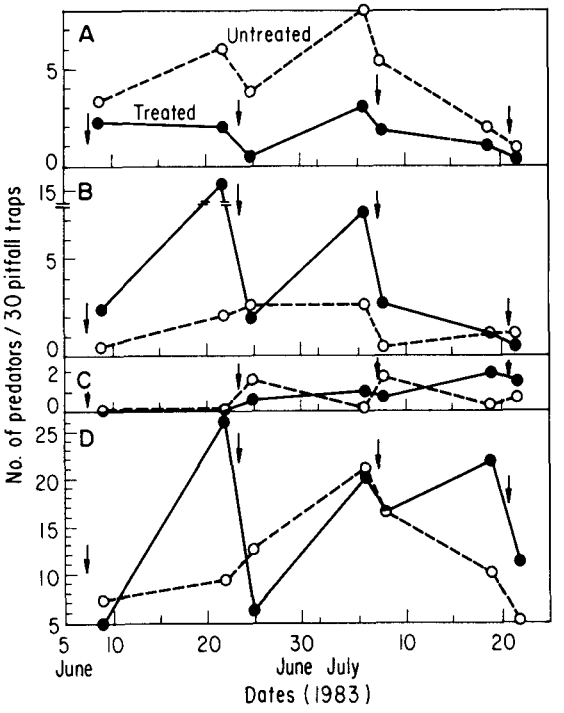

Figure 5.
Effect of methomyl treatments on predatory arthropod populations captured in pitfall traps from cabbage field in SHES. ▼: date of treatment, A: lycosid spiders, B: *Cicindela japana*, C: Harpalidae, D: *Labidura riparia japonics*.

Susceptibility of DBM and *Pardosa astrigera* to methomyl

P. astrigera is the most common lycosid in the cabbage field. The LC_{50} value of methomyl was greater to DBM larvae than to *P. astrigera* (Figure 6). The LC_{50} to lycosids was around 10 ppm as against about 7500 ppm for 4th instar DBM larvae using the dipping method and about 20,000 ppm for 3rd instar larvae by feeding methomyl-contaminated cabbage leaves. Methomyl is generally sprayed at 450 ppm to control crucifer pests.

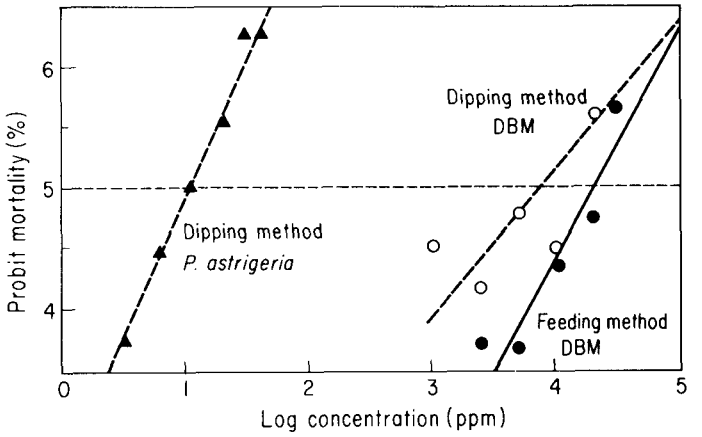

Figure 6. Concentration-mortality curve of methomyl for the spider, *Pardosa astrigera* and DBM.

Discussion

One of Ripper's hypotheses (1956) that insecticide treatment directly stimulates reproductive potential of insects was supported by our data with DBM. It is apparent that several factors such as larval and pupal survival rate, adult longevity, oviposition period, and fecundity affected the intrinsic rate of natural increase (r). Results of our precipitation test showed that lycosid spiders played an important role as a biotic mortality agent of 3rd to 4th instar larvae of DBM. These predators were also more susceptible to methomyl than the DBM larvae.

Resurgense of DBM is indeed induced by application of methomyl in the cabbage fields. This is due in part to stimulation of reproductive potential of DBM and also to differential mortality between predators and DBM larvae. The involvement of additional factors contributing to resurgence and the relative importance of these factors in the induction of resurgence of DBM needs to be investigated.

Acknowledgement I am indebted to K. Kiritani, Division Head, National Institute of Agro-Environmental Sciences, for his valuable suggestions during the course of this work and for critical reading of the manuscript. My thanks are also due to Y. Sekijima, Professor, Saitama College of Health, for his helpful advice on immunological method. I am especially grateful to S. Shibukawa, section chief and H. Udagawa, Director, SHES, for their encouragement.

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Discussion

E. D. MAGALLONA: I find your results with mevinphos interesting because it agrees with our own work in the Philippines. Based on your results would you suggest that mevinphos be used as a reference material in DBM resistance studies.
E. Y. CHENG: Yes, but one must standardize the test condition because different insecticides show different initial and residual effect. Mevinphos will be a good standard for short spray interval tests.

N. S. TALEKAR: Is the existence of susceptible strain in I- lan due to less pesticide use there?
E. Y. CHENG: Yes, the I-lan area has high annual precipitation which reduces the persistence of pesticide residues on the treated plants. This in turn reduces the insecticide selection pressure.

H. CHI: In general, the relationship between cv and sample size is dependent on population density and distribution pattern. However, you concluded that a sample size of 5 gives about 10% cv disregarding population density. Any comment?
E. Y. CHENG: We did not disregard the population density factor. We established insecticide resistance information for 16 locations in one area as the sample population and found that by sampling five of them we could get a cv of about 10%. It is a practical way to reduce the sample size to save time and labor, and still get information accurate enough to reflect field condition.

H. CHI: Based on findings of your experiments in the laboratory, have you conducted any experiments at specific locations where DBM has developed resistance to insecticides? If so what are your results?
E. Y. CHENG: Most of our field study was carried out in TARI's farm which is located in Taichung. The DBM population in this area is resistant to most insecticides. Generally, our laboratory finding fit very well with the test of DBM resistance on our farm.

A. SAGENMUELLER: In your conclusions you are recommending alternative spraying of products with different modes of action. The sequence may be quite complicated in practice. Does it mean that mixtures of these compounds are less suitable to avoid or reduce the probability of resistance build-up?
C. N. SUN: Our recommendations are not that complicated once the principles are grasped. I even think they are quite suitable for 'package deal'. We have no data regarding the use of mixtures and resistance development.

B. MORALLO-REJESUS: What is the explanation for the effectiveness of MGK-264 against fenvalerate/piperonyl butoxide (PB) resistant DBM?
C. N. SUN: As a microsomal oxidase inhibitor, MGK 264 has different chemical structure from that of PB, a methylenedioxyphenyl compound. We assume that DBM selected with fenvalerate/PB develops a resistance to PB (and possibly other methylenedioxyphenyl compounds). Fortunately, DBM seems to retain its response to the synergistic action of MGK-264, and hopefully of other types of microsomal oxidase inhibitors.

B. ROWELL: You seem to have made a strong recommendation that we should use organophosphorus insecticides until they lose effectiveness. Is this not recommending the same old course that has been followed during the past 10 to 15 years? Would you still recommend these chemicals where parasitoids are important and in the light of safety hazards to the applicators?
C. N. SUN: Our recommendations are based solely on considerations of resistance development. It is definitely important than an integrated approach be made.

H. GLASS: You said that DBM has 'little or no resistance to IGRs'. What does little resistance mean?
C. N. SUN: Our limited data show that some IGRs, such as IKI- 7899, are effective against both susceptible and field resistant strains of DBM. But it is still more effective against the susceptible strain. CME 134 is also very effective according to what I saw in the AVRDC farm during yesterday's field trip.

N. S. TALEKAR: Is there any health hazard associated with the use of PB in the field?
C. N. SUN: PB was reported to be cocarcinogenic in mice (Epstein et al. 1967. Nature 214:526-528). But I am not aware of any serious concerns regarding any possible health hazards.

G. S. LIM: The suggested rotation and change of insecticides for overcoming some of the insecticide resistance problems certainly looks very reasonable. However, in your presentation you do not put any indicative value on the degree of the resistance that may be used as a guide for making the relevant decision of change. Do you have any suggestions for such values?
C. N. SUN: It is quite easy to detect the onset of resistance in the laboratory. However, it is not so easy to make observations in the field. Our data show that one to two generations of selection with pyrethroid fenvalerate are sufficient to lower the effectiveness significantly. So, one may have to shift right away to organophosphorus compounds before actually observing the failure of the third spray. It takes six to eight generations of selection with pyrethroid/PB before an apparent decrease of effectiveness of this combination appears in the laboratory. Subsequently, this combination may be applied for a longer period of time in the field. I have to remind you again that the validity of our recommendations has not been tested in the field. And we would like to know the outcome of such a test in case anyone would like to try.

G. S. LIM: Different authors use different susceptible strains such as French strain, I-lan strain, Penghu strain, Japan strain of DBM for base comparison. Is it necessary to standardize the susceptible strain? What are the advantages of such exercise? How should we go about doing it?
C. N. SUN: It is helpful in the study of resistance mechanisms to have a standard susceptible strain of DBM, like the NAIDM strain for housefly work. On the other hand, it is not a bad thing to retain a few (not too many) susceptible strains from locations quite apart from one another. They may have unique genetic make-up with regard to their responses to insecticides.
T. MIYATA: If we have a standard susceptible strain, it is very easy for us to compare the data obtained at different locations. But the problem is how we can get a standard susceptible strain. If you compare the susceptibility of susceptible strains used by different institutions, you can find some differences. Another problem which would be solved is the plant quarantine one. Even if we do not have a standard susceptible strain, if the strain is susceptible to certain insecticides, we can use it as a susceptible one.

E. Y. CHENG: I agree with you that it would be most desirable to have standard susceptible strain for all studies. The advantage will be an easy comparison of research results from different labs. I really do not know how to have everybody to cooperate on this, but cooperation is essential in selecting a standard strain.

N. WILDING: Dr. Cheng stated that there was crossresistance between organophosphorus and synthetic pyrethroids; Dr. Sun that there was not. Of course, different labs obtain different results but this seems to be a very fundamental point. Has anyone else any relevant information?
C. N. SUN: I think this inconsistency of results is inevitable when the study of DBM resistance is so scanty. Think of studies of housefly resistance that started only a couple years after the second World War. This insect deserves more attention from the research than it has received.
T. MIYATA: In Japan, Miyata et al (1982), Noppun et al (1983) and Hama (1984) reported that there was no crossresistance between organophosphorus insecticides and synthetic pyrethroids. Crossresistance is recognized in two different ways. In a narrow sense, the same gene(s) controls resistance for different chemicals. In a wide sense, crossresistance is a phenomenon obtained only from mortality data. In some cases the crossresistance may not be controlled by the same gene(s). When only one major gene is responsible for crossresistance, we may get the same results from different strains. However, when different genes are responsible for crossresistance, it is easy to understand that we get different results from different strains. Resistance is thought to be an evolutionary phenomenon; different strains with a different history of insecticide treatment may show different phenomena of crossresistance. Unfortunately we have no information about the genes responsible for resistance.
E. Y. CHENG: We stated that crossresistance exists between synthetic pyrethroids and some organophosphorus, but it is not a general phenomenon. We do believe that more research effort is needed in this aspect. We have also doubts about the crossresistance between synthetic pyrethroids and carbamates, although both were detoxified mainly by mixed function oxidase. There is certain specificity in MFO to detoxify different carbamates; for example, I-lan strain DBM is highly susceptible to synthetic pyrethroids and carbofuran but is rather insensitive to carbaryl.
M. SAKAI: Few cases of resistance development have been found for cartap in spite of its wide use in Japan. On the other hand, quite rapid resistance development has been reported in tropical countries. Probably the difference in the speed of resistance development between different regions depends on the type of insecticides and duration of their use before the introduction of newer chemicals. Further studies on genetics and on the biochemistry of DBM insecticide resistance should be conducted to clarify the aspects of the resistance.

S. A. RAHMAN: In toxicity and resistance studies different workers use different methods. I would like to know which method is most suitable and whether it is possible to agree upon a standard bioassay method.
E. Y. CHENG: I do not think it is necessary. The bioassay method to be used should depend on what the final objective of the study is. In a practical field study, commercial grade pesticides diluted in water as test spray will provide you much more direct information than the insecticide/acetone solution in the topical application method. In the resistance mechanism study, the situation is different.
C. N. SUN: I think FAO proposed topical application as the standard bioassay method for DBM. We have been routinely using spraying, and lately have also tried the residual film (on glass surface) method. Results from the two methods on pyrethroids are well correlated. Topical application requires CO_2 anesthetization or lowering of

temperature. We have found the residual film method suitable to observe the knockdown effect of pyrethroids against DBM. But with compounds of different properties, they may not apply. For instance, to test IGRs will require a different bioassay method.
Y. I CHU (COMMENT): I-lan county of Taiwan is a special area from the point of view of insect distribution. We observed this in the case of brown planthopper. It is possible that there is a separate DBM strain.
C. N. SUN: Here the definition of strain is rather dubious. But I am in no position to discuss that. It has generally been believed that less insecticides have been used in the I- lan area, for the control of DBM, brown planthopper and possibly other insect pests. But there is no actual data (record of insecticide usage) to support this statement.
E. Y. CHENG: We used the I-lan strain as the native susceptible strain for all the resistance simultion study. We have obtained satisfactory results in terms of selection of strain resistant to organophosphorus insecticides. But we are not yet successful in the case of synthetic pyrethroids. The reason for this is not clear so far.

R. S. REJESUS: What is your prediction or speculation regarding DBM developing resistance to *Bt*?
C. N. SUN: Devriendt and Martouret (1976. Entomophaga 21:189- 199) reported that selection for 10 generations of the 4th instars of DBM did not result in significant resistance to *Bt*. However, I tend to think that if *Bt* were used on a scale comparable to that of the synthetic insecticides, DBM might become just as resistant.

H. T. FENG: For the practical purposes of DBM control in the field, comparing the susceptibility of a strain with a specific dose is more appropriate than the use of RF values to clarify the impact of resistance on the effectiveness of an insecticide. Any comment?
C. N. SUN: A laboratory test including the construction of a concentration-mortality curve is meant to give a more accurate estimation of the susceptibility of a certain population. Using only one dose to compare the susceptibility inherently is subject to much greater error. One, of course, should be constantly aware of the limitations of applying laboratory data to the field.
T. MIYATA: As a initial step to monitor the existence of resistance, to use a specific dose will be helpful. But to get more information about the resistance, more detailed toxicity tests are required.
E. Y. CHENG: It has always been our point of view. For susceptibility test we usually use formulated insecticides, diluted in water at different concentrations. This provides not only the information on resistance, but also on the effective dosages for field practice.

N. S. TALEKAR: Despite the widespread use of cartap, DBM doesnot seem to have developed strong resistance to it. What are the reasons?
C. N. SUN: Since the chemical structure of cartap is quite unique and its mode of action is different from that of conventional insecticides, the insect may have to muster up additional weapons from its arsenal to cope with it. Our work indicates about 200-fold difference in cartap susceptibility between the FS strain and the resistant BC strain. Besides, the usage of cartap in the field is hardly comparable to that of OP, and pyrethroids. Consequently, the selection pressure of cartap has been much less.
M. SAKAI: Yes, in Japan, despite widespread use of cartap the level of resistance in DBM to cartap is insignificant. We have data on cartap selection studies with *Chilo suppressalis*, which showed a resistance factor of only 1.2 to 1.3. My hypothesis to explain this is as follows: insects poisoned by cartap can revive if they are in favorable conditions for survival. In the field poisoned insects are exposed to unfavorable circumstances and die. Even susceptible strains probably have an enzymatic detoxication mechanism, but

have little room to develop resistance after cartap poisoning in the field because of their rapid death.

S. A. RAHMAN: Since DBM has developed resistance to commonly used insecticides, I would like to know from chemical industry as to what will be their approach. Will it be IGRs or new pyrethroids or just follow Dr. Sun's recommendations of rotating the compounds?
P. WEBER: What kind of strategy should the chemical industry adopt with respect to DBM control? It is not easy to give a general answer. It depends on the range of products a company has to offer. At present IGR compounds are gaining popularity with vegetable farmers. However, continuous use of these compounds may not be the right strategy. It would be desirable if we could include them in a spray rotation with conventional chemicals some of which are still effective, but use of them alone will lead to the inevitable development of resistance. Rotation will delay development of resistance to IGR as well as conventional chemicals.

A. SIVAPRAGASAM: What do you mean by percent control?
R. YEH: The percent control shown in my slides is adjusted from the number of live insects before and after application of the target chemical and is computed by the Henderson and Tilton Formula.
J. L. LIM (COMMENT): Mr. Sivagaprasam brought up the subject of percent control. Results expressed as percent control are relative, they are only ratios. For example: one larva on a treated plot and 10 on a check plot is 90% control; 10 larvae on a treated plot and 100 on a check plot is also 90% control; 0.1 larvae on a treated plot and one on a check plot also 90% control. Thus unless the data expressed in this form is supported by damage rating and yield, it would appears to be rather meaningless in field trials.

M. SAKAI: How effective is deltamethrin + *Bt* combination against insecticide resistant DBM?
R. YEH: After continuous applications of deltamethrin + *Bt*, the DBM populaton is still there but it is less than on untreated plants and most of them, I would say more than 90%, are restricted to the lower part and unproductive leaves.

S. SUDARWOHADI: Your conclusion does not indicate the type of synergistic effect of deltamethrin and *Bt*. You used much higher rates of deltamethrin (12.5 g AI/ha) and *Bt* (1 kg product/ha). Any comment?
R. YEH: The effects of deltamethrin and *Bt* are quite independent of each other; there is additive effect between them, not synergistic. To have satisfactory control of DBM, deltamethrin applied at 12.5 g AI/ha and *Bt* applied at 1 kg, product/ha is quite reasonable. Besides, to obtain the additional repellent effect to restrict DBM larvae to the lower and unproductive part of the plant, the dose at 12.5 g AI/ha is certainly necessary.

V. HARRIES: You mentioned the antifeeding effect of deltamethrin which forces DBM larvae to the lower parts of the plant. Do not you consider these larvae as potential re - infestation source?
R. YEH: Yes, I agree that DBM larvae restricted to the lower plant parts might be the source of re-infestation. That is why it is necessary to apply the mixture at weekly interval during the whole crop growing period.

V. HARRIES: What method did you use to assess the number of adults landing on a cabbage plant?

R. YEH: In the open field, patting the randomly selected cabbage head in an unit area, such as an experimental plot, and counting the number of adults flying out from it was used in our observations. It is important to avoid to sample two adjacent plants as well as taking more than one observation in a single day in the same plot.

P. A. C. OOI: You mentioned an increase in fecundity of about two times due to stimulation by methomyl application. Do you think this is sufficient to account for the resurgence of the DBM population in the field? How important is this factor as compared to the differential mortality between predators and prey?
H. NEMOTO: The application was made only once. I think it is not sufficient to account for the resurgence in my case. Predator mortality is more important.

H. CHI: Why did you express the finite rate using the time unit 'month'?
H. NEMOTO: This is because DBM lifespan in Japan, especially in spring and autumn, is one month.

Y. I. CHU: Do you have any data regarding the mortality of predators by insecticides, such as accumulation of insecticide in the predator's body, or inactivation of predatory behavior?
H. NEMOTO: I have not examined it yet.

S. SUDARWOHADI: Did you also apply methomyl to the cabbage plants and does it have any effect against the resurgence of DBM?
H. NEMOTO: I have not examined it yet. Because it is difficult to divide the stimulating influence of the pesticide on the pest directly from that achieved via the plant.

N. WILDING: It is very interesting that in the laboratory methomyl treatment increased the fecundity of the insect and the fertility of the eggs. Did you study the survival of the larvae?
H. NEMOTO: No, not yet.

O. MOCHIDA: H. Nemoto presented a paper on resurgence of DBM due to methomyl. Do you have any information on resurgence of DBM to insecticides other than methomyl?
C. N. SUN: No.
T. MIYATA: No, I have not.
E. Y. CHENG: We did not study in this area, but we are looking forward to this kind of study and cooperating with the specialists in Taiwan.

Integrated Control of Diamondback Moth and Other Insect Pests Using an Overhead Sprinkler System, an Insecticide, and Biological Control Agents, on a Watercress Farm in Hawaii

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Abstract

The diamondback moth, *Plutella xylostella* (Linnaeus), was effectively and economically controlled on a 3.84 ha commercial watercress farm at Aiea, Oahu, Hawaii, through the implementation of an overhead sprinkler irrigation system and the establishment of a larval parasite, *Cotesia plutellae* (Kurdjumov). The intermittent application of water on the watercress field during the early evening hours is believed to disrupt the mating and oviposition activities of diamondback moth adults. The grass sharpshooter, *Draeculacephala minerva* Ball, thrived in the new environment created by the sprinkler system but was easily controlled with several timely applications of diazinon. The cotton aphid, *Aphis gossypii* Glover; the green peach aphid, *Myzus persicae* (Sulzer); the turnip aphid, *Hyadaphis erysimi* (Kaltenbach); and a recent aphid immigrant, *Aphis nasturtii* Kaltenbach, were effectively controlled by established predators and timely applications of diazinon. The integrated system to control the diamondback moth and other insect pests of watercress was commercially cost effective. Chemical control costs were reduced by 89%, while production increased by 93%.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (Linnaeus) (Lepidoptera: Yponomeutidae), has been established in Hawaii since about 1892 (Zimmerman 1978). It is a major insect pest of crucifers in Hawaii, occasionally causing considerable damage to various commercial crops, including cabbage, *Brassica oleracea* var *capitata*; broccoli, *B. oleracea* var *botrytis* subvar *italica*; mustard, *B. juncea*; Chinese cabbage, *B. campestris* ssp *pekinensis*; white-stem cabbage, *B. campestris* ssp *chinensis*; radish, *Raphanus sativus* var *longipinnatus*; and watercress, *Nasturtium officinale*.

DBM larvae damage watercress by feeding on the leafy portions, petioles, stems, and terminals of the plant. Watercress is an aquatic perennial vegetable crop native to Europe and Asia Minor. Most of Hawaii's watercress crop is grown on the island of Oahu in the Aiea, Pearl City, and Waipahu districts bordering Pearl Harbor, where the supply of spring and artesian well water is plentiful. Watercress is grown in shallow ponds or beds of water and large quantities of clean, continuously flowing water are essential for production. Water temperatures above 25.5°C cause slow or poor growth. Optimum day time air temperatures are 21-29°C. Therefore, optimum watercress growing conditions occur during the cool winter season in Hawaii (McHugh et al 1981).

Periodic surveys conducted during 1976-1980 showed that the major pests affecting watercress were DBM; green peach aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae); and broad mite, *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae). For many years, efforts to control DBM infestations on watercress with insecticides were moderately effective. During 1982, however, DBM infestations increased considerably in watercress fields on Oahu resulting in a greater usage of insecticides by growers. Despite the use of insecticides one or more times a week, DBM infestations and damage were heavy on most watercress plantings by the spring of 1982 (Nakahara and Lai 1983). The apparent ineffectiveness of registered insecticides against DBM prompted an increased usage of these chemicals on watercress. As a result, unacceptable residue levels of two registered insecticides, diazinon and endosulfan, were discovered on watercress by State of Hawaii Health and Agriculture officials and five Oahu farms were ordered to halt their harvests in May and June 1982. In September and October 1982, watercress was again recalled from two Oahu farms due to excessive endosulfan residues. The resulting adverse publicity over excessive insecticide usage caused many consumers to refrain from purchasing watercress. This prompted growers to seek other means of controlling DBM populations.

The Hawaii Department of Agriculture (HDOA) had been introducing, mass-rearing, and releasing various parasites to control DBM infestations for several years. Previous attempts to establish a DBM larval parasite, *Cotesia* (=*Apanteles*) *plutellae* (Kurdjumov) (Hymenoptera: Braconidae) (Mason 1981), in Hawaii during 1972-1974 from Taiwan and Trinidad were unsuccessful. In November 1980, the Trinidad strain of *C. plutellae* was re-introduced through the courtesy of the Commonwealth Institute of Biological Control in Trinidad, West Indies, and efforts were made to establish the species on the islands of Maui, Kauai, and Hawaii in DBM infested cabbage fields. Releases were made primarily in large, commercial cabbage fields where insecticides were being applied for DBM control. In August 1982, the HDOA began releasing *C. plutellae* in watercress fields on Oahu.

Earlier, it was observed that watercress grown under an overhead water sprinkler system provided favorable growing conditions through evaporative cooling (McHugh and Nishimoto 1980). It was later found that watercress treated in this way also sustained very little damage from adjacent high DBM populations. As plans were made to install the sprinkler system throughout the farm, an insect monitoring program was developed by the HDOA for a portion of the watercress farm in Aiea.

We report herewith results of the studies on the effectiveness of integrated methods to control DBM and other insect pests in the watercress planting.

Materials and Methods

The study was conducted during 1982-1983 on a 3.84 ha watercress farm at Aiea, Oahu. The farm was bordered to the south by a highway and to the northeast by another farm producing taro, *Colocasia esculenta* var *antiquorum*. A major shopping center surrounded the watercress and taro farms along the eastern, northern, and western sectors. Although various fruit trees, vegetables, ornamentals, and weedy grasses were found along the watercress farm's perimeter, none was known host of DBM. The watercress farm was divided into 100 smaller ponds or beds, each approximately 12.2 x 24.4 m. Dikes made of 20 x 20 x 40 cm hollow concrete tiles encompassed each bed to regulate water flow and to provide a footpath for access to beds. Samples were initially collected from five beds (about 0.1 ha) adjacent to the highway where no insecticides were applied. Insecticide treatments continued on remaining beds until the sprinkler system was in operation. Subsequently, all insecticide treatments were temporarily

discontinued throughout the farm and the sampling area was increased to include the 14 beds (about 0.4 ha) adjacent to the highway.

C. plutellae was first released in the watercress planting on 31 August 1982 and continued at weekly intervals throughout the year. In December 1982, a Taiwan strain of *C. plutellae* was introduced through the courtesy of the Taiwan Agricultural Research Institute, Taichung, Taiwan, and was subsequently released in February 1983 in various Oahu watercress plantings. In May 1983, rearing of the Trinidad strain was discontinued in favor of the more aggressive and productive Taiwan strain. Weekly releases of the Taiwan strain continued in watercress plantings until August 1983.

On 31 August 1982, weekly insect surveys were initiated in the 0.1 ha sampling site. To determine the recovery, establishment, and effectiveness of *C. plutellae* in the field, 50 4th instar DBM larvae were randomly collected each week after carefully searching insecticide-free areas of the study site. The DBM larvae were brought to the laboratory and reared on insecticide-free watercress until adult emergence. The number of *C. plutellae* cocoons and adults which emerged from the 50 DBM larvae collected each week was recorded to determine rate of parasitism. This procedure was discontinued when DBM larvae became scarce and difficult to find in the field.

Modified sweep net samples were collected weekly from 21 September 1982 to determine abundance of pests and predators (Delong 1932, Rudd and Jensen 1977). Insects and other arthropods were collected with a beating net. Five samples, each consisting of 20 consecutive sweeps with a 30.5 cm diameter beating net equipped with a cone-shaped unbleached muslin bag, were collected each week. Each sample was collected by swinging the net across the canopy of the watercress with sufficient force so that the bottom edge of the net passed slightly above the water line. The force of the net had a beating affect on the watercress, parts of which broke off and became part of the sample. The sampling area was confined to one section of the farm as the sampling method was temporarily destructive to the watercress plants. The net was swung perpendicular to the path of the sampler while walking diagonally across a watercress bed. Five beds with watercress plants at least 20 cm above the water line were randomly sampled each week. The entire contents of each sample, which consisted of various arthropods and plant parts, were placed in a 15.2 x 7.6 x 38.1 cm polyethylene bag with the top loosely tied. After the implementation of the sprinkler system, the wet contents of the beating net were further rinsed in the field. The wash was collected and examined separately for smaller individuals which adhered to the wet net. Samples were processed immediately after collection or frozen for later examination. All samples were collected at mid-morning between 9:00 AM and 10:00 AM under light wind conditions.

In the laboratory, each bag was filled with about 250 ml soapy water containing 0.2-0.3 ml of Crystal White detergent and shaken vigorously for several seconds. The contents were then emptied into a 35.6 x 30.5 x 12.7 cm white plastic pan. The bag was rinsed three more times with water and the contents added to the pan. Vegetation and other debris were removed and the pan contents were examined with a headvisor magnifier and a dissecting microscope. Specimens were segregated in vials, identified, and counted.

Initially, all beds except for those in the sampling area were treated with combinations of methomyl (0.56 kg AI/ha), diazinon (0.56 kg AI/ha), and *Bacillus thuringiensis* Berliner (Thuricide HPC at 2.3 l/ha) one to two times/week. Despite these treatments, DBM infestations and damage increased and production declined. All insecticide treatments were temporarily discontinued on the farm on 16 November 1982. Later, as other pest problems developed, limited usage of diazinon was incorporated into the control program.

On 2 December 1982, an intermittent overhead sprinkler irrigation system was put into operation at the watercress farm to replace the use of insecticides. Unlike

chemigation (Chalfant and Young 1982), the system discharged only water as a means of controlling DBM. The 3.84 ha field was divided into seven sections with two to three valves/section. The valves were either 5.08 or 7.62 cm diameter electrically actuated Richdel valves. Each valve controlled the flow of water of 8 to 14 sprinkler heads. In each section, water was allowed to discharge for 5 min at 30 min intervals. The cycle was repeated throughout the day from 8:00 AM to as late as 10.00 PM. A Dramm Rain Robot 14 Station Controller was used to set sprinkler duration.

In this operation, runoff water from the watercress field was recirculated through the sprinkler system. A Berkeley B-3 TPM 15 horsepower pump, powered by a 240 volt three phase General Electric Tri Clad motor, spinning at 3500 rpm, was used to pump water from a collection basin and move it through the sprinkler system at a maximum of 1514 l/min and at an operating pressure of 4.17 kg/cm^2. A spot Systems Screen filter, SMS 8-36-7, with two 75-mesh stainless steel screens and a manual backwash for cleaning, was incorporated into the main line for filtering organic material and other debris which could cause clogging of the sprinkler heads.

Two types of sprinkler heads were installed. Full circle Weather Tec 10-30 impact heads, with a main orifice of 0.4 cm and a back jet orifice of 0.24 cm, were used in the interior portion of the field. Part Circle Weather Tec 15-20 impact heads, with an orifice of 0.44 cm, were used along the perimeter. Water was discharged at the rate of 28.6 l/min and 24.9 l/min for the Full Circle and Part Circle heads, respectively. A total of 212 sprinklers were spaced 12.2 m apart in the farm. Sprinkled water overlap was 90-100%.

All pipes used were class 200 Polyvinylchloride (PVC) plastic. Pipe diameters ranged from 1.9 to 15.2 cm. Pressure relief and air relief valves were incorporated into the main line at four different locations.

Results and Discussion

DBM

DBM infestations in watercress were apparently more difficult to control in 1982 than in previous years. Increased resistance to available insecticides and favorable environmental conditions may have been contributing factors. During 1980-1981, other vegetable farmers in Hawaii had experienced greater difficulty in controlling DBM resulting in an emergency registration of Pydrin. Although Pydrin was effective in controlling DBM populations, it was not registered for use on watercress. In addition, an unusually wet winter followed by a wet summer may have contributed to DBM increase due to the increased availability of adult food sources, primarily flowering weeds, near watercress farms. Total rainfall at nearby Waipahu Sugar Company was 742 mm (2.7 times above normal) during the period December 1981 to April 1982 and 137 mm (1.9 times above normal) during the period May to September 1982 (NOAA 1981, 1982).

DBM populations and damage were high when the study was initiated. The number of DBM individuals collected in samples reached peak numbers of 155.6 larvae/20 sweeps on 13 October 1982 and 22.8 adults/20 sweeps two weeks later (Figure 1). Adult numbers declined to 0.4 individuals/20 sweeps on 4 November 1982 following heavy rains from 26 to 28 October 1982. Insecticides (methomyl, diazinon, and Thuricide HPC) appeared to be ineffective in controlling DBM infestations in non-surveyed beds and all treatments were discontinued on the entire farm on 16 November 1982. Watercress production declined considerably as plants in most ponds were severely damaged. Harvesting was discontinued for the next four weeks. With a reduction in the availability of watercress, DBM larval counts also declined with peak counts occurring at three to four-week intervals.

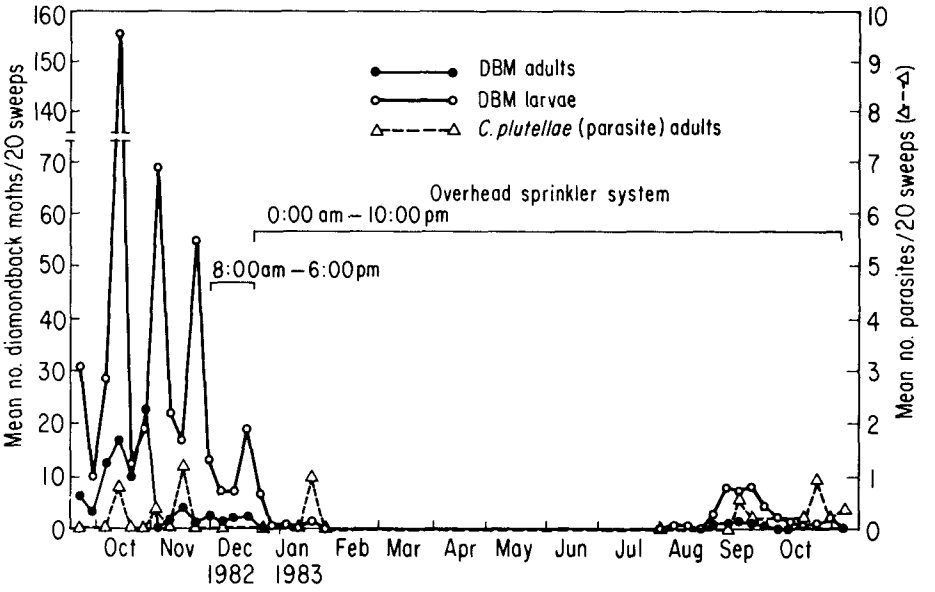

Figure 1. DBM adult and larval populations in relation to *C. plutellae* adult populations and an overhead water sprinkler system during 1982 and 1983 in watercress at Aiea, Oahu, Hawaii. Dashes indicate portions of the sprinkler system were turned off during this period

On 2 December 1982, the intermittent overhead sprinkler system began discharging water daily on the entire farm from 8:00 AM to 6:00 PM. DBM larval counts persisted at damaging levels and the operation of the sprinkler system was extended to 10:00 PM from 23 December 1983. The DBM population subsequently declined. No DBM adults and larvae were collected in samples between 8 February to 25 July 1983 and between 1 February and 28 June 1983, respectively. During mid-June to early September, treatment by the sprinkler system was reduced to only selected areas of the farm. The system was turned off for several days at a time on ponds requiring maintenance. All ponds were cleared of debris that had accumulated over a period of two years and prepared for replanting. DBM adults and larvae were recovered during this period and persisted until sampling was discontinued in November 1983.

The overhead sprinkler system was very effective in reducing DBM infestations. Operation of the overhead sprinkler system during the daytime creates favorable growing conditions for the watercress. However, leaving the sprinkler system on from dusk through the early evening hours is believed to disrupt the mating and oviposition activities of DBM adults. According to Harcourt (1957), mating begins at dusk on the day of emergence. Oviposition begins shortly after dusk, reaching a peak two hours later. In addition, droplets of water discharged through the system may contribute to adult and larval mortality by knocking individuals off the plants and into the ponds causing them to drown. Heavy rainfall may also contribute to adult mortality as suggested by the decline in DBM adults on 4 November 1982 following heavy rains (210 mm recorded at Waipahu Sugar Company) during the three-day period in late October.

Since the entire farm was treated with the overhead sprinkler system, no comparisons could be made with untreated watercress. Efforts to establish control sites on other nearby watercress farms were unsuccessful as other growers quickly adopted the new technology and converted their operations to include overhead sprinkler systems.

Surveys of other farms indicated that farm size may also be an important factor in obtaining DBM control with overhead sprinkler systems. DBM control was more effective on the 3.84 ha farm than on smaller plantings, some as small as 0.1 ha. The smaller plantings had a high incidence of flowering weeds which may have served as refuge and food sources for DBM adults. Weeds growing along the farm perimeters were more accessible to DBM adults on small farms than on large farms. In addition, the 3.84 ha farm used concrete hollow-tile banks that remained weed-free. On other farms where earthen banks were used to separate beds, weed control was difficult.

A total of 28,355 *C. plutellae* adults was released in watercress fields around the Pearl Harbor Basin area during the study. Most of the Trinidad strain (10,519 adults) and only 480 adults of the Taiwan strain were actually released in the study site. Of the 950 DBM larvae held in the lab from the weekly collections, *C. plutellae* was the only DBM parasite recovered despite the establishment of another DBM parasite, *Diadegma insularis* (Cresson), on other vegetable crops on the island. DBM larvae parasitized by *C. plutellae*, were first recovered three weeks after the parasite's initial release. Parasitism rate during September through December 1982 ranged from 0-17% (average 5%). No DBM larvae were sampled for parasites during 1983 due to very low DBM populations in the field. Efforts to collect 4th instar DBM larvae during September 1983 were also unsuccessful due to insufficient numbers.

C. plutellae adults were periodically recovered in low numbers by sweepings from 13 October 1982 to 16 November 1982 (Figure 1). Thereafter, no adults were collected until 20 September 1983 when adults were again recovered in sweep net samples. *C. plutellae* adults were recovered weekly until the study was terminated in November 1983. Although *C. plutellae* was not effective in controlling DBM from September to December 1982, parasite abundance during September to November 1983 suggests otherwise. The ratio of adult parasites collected versus DBM larvae collected was 14 times higher during the latter period (1 parasite:7 DBM larvae) as compared to the former (1 parasite:100 DBM larvae). The increase in parasite activity in 1983 may be due to the subsequent establishment of the Taiwan strain in the Pearl Harbor Basin area. The low incidence of *C. plutellae* in 1982 samples suggests that lab-reared adults and first generation progeny may have been the primary constituents of these recoveries since Trinidad parasite releases were being made concurrently. *C. plutellae* establishment and increase were also noticeable in other watercress farms in the Pearl Harbor Basin following the release of the Taiwan strain in 1983.

In addition to the overhead sprinkler system and *C. plutellae*, a granulosis virus also affected DBM larvae. Observations in the field and the laboratory suggest that granulosis virus may be a contributing factor to DBM control in Hawaiian watercress.

Grass Sharpshooter

Adults of the grass sharpshooter (GSS), *Draeculacephala minerva* Ball (Homoptera: Cicadellidae), were first recovered from sweep net samples on 24 January 1983. Later, GSS nymphs were collected on 9 March 1983. GSS infestations increased rapidly during the next two months as efforts to control the populations without the use of insecticides were pursued (Figure 2). Alternative control methods were sought to take advantage of the marketing strategy of producing a pesticide-free product. Initial trials using a surfactant solution (Triton B-1956) were not effective in controlling GSS. GSS reached a peak of 78.6 adults and 166.4 nymphs/20 sweeps on 10 May and 17 May 1983, respectively. On 23 May 1983, the first of three primary applications of diazinon was made on the watercress. Each primary treatment was followed by a secondary application of diazinon two to three weeks later as surveys and lab studies indicated that most of the GSS 1st instar nymphs had emerged from eggs deposited in the watercress stems

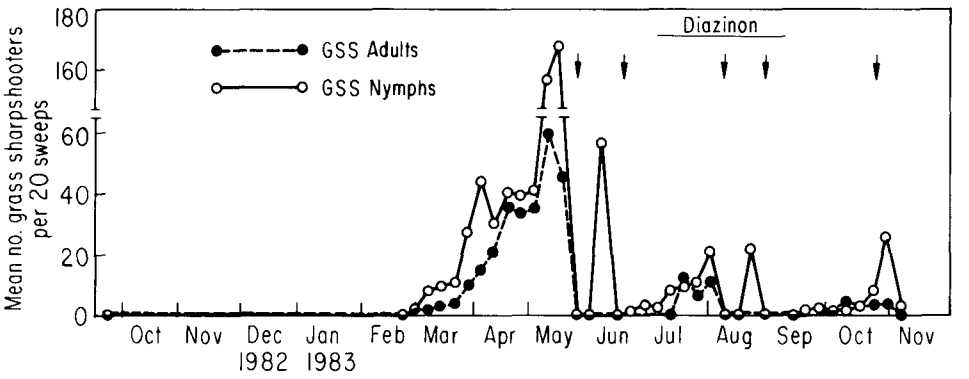

Figure 2. GSS adult and nymphal populations in relation to insecticide applications (arrows) during 1982 and 1983 in watercress at Aiea, Oahu, Hawaii

and petioles by that time. GSS eggs did not appear to be affected by the diazinon treatments. A total of five applications were made each at the rate of 0.56 kg AI/ha using ground power sprayer equipment. The overhead sprinkler system was turned off during each insecticide treatment and remained off for about 24 h. Beds scheduled for harvesting were left untreated. Primary treatments on 3 August and 1 November 1983 were initiated when counts of GSS exceeded an economic injury level of 20 nymphs/20 sweeps.

GSS damage to new growths of watercress was first noticeable in mid-April 1983 and reached a peak by mid-June. Symptoms started with a slight wrinkling of the leaves, followed by interveinal mottling, and ended with the entire leaf turning yellow and dropping prematurely. Similar symptoms were reported by Holdaway (1945) following a serious outbreak of GSS on Oahu during September 1944. He noted crinkling of the young leaves, yellow blotches on less mature leaves, and a general yellowing of the older leaves. Holdaway also reported that this injury was associated with GSS infestations and ceased when the leafhoppers were brought under control. As with the GSS outbreak described by Holdaway, damage was greatly reduced in the study site as GSS was brought under control by diazinon treatments. Damage is believed to be directly related to feeding injury rather than to a disease. Although turnip mosaic virus was recovered from many samples showing the mottling symptoms, it was also recovered from plants displaying no symptoms. Since watercress is grown vegetatively, most plants may be symptomless carriers of the virus.

GSS may have thrived in the new watercress environment created by the overhead sprinkler system because of the dramatic reduction in pesticide usage on the watercress. Few GSS were recovered in surveys conducted in grasses along the perimeter of the farm indicating that the large population of GSS was due to its breeding in the watercress. Since no GSS parasites were recovered in watercress throughout the study, the absence of natural enemies may also have been a factor in the increase. This is consistent with the observations of Napompeth and Nishida (1971) who suggest that established egg parasites in Hawaii do not attack the GSS when it infests watercress.

Aphids

Aphids feed on the terminals and leaves of watercress causing crinkling and stunting damage which affects the quality and yield of the product. Several species of aphids were found on the watercress during this study, while previous surveys during 1976-1980

showed only the green peach aphid, *M. persicae*, to be the predominant aphid pest. In this study, the cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), was the predominant aphid followed by *M. persicae*; the turnip aphid, *Hyadaphis erysimi* (Kaltenbach) Homoptera: Aphididae); and a recent immigrant, *Aphis nasturtii* Kaltenbach (Homoptera: Aphididae). The increase in aphid diversity is believed to be due to the reduction of insecticide use in the planting which allowed other species of aphids to become established. No aphids, for example, were collected in samples during 1982 when frequent insecticide applications were made to control DBM.

Aphids were first collected in sweep net samples on 24 January 1983 (Figure 3). The counts remained low until late February. The number of aphids collected in samples increased rapidly during March accompanied by a rise in the number of aphid predators (syrphid and coccinellid larvae). A declne in aphid counts on 12 April 1983 suggests that predators, primarily syrphid larvae, were responsible for the reduction in aphid numbers. The use of diazinon to control GSS populations was also effective in controllng subsequent aphid populations.

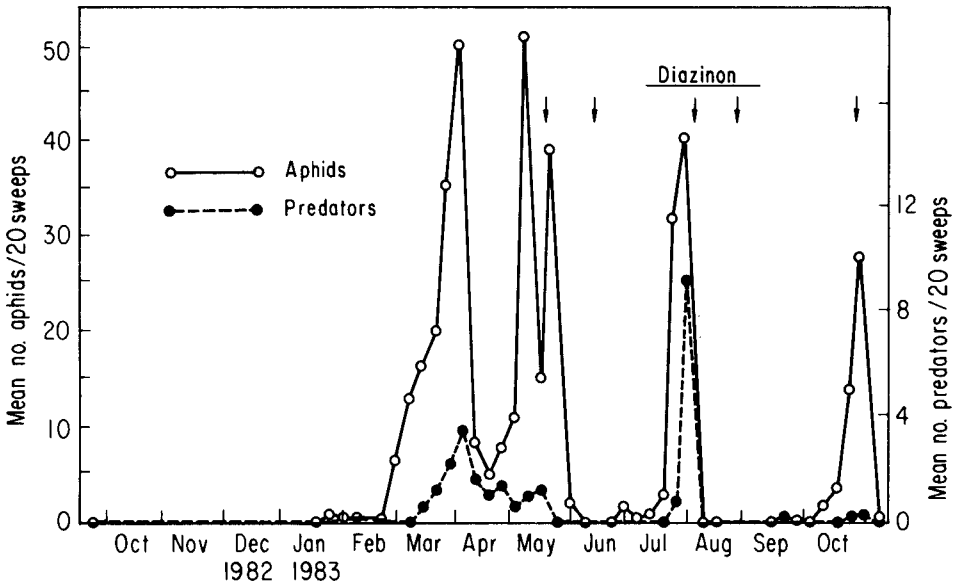

Figure 3. Aphid populations in relation to predator populations and insecticide applications (arrows) during 1982 and 1983 in watercress at Aiea, Oahu, Hawaii

Several predators were observed preying on aphid colonies. About 72% of the predators collected were larvae of two species of the syrphids, *Allograpta obliqua* (Say) and *Toxomerus marginatus* (Say). *A. obliqua* is a common predator of aphids and whiteflies in Hawaii. Its effectiveness is frequently undermined by the parasite, *Ooencyrtus guamensis* Fullaway, which parasitizes the larval stage of syrphids. *O. guamensis*, however, was never recovered in the watercress planting. In addition, several species of coccinellids, constituted about 28% of the total numbers of aphid predators collected in sweep net samples. These were *Scymnus loewii* Mulsant, *Coccinella septempunctata brucki* Mulsant, and *Brumoides suturalis* (Fabricius).

Other pests and problems

Adults of the southern green stink bug, *Nezara viridula* (Linnaeus) (Heteroptera: Pentatomidae), which caused injury to the growing tips of the watercress, were occasionally recovered in samples. However, since the surveys showed that no breeding populations were established, no control measures were initiated against this pest. A few larvae of the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae), and imported cabbage worm, *Artogeia rapae* (Linnaeus) (Lepidoptera: Pieridae), were also found in the planting but did not warrant any control actions. Previously a serious pest of watercress, the broad mite, *P. latus*, was recovered only along the borders of the farm near alternative hosts. No significant disease problems were encountered in the watercress planting.

Cost effectiveness

This integrated system to control DBM, GSS, and aphids was commercially cost effective. Watercress production increased by 93% during the first year the program was implemented (Figure 4). Monthly production of watercress averaged 1.79 t/ha before the management program was established and 3.46 t/ha thereafter. Chemical control costs ($36,000/annum), which included costs of chemicals and labor, were reduced by 89%. Capital costs for the overhead sprinkler system were $25,000 which were recovered during the first year of operation. Operational costs (electricity and maintenance) of the overhead sprinkler system were approximately $300/month. Since the overhead sprinkler system also improved watercress growth through evaporative cooling, only a fraction of the capital and operational costs of the system can be apportioned to DBM control.

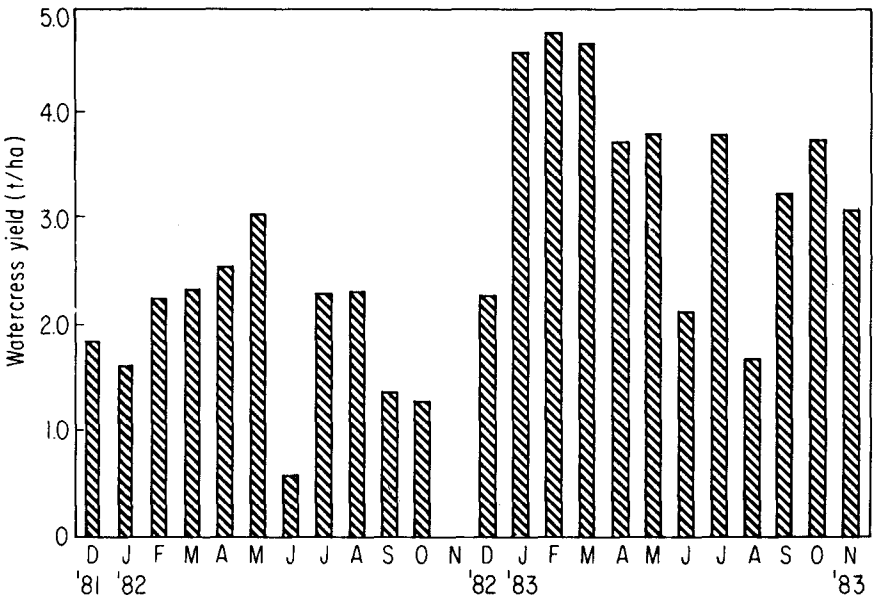

Figure 4. Watercress yields before (December 1981-November 1982) and after (December 1982-November 1983) the use of integrated control strategies on a farm at Aiea, Oahu, Hawaii

Conclusion

DBM was effectively and economically controlled on the 3.84 ha watercress farm at Aiea, Oahu, Hawaii, through the use of an intermittent overhead sprinkler system and the parasite, *C. plutellae*. Although it is believed that discharging water through the system during the early evening hours disrupted the mating and egg-laying activities of DBM adults, further studies are needed to confirm this. GSS populations were controlled with timely applications of diazinon. The development of GSS from minor to major pest status, however, is an example of the kind of change that can occur in the pest complex when the environment of the crop is altered. Similarly, aphid numbers and diversity also increased as insecticide applications were temporarily discontinued. However, predators and timely applications of diazinon were sufficient in controllng this pest. Equally important in developing a sound integrated pest control system is deciding when not to treat for minor pest problems. Although several pest problems requiring insecticides surfaced when the overhead sprinkler system was implemented, the integrated system was successful in controlling DBM and other insect pests. This system also reduced control costs, reduced overall insecticide usage on the crop, and nearly doubled watercress production.

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Ecology and Control Thresholds of the Diamondback Moth on Crucifers in Taiwan

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Abstract

Diamondback moth (*Plutella xylostella*) can complete its lifecycle within a temperature range of 10-30°C, with the optimum at 20-25°C. In general, as the temperature rises the development speeds up. The mean generation time at 20, 25 and 30°C is 23, 15.5 and 13 days, respectively. Two to three generations can be completed during a crucifer cropping season. The species can complete 18-21 generations a year in Taiwan, with a considerable generation overlapping. A female moth in her 23, 12 and 7 day lifespan can lay 300 ± 80, 143 ± 85 and 107 ± 47 eggs at 20, 25 and 30°C, respectively. When reared on common kale in a growth chamber, the intrinsic rate of increase at 20, 25 and 30°C was 0.1986, 0.2130 and 0.2389, respectively. Population peaks in the field occur from February to March, June to July and October to December in northern Taiwan, from January to February in central Taiwan, and from January to March in southern Taiwan. Availability of food plants and rainfall are the major factors limiting its population density. Leafy crucifers, such as green petiole pai-tsai, because of their short growing period (about 5 weeks), suffer less damage from the diamondback moth compared to heading types, such as cabbage and cauliflower. The spatial distribution of DBM larvae on cauliflower can be adequately described by a negative binomial distribution. The index of patchiness ranges from 1.36 to 2.90. The relation between variance and mean density is $S^2 = 2.0528\overline{X}^{1.4067}$. Thus, data transformation of field counts and sampling plan are based accordingly. Measurement of feeding on cauliflower as influenced by temperature has been studied. This information serves as a common denominator for the conversion of other caterpillar counts into diamondback moth equivalent units for the development of multispecies control thresholds. The control thresholds of this pest on cauliflower are tentatively determined. Cauliflower seedlings should be protected for three weeks after transplanting to enable seedling establishment. Further control is needed from 31 to 45 days after transplanting to keep insect population density below one larva per plant. Thereafter the threshold is 10 larvae/plant. On cabbage, control action should be taken when its density reaches one per plant before the 10-leaf stage and two larvae per plant thereafter.

Introduction

The diamondback moth (DBM), *Plutella xylostella* L (Lepidoptera: Yponomeutidae), was first recorded as a pest on crucifers in Taiwan by Sonan (1942). It was considered as a potential pest by 1960, although its density was still quite low (Chang 1960, Tao et al 1960). However, in the mid 1960s it ranked as an important pest second only to the pyralids on summer radish (Tao 1966). Extensive field screenings of insecticides for its control were conducted during the late 1960s, indicating that it was already a serious problem (Ho and Liu 1969, Lee 1968, 1969, Tang 1967). So far 36 insecticide

formulations have been recommended (PDAF 1984) for DBM control. But poor control by these insecticides has been reported since the late 1960s (Wu 1968). DBM's status as a key pest on crucifers has been scientifically evaluated by Chen and Su (1982). The upsurge of this insect as a serious pest could be due to (1) its rapid development of resistance to insecticides, (2) the lessening of competition for food and habitat with other caterpillars which are more easily controlled by most insecticides, and (3) the elimination of its natural enemies by insecticides.

A survey of literature indicates that from 1940 to 1984 fifty-eight papers—12 on bionomics, 24 on control measures, 15 on pesticide resistance and 7 on sex pheromones—have been published on this pest in Taiwan. Most papers, however, were published from 1971 to 1980 (Table 1). In this paper, we will focus our attention only on DBM bionomics and control thresholds.

Table 1. A survey of publications on DBM in Taiwan[a]

Subject	Number of papers published during				
	1940-60	'61-70	'71-80	'81-84	Total
Bionomics	1	2	5	4	12
Control					
chemical	3	4	2	1	10
biological	0	1	7	0	8
microbial	0	1	2	0	3
integrated	0	1	2	0	3
PesticideE					
resistance	0	0	8	7	15
Sex pheromone	0	0	4	3	7
Total	4	9	30	15	58

[a] Source: Survey of literature in Chiu 1958, Editorial Board on literature on Taiwan's Agriculture, 1956, 1966, 1977, 1983, and Plant Protection Bulletin (Taiwan).

Life History Traits and Population Parameters

Life history statistics have been collected under various rearing conditions. In general, the lifecycle can be completed at temperatures ranging from 10 to 30°C. As temperature increases the period for each stage shortens. The longer the larval period the greater is the foliage consumption. DBM takes 18, 11, and 9 days and consumes 7, 5, and 4 cm^2 cauliflower leaf to complete its larval period at 15, 20 and 25°C, respectively (Chen and Su 1978). The optimum for growth and development is somewhere around 20—25°C. In the growth chamber at 20—25°C DBM takes 17-20 days to complete a lifecycle. While in a screenhouse with fluctuating temperature, DBM takes 18-39 and 28-48 days, respectively in southern and northern Taiwan (Table 2).

A high variation exists in reported fecundity, ranging from zero to several hundreds eggs/female. This could be a result either of inclusion of data taken from unmated females, or because the number of eggs laid is directly related to the longevity of a female which is also quite variable. A female in her 23, 12 and 7 days lifespan can respectively lay 300+80, 143+85 and 107+47 eggs at 20, 25 and 30°C (Liu et al 1985).

Population parameters have been obtained by rearing the insect on common kale in a growth chamber. The intrinsic rate of increase, r, at 20, 25 and 30°C is 0.1986, 0.2130 and 0.2389 and the mean generation time (T) 23, 15.5 and 13 days, respectively (Table 3) (Liu et al 1985). Variation, however, exists in local populations. Thus, the r values for Banchau (northwestern), Hsihu (centralwestern) and Taitung (southeastern) populations are 0.1514, 0.2281 and 0.1884, respectively (Liu 1983). The r value is

Table 2. Life history statistics of DBM in Taiwan[a]

Duration (days)	Screen house (natural conditions)	Growth chamber (20-25°C)
Egg	3- 4	3- 5.5
Larval	7-10	8-11.5
Pupal	4- 6	5- 7
Adult	5- 8	12-23
Oviposition	3- 5	5- 9
Generation	18-39(S)[b]	17-20
	28-49(N)[b]	
Eggs/female	47-120	145-300

[a] Data compiled from Chen and Su (1978), Hsu and Wang (1971), Hwang (1970), Leu and Lee (1984), Liu et al. (1985) and Wu (1968). [b] S = southern and N = northern part of Taiwan.

Table 3. Population parameters of DBM reared on common kale in the growth chamber[a]

Temperature	$\bar{T}$	Ro	r	λ	$\bar{x}$ eggs/female
20°C	23	90.66	0.1986	1.2197	300 ± 80
25°C	15.5	27.00	0.2130	1.2374	143 ± 85
30°C	13	21.60	0.2389	1.2698	107 ± 47

[a] Source: Liu et al 1985.

predominantly determined by the reproductive schedule; the earlier oviposition begins and the sooner egg-laying reaches its peak the greater is the r value (Table 4 and Fig. 1) (Liu et al 1985).

Table 4. Population parameters of DBM collected from different locations in Taiwan[a]

Deme source	$\bar{T}$	$\bar{X}$ eggs/female	Oviposition Time		Ro	r	λ (day^{-1})
			1st	peak			
Banchau (Northern)	23	139 ± 48	19	22	31.9	0.151	1.1635
Hsihu (Central)	14	128 ± 56	11	13	26.1	0.228	1.2562
Taitung (Eastern)	16	86 ± 57	13	15	20.0	0.188	1.2073

[a] Source: Liu 1983. Rearing conditions: Common kale, 25 ± 1°C, 60 ± 5% RH, 12D:12L.

Field Population Ecology

DBM can be found on crucifers year round, provided that the host crop is planted continuously (Chang 1960, Wang 1984, Leu and Lee 1984, Talekar and Lee 1985). In Taiwan DBM has 18 to 21 generations per year. The population is more abundant during the winter crop season (December to March). Thus, population peaks occur from February to March in central and northern Taiwan and January to March in southern Taiwan (Table 5). In summer (June-September) DBM is almost absent from the fields under conventional culture conditions. High temperature (Chin 1973, Hwang 1970, Lee and Lee 1984, Wang 1984), food availability (Wang 1984), and heavy rain (Leu and Lee 1984, Talekar and Lee 1985, Wang 1984) are important factors affecting DBM's abundance. We feel that high temperature limits the food availability in space and time, which in turn puts constraints on the pest's abundance. But we agree with Talekar and Lee (1985) that heavy rainfall is the major decimating factor accounting for the minimum

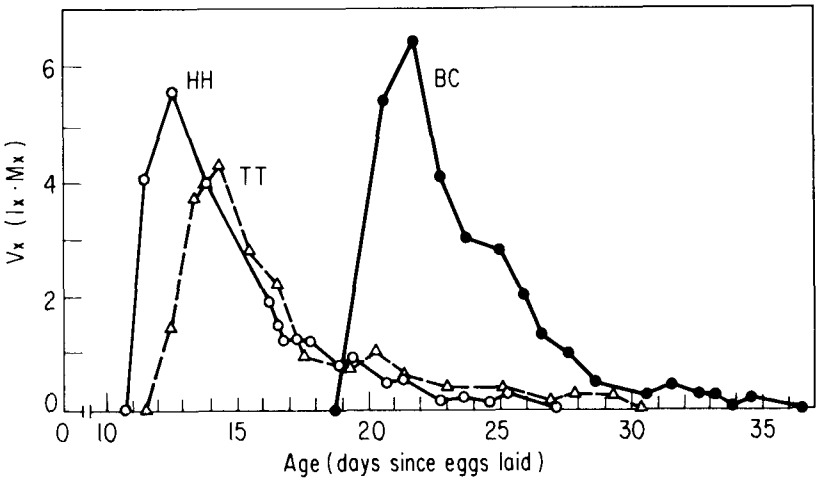

Figure 1. Reproductive schedule of DBM collected from Banchau (BC), Hsihu (HH), and Taitung (TT) and reared at 25°C

Table 5. Number of generations and population peaks of DBM at different regions in Taiwan

Region	Host plant	Generations per year	Population peaks	References
North	Cabbage	18-19	Feb - Mar	Chin 1973
	Common kale		Feb - Mar Jun - Jul Oct - Dec	Wang 1984
	Pak-choi		May & Aug	Chang 1960
Central	Cabbage & cauliflower	19-20	Feb - Mar	Su and Chen 1984
South	Common cabbage Chinese cabbage	20-21	Jan - Mar	Talekar and Lee 1985

population level in summer. Heavy rainfall not only washes off young larvae from the plant, but also hinders flight and egg-laying activity of the adults. Nevertheless, an intensive study of DBM's population dynamics in Taiwan is still lacking.

The pest is more serious on crops which require longer growing periods (Wang 1984). For instance, the pest seldom has the chance to build up its population so as to cause heavy damage to pak-choi (*Brassica campestris* ssp *chinensis*), which takes only 1 to 1.5 months per crop season. By contrast, cabbage (*B. oleracea* var *capitata*), which requires 2.5 to 3 months per crop season (long enough for the pest to complete two to three generations), is often severely attacked.

DBM larvae tend to aggregate on the plants. Their spatial distribution on cauliflower can be adequately described by a negative binomial distribution. Index of patchiness ($\hat{m}/m$) ranges from 1.36 to 2.90 and the relation between mean ($\bar{x}$) and variance (s^2) is $s^2 = 2.0528\bar{x}^{1.4067}$ (Chen and Su, unpublished). Accordingly, data from field counts can be transformed by $Z = x^{0.3}$ (Taylor 1961) for further statistical analysis. And optimal sample size (n) can be obtained (Table 6) according to $n = (t/D)^2 am^{b-2}$ (Chen

Table 6. Optimal sample size for DBM sampling[a]

Mean density (larvae/plant)	Sample size	
	D = 0.1	D = 0.2
0.1	3754	939
0.5	1445	361
1.0	958	239
5.0	368	92
10.0	244	61
20.0	162	40

[a] Source: Chen and Su (unpublished data).

1984), where t is the Student's t value at p = 0.05, D = precision level, m = mean density, a and b are parameters in Taylor's power law shown above.

Optimal Control Thresholds

Because the demand of vegetables in terms of quantity and quality is ever-increasing, farmers in Taiwan tend to take an 'insurance approach' to reduce risk of crop loss due to pests. Thus, insecticides are still the major weapon for the control of DBM and other pests on vegetable crops. At least weekly applications of chemicals are common. As a result, the rapid development of DBM resistance to pesticides is the bane of scientists, and farmers are faced with the escalation of pesticide use and thus of input cost. The general public regards pesticide residues in vegetables as one of its major health concerns nowadays. At any rate, to find a way to cut down on pesticide usage is an urgent problem.

One way to reduce the frequency of chemical application is to work out the optimal control thresholds for DBM. In this regard, we conducted a series of both laboratory and field experiments during 1976 to 1981.

By means of artificial defoliation we found that the cauliflower plant is more sensitive to defoliation within 65 days after transplanting (DAT); the earlier injury occurred the heavier was the damage. Persistent leaf loss of up to 25% of total leaf area after 75 DAT will not affect the normal growth of the curd (Su and Chen 1984); field experiments support the findings. In order to ensure seedling establishment, protection of the seedlings from attack by the pest is definitely needed. Further, the control is warranted only when the pest level reaches one larva per plant during 31 to 45 DAT. Thereafter, the control threshold can be set at 10 larvae per plant. According to these thresholds, only four to five applications of insecticide (in this case methamidophos 50EC) are needed to keep the DBM level under the control thresholds, while conventionally at least nine weekly sprays are practiced. If *Bacillus thuringiensis* mixed with carbaryl or methomyl is used, six to seven applications are optimal according to the cost-benefit analysis, provided that the unit price of the produce is NT$7 (US$0.18) per kg (Su and Chen 1984).

Since two to three species of caterpillar can be found attacking crucifers at the same time, we have established a conversion system to convert the caterpillar counts into DBM-equivalent units as shown in Table 7 (Chen and Su 1982). Hence, control thresholds for the caterpillar guild can be expressed in DBM equivalent units. Based upon this, we concluded that for the best results of caterpillar management on cauliflower the following control strategy is recommended. (1) Keep DBM units at a minimum during the first three weeks after transplanting (WAT). This will ensure a high percentage of plants harvested. (2) Spray only when DBM units reach one per plant during 4-7 WAT.

Table 7. Conversion of caterpillar counts into DBM-equivalent units[a]

Instar	Mean daily leaf consumption (cm^2/larva)			DBM-units[b]		
	SCW[c]	CL	TAW	SCW	CL	TAW
2	0.27	0.26	0.77	0.7	0.7	2.0
3	2.20	1.00	3.13	5.5	2.5	8.0
4	6.23	3.40	5.03	15.6	8.5	12.6
5	6.93	13.00	10.77	22.3	32.5	27.0
6	—	—	19.23	—	—	48.0

[a] Source: Chen and Su 1982. [b] 1 DBM-unit = 0.4 cm^2/larva/day. [c] SCW = Small cabbage white butterfly (*Artogeia rapae crucivora*), CL = Cabbage looper (*Trichoplusia ni*), TAW = Tobacco armyworm (*Spodoptera litura*).

This will prevent the loss of average curd weight. (3) Spray again only when the level reaches 10 units per plant after 7 WAT. This will protect the curd from contamination by larval feces or pupae and increase marketability. In central Taiwan five or six sprays of fenvalerate, quinalphos, carbofuran or *B. thuringiensis* will be needed to keep the caterpillar guild under control thresholds (Chen and Su unpublished).

The same approach has been taken for tests on winter cabbage. We reached the following conclusions. Control action should be taken whenever DBM units reaches one per plant before the 10-leaf stage, and two per plant thereafter. Cost-benefit analysis showed that in a 1980 crop, three sprays of either fenvalerate, permethrin or cartap were needed. The net profit per NT$1 input was 8.7, 6.7 and 3.0 NT$, respectively. In a 1981 crop five sprays of either deltamethrin, permethrin or prothiophos were warranted. The rate of return on investment was NT$4 per NT$1 invested. (Chen and Hsiao unpublished).

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Developments in Diamondback Moth Management in the Philippines

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Abstract

A discussion of what is known about the individual components of pest management applied to the diamondback moth, *Plutella xylostella*, in the Philippines is presented. This includes aspects relating to the pest, the agroecosystem, the plant, and preventive and curative control measures. Some successes have been obtained with a few of the components but many have not been tried in the field nor have there been sustained efforts to apply pest management in its totality. From the identification of the constraints in adoption of a holistic approach, it is evident that while there are certainly technical problems, social problems are just as important. These constraints must be overcome if a successful DBM management program is to be established.

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L) (Lepidoptera: Yponomeutidae), in the Philippines is a serious limiting factor in the production of crucifers. For example, Quebral and Caramancion (1972) reported that in the highlands, farmers concede much reduced yield (up to 100% yield loss) if insecticides are not used to control this pest. It is now widely accepted that in the lowlands also successive crucifer production is very difficult once this pest's population is allowed to build up, as usually occurs from the second crop.

The problem is compounded by the unreliability of control by chemicals as a consequence of, among others things: (1) the development of resistance by the pest, to the chemicals, (2) a much reduced rate of introduction of new compounds to the market, (3) the high cost of insecticides, and (4) problems of supply brought about by foreign exchange restrictions. The first problem also indirectly results in the build-up of residues in commodities because farmers are tempted to use cocktails or application rates higher than recommended. When cocktails or tank combinations of two or more chemicals are used, these compounds are often used at the dosages recommended for each compound individually, so that the actual application rate is double or triple the recommended rate.

Cabbage ranks first among all leafy vegetables in terms of quantity in the Philippines and in 1972, 7120 ha area was devoted to this crop with annual production estimated at 49,522 tons with a value of $5.4 million.

This paper considers what has been done to manage this pest and also what could still be done. As in many developing countries, the individual components of what could constitute a dynamic technology package are known, and some of them have been evaluated, but much still remains to be done in terms of putting them into practice.

Aspects of Pest Management Applied to DBM in the Philippines

Pest management is not alien to the Filipino consciousness and Filipino scientists have long been advocating it. However, its full potential has not been realized. What we find therefore is the adhoc application of individual components based principally on the use of insecticides (Magallona 1981, Magallona et al 1982). It has been stressed that insect pest management requires a good working knowledge of the following aspects (Reynolds et al 1975, Beingolea et al 1982):
1. The agroecosystem, 2. the plant, 3. the pest, 4. preventive control methods (Host plant resistance and cultural management), 5. suppressive control methods (biological agents—parasitoids, predators, pathogens, and chemicals—synthetic or naturally-occuring compounds).

Let us now discuss briefly what is known in the Philippines about each of these aspects.

The agroecosystem

In the Philippines, two general types of agroecosystems can be identified, the highlands and the lowlands. The cool highlands include Benquet (La Trinidad, Atok, and Bugias), Kanlaon in Negros, and to some extent Claveria in Mindanao, Mantolongon in Cebu, Sariaya in Quezon, and Bongabon in Nueva Ecija (Figure 1). Benquet and Kanlaon grow quite extensively a variety of crucifers on a year-round basis. The setting is basically agricultural although in La Trinidad, urban encroachment has become serious of late.

Most of the other areas have been more recently cleared from forest lands. Poor accessibility to the market, and a market in itself small are the main constraints. In Nueva Ecija, the area is devoted to rice during the wet season.

Plantings of crucifers are also made in the lowlands with cabbage and petsai (*Brassica campestris* spp *chinensis*) being the two main crops; cabbage plantings have increased recently because of the introduction of superior hybrid cultivars. Three types of plantings are recognized here-those of traditional small farmers wherein crops are rotated in accordance with seasonality; those of the newly emerging agribusiness concerns; and opportunity plantings in urban or semi-urban settings.

In the traditional crucifer-producing areas of the highlands, crucifers are grown extensively the year-round and it is not unusual to observe virtually whole mountainsides devoted to crucifers. Furthermore, for obvious reasons, there is a continuous planting and harvesting of crucifers in these areas. DBM, therefore, has a year-round supply of host. By the same token, however, natural biotic mortality factors are present throughout the year. Insecticide use is heavy and this serves as selection pressure both to DBM and its biotic natural enemies. It is, therefore, natural that these organisms will develop resistance to these chemicals.

On the other hand, in the lowlands, DBM becomes a serious problem only in continuous plantings as it takes some time before a population builds up to infestation levels. Here, however, the farmer simply shifts to another crop, such as mungbean, tomatoes or green beans, to minimize the impact of DBM on his operations.

Besides cabbage and petsai, DBM has several other hosts in the Philippines. Barroga (1980b) listed cabbage, cauliflower, turnip, swede, kale, Chinese mustard, petsai, watercress, horse radish, sweet alyssum, candytuft, radish, and chickpea as DBM food plants. Alternate hosts are cruciferous weeds including ornamental cabbage and cactus. We have observed DBM in *Cassocephalum crepidiodes* (Benth) S. Moore. It is a lowland weed but has been encountered in Baguio as well. *Galinsoqa parviflora* Cav and *Spergula*

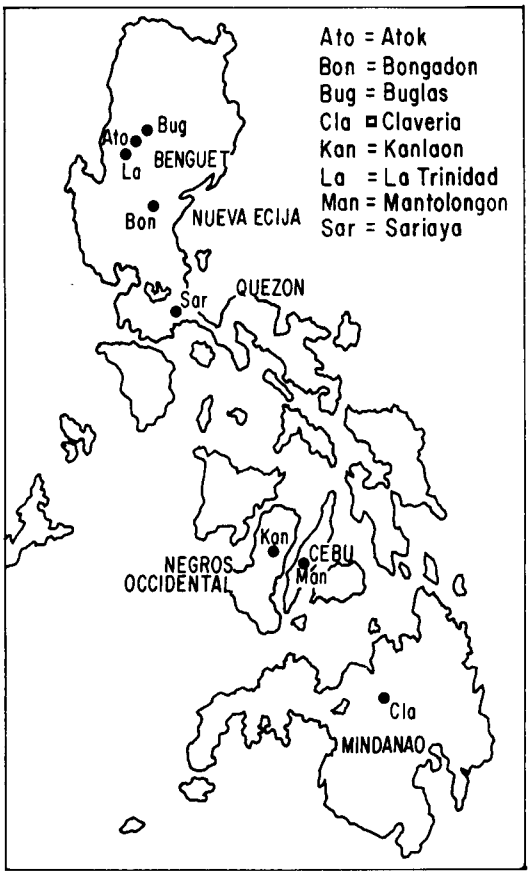

Figure 1.
Map of the Philippines showing major crucifer growing areas

arvensis L are also notorious weeds in the highlands which could also serve as alternate hosts (Paller 1985). DBM adults are also attracted to marigold (*Tagetes* spp) in the field.

The importance of these weeds or crops as alternate hosts has not been assessed but is the subject of an on-going investigation. It should perhaps be noted that these weeds, if indeed they serve as alternate hosts to DBM, also ensure the perpetuation of natural enemies.

The plant

DBM subsists principally on crucifers. As pointed out by Gupta and Thorsteinson (1960) the free mustard oils of the crucifers are involved in confining DBM's host range amongst crucifers. Most crucifers thrive best in a cool moist climate so that the quality produce is obtained in the highlands. Here, a wide variety of crucifers are grown. In the lowlands, only petsai and cabbage are of importance.

The pest

In the Philippines, the biology of this pest has been reported by Otanes and Sison (1927), Esguerra and Gabriel (1969), Gabriel and Cadapan (1970) Medina et al (1977), and Barroga (1980b).

It is known that the developmental period for this pest is 13 to 22 days or an average of 20 days; a shorter period is expected in the warmer lowlands than in the colder highlands. The adult is most active after sunset and mating begins one day after emergence with the female mating only once. Oviposition occurs shortly after dusk with the peak occurring about two hours later. Peak of oviposition occurs during the first evening of ovipositon.

Preventive pest control methods

These are generally taken to prevent the establishment of a pest-plant relationship. They include among others the use of (a) resistant cultivars, (b) cultural management, and (c) protectant chemicals.

(a) Resistant cultivars The use of resistant cultivars offer a number of advantages in pest management because they easily supplement or can be supplemented by biological, chemical, and cultural controls. In the Philippines, while the potential for a variety/line resistant to pests in general and DBM in particular is realized, there has been no positive development so far. However, this is one of the concerns of the vegetable breeding group at the Department of Horticulture and the Institute of Plant Breeding, at UPLB (Rasco 1985).

(b) Cultural management The idea is to manage the immediate environment so that there is disruption of the lifecycle of the pest. Two basic principles are involved: (1) manipulation of the agroecosystem to make it less favorable for the pest, and (2) manipulation to make the agroecosystem favorable for DBM's natural enemies. Crop rotation, crop refuse destruction, and intercropping are among the approaches to cultural management. Not all of these are applicable at any given time and some reports have been contradictory in that some workers report success while others report failure. It is thus important to show that a technique will work rather than to assume that it will. Crop rotation: A crop which is not a host or is not attacked by the pest is introduced before or after a susceptible plant. This causes a disruption in the lifecycle of the pest or the insect may be forced to subsist on an alternate host which is not as abundant as the crop plant.

While crop rotation is certainly practised, many farmers do this not so much with pest control in mind as to take advantage of favorable growing conditions. Thus, in the highlands, an area may be shifted from crucifers to potatoes, carrots, sweet peas, strawberry, tomatoes, and so on but the adjoining fields may still be devoted to crucifers. Crucifers are also avoided during the wet season because of softrot and other diseases. In fact, during the wet season, DBM populations are low but production is also low because of these diseases (Magallona 1981).

In the lowlands, crucifers are considered cash crops so that they may be planted after rice or in rotation with tomato, mungbean and other crops.

Where agribusiness concerns have several plantations but require a continuous supply of crucifers, a different approach is used. Here plantings are rotated in different plantations, making sure that in any firm's operations, there is a crucifer-free period. This deprives DBM populations of food, thus forcing them to subsist on alternate hosts. When crucifers are reintroduced, the early planting (up to two months of continuous plantings) generally have manageable DBM populations. The moment this population becomes serious, another farm takes over production. While this approach appears opportunistic, it reduces the intensity of insecticidal control, assures continuous supply of crucifers, and reduces costs considerably. Crop refuse destruction: DBM can complete its lifecycle in crop residues or refuse. For example, when cabbage is harvested, the leaves

are left behind. Unfortunately, this is where DBM congregates so that unharvested areas or new plantings have a ready reservoir of the pest. Prompt removal of these cropresidues, a tedious job the value of which is not appreciated by many farmers, followed by burning or burying, would eliminate this reservoir.

It is only after the first harvest, when crop residues are left in the field, that DBM population surges (Manalastas 1985).

Intercropping: Tomatoes have been claimed by some researchers as a good intercrop with cabbage. Thus, Buranday and Raros (1973) observed significantly more DBM adults and eggs in a plot of cabbage as the sole crop than in a plot of cabbage-tomato intercrop. This is presumably because of the repellent effects of tomatoes. They recommended a planting pattern of two rows of cabbage between two rows of tomatoes.

In a later experiment, Magallona (1980) evaluated tall and short tomatoes and sweet peas as barrier plants. Tall tomatoes gave better cabbage yields while sweet peas were not considered a good barrier because of their shading effect. However, insecticide application gave better yields than barrier plants, though this does not detract from the potential of the barrier plant approach especially at low DBM population levels.

Barriers: This approach holds tremendous promise especially for agribusiness concerns that can afford the large capital requirement. Crucifers are grown in areas protected from DBM by mechanical barriers such as fine-mesh netting and plastic sheets. In this manner, the crop can be raised throughout the year and pesticide application is minimized, if it is needed at all. Furthermore, biological control with natural enemies may have greater effectiveness because of the enclosed space.

In using this approach, the following advice is offered: 1. the area should be fully enclosed even at the top because DBM can climb up the net or plastic wall; 2. while in the nursery, the seedlings should be kept free of DBM; 3. considering that DBM has been observed to oviposit on the green net at the top, crop rotation may still be advisable. Tomato appears to be a promising rotation crop.

Suppressive control methods

In this case, the pest-plant relationship is sufficiently well understood for efforts to be made to reduce pest population to an acceptable level.

Biological agents These organisms are being hailed as replacements for pesticides but so far, their potential has not been realized. Parasitoids: Several of these have been reported. This include *Nythobia insularis* and *N. plutellae, Microplitis* sp, *Apanteles* sp, *Angitia maculipennis* (Esguerra and Gabriel 1969, Gabriel and Cadapan 1970, Barroga 1974, 1980a, Velasco 1982, Magallona 1980).

Velasco (1982) studied the field parasitism of *A. plutellae* on DBM as a continuation of earlier research (Magallona 1980). This parasite was considered the predominant biotic mortality agent in Baguio City but its effects were antagonized by *Erynia*(= *Entomopthora*) *radicans* Brefeld, a fungus which is also a significant biotic agent. From cage-field releases, it was concluded that this parasite is worth pursuing. The parasite prefers second and third larval instars. It also has a hyperparasite, *Trichomalopsis* sp.

Pathogens:-*Entomophthora sphaeraosperma* or *E. radicans* appear to be effective pathogens (Esguerra and Gabriel 1969, Magallona 1980, Velasco 1982). Other disease organisms include nuclear polyhedrosis and granulosis viruses (Barroga 1974, 1980, Liquido 1975). The potential of these organisms remains to be explored.

On the other hand, *Bacillus thuringiensis* has been widely used to control DBM and notwithstanding its erratic results and inability to compare with the synthetic insecticides from the point of view of efficacy, was nevertheless a major insecticide in the Baguio-La Trinidad area in 1982 (Magallona et al 1982). In as much as it is easily

produced by fermentation, there have been attempts to produce this using locally available materials. Perez (1972) and Ocampo (1973) tried coconut water but failed to obtain ideal conditions for growth. Guevarra (1974) tried alcohol slop waste, lambanog slop waste, coconut water, cow and poultry manure, and nutrient broth. They found cow and poultry manure to be better media than nutrient broth for the growth and sporulation of *B. thuringiensis* var *thuringiensis*. Batalla (1975) later determined the best concentration of the above substrates for the commercial production of this bacterium.

Further work is done on the production and formulation of this agent at the National Crop Protection Center and at the Institute of Biotechnology and Microbiology at UPLB.

Insecticides Insecticides are considered the most powerful tool for pest management. However, there has been a complete turnaround in philosophy so that instead of being the first method of choice, the use of insecticides is now considered the technique of last resort. Insecticides naturally draw their usefulness from their rapid action and convenience in use.

Almost all the insecticides used in other countries have been tried in the Philippines and the trend has been essentially the same—there was a shift from the early botanicals to the organochlorines, then to the organophosphorus and carbamates, and now to the pyrethroids. This shift was due in a large part to the development of resistance by DBM to the insecticides. In fact, the problem pests before the advent of organic pesticides were the sulfur butterflies (*Pieris* spp) but they were edged out from this niche by DBM which was better adapted to these chemicals; this view is also shared by Barroga (1980). This statement is borne by the studies of Agpad (1959) who reported that DBM was an insignificant pest of petsai and that endrin, diazinon, *Ryania*, and rotenone were effective against the cabbage moth, *Crocidolomia binotalis* Zeller. De Los Reyes (1960) and Retuerma (1961) also focused attention on the cabbage moth, a serious pest at that time, and tested endrin, diazinon, and DDT for controlling this insect. It was only later that insecticides were tested against DBM (Barroga 1967, Cadapan and Gabriel 1972, Calora et al 1968, Sanchez et al 1968). Granular insecticides were tested in the hope that they would solve the problem (Calora et al 1968, Pajarillo 1978).

The development of resistance is nowhere better attested to than by the number of compounds which were effective against DBM when first introduced only to become ineffective or marginally effective later; Barroga (1980) gave an extensive summary of these. More recently, in a survey of 155 farmers in 1982 (Magallona et al 1982) it was shown that cypermethrin, triazophos, *B. thuringiensis*, cartap, fenvalerate, deltamethrin, and metamidophos were most widely used (Table 1). These compounds, especially the pyrethroids, came onto the market only in the late 1970s, except for triazophos which was introduced in the early 1970s. The development of resistance to insecticides can be assessed through the comparative LD_{50} values of insecticides tested by topical application in 1978 in 1982 (Table 2) (Magallona et al 1982).

To get around the problem of resistance, farmers resort to mixtures of two or more compounds; the 1982 survey showed that about 50% of the farmers interviewed used mixtures (Magallona et al 1982). In the field, a hit-or-miss approach is used although some researchers have tried to provide a more scientific basis for the practice. Thus, Morallo-Rejesus and Eroles (1974) tried pairing such compounds as EPN, mevinphos, malathion, methyl parathion, dichlorvos, and carbaryl while Barroga (1980a) elucidated the mechanism of joint action of insecticides on malathion-resistant DBM.

Some attempts have also been made to place pesticide usage on a sound scientific basis by determining the critical time for application. Lumaban and Raros (1975) showed that the injury caused by DBM was most critical, thus requiring pesticidal treatment, four to five weeks after transplanting; damage before and after the period did not appears

Table 1. Main insecticides used in the Baguio-La Trinidad area, March, 1982[a]

Insecticide	Users	%
Kafil (cypermethrin)	29	18.7
Hostathion (triazophos)	26	16.8
Thuricide (*Bacillus thuringiensis*)	21	13.5
Vegetox (cartap)	19	12.2
Sumicidin (fenvalerate)	19	12.2
Decis (decamethrin)	18	11.6
Tamaron (methamidophos)	11	7.1
Others		7.9

[a] Source: Magallona et al 1982.

Table 2. Changes in toxicity of different insecticides tested against DBM[a]

Insecticides	LD_{50} mg/kg body weight 1978	1982
Deltamethrin	0.00048	0.089
Fenvalerate	0.0012	0.446
Rotenone	0.0023	0.275
Mevinphos	0.002	0.069
Triazophos	0.013	2.759

[a]Source: Magallona et al 1982.

to be critical. As reported in Velasco (1978), Magallona and Velasco (1980) showed that at high infestation levels, insecticidal protection is required four to seven weeks after transplanting whereas at low infestation levels, only marginal advantages are obtained with insecticidal application. However, these studies, which were done in the lowlands, appear to be too optimistic compared to actual practice in the Baguio-La Trinidad area, as shown by our survey (Magallona et al 1982). As seen in Figure 2, most farmers (about 73%) apply insecticides on the first nine days of transplanting while 58% apply them within 10 days of harvest.

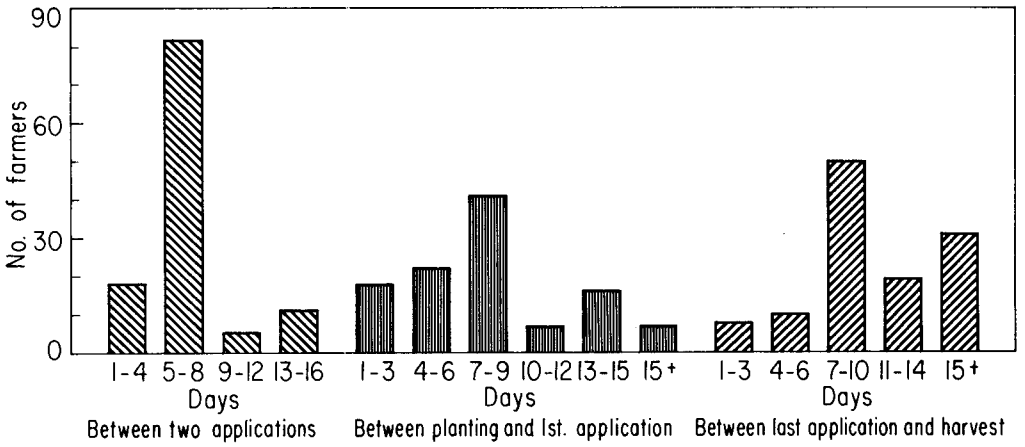

Figure 2. Results of the survey of farmers' insecticide application practices for crucifer pest control in Baguio-La Trinidad area

Medina (1979) reported the injury threshold of cabbage to DBM. DBM larvae of 3rd and 4th instars cause more damage than 1st instar ones. Significant yield reduction was observed with 1st instar larvae at 16 to 20 days after transplanting. The economic threshold is one larvae per plant. Gonzaga (1981) also developed a forecasting system for economical chemical control of DBM based on analysis of chemical control data. He found that early infestation up to the 26th or 32nd day after transplanting was critical for providing protection to cabbage. Late infestation did not have a significant effect on yield.

The residue aspects of pesticide usage against the DBM have also received attention. An earlier concentration was on residues in crops and soil as a consequence of application

(Morallo-Rejesus et al 1972, Magallona et al 1977, Magallona and Callejas 1977, 1979). On cabbage, the residues were concentrated in the leaves and wrapper leaves; removal of the wrapper leaves and washing should reduce residues considerably. In soil, degradation rates are rapid depending on the insecticide as well as on soil type. A shorter preharvest interval than in temperate countries can be allowed. These findings are generally in accord with expectations about the behavior and fate of pesticides in the tropics (Magallona 1983, Tejada et al 1976).

Subsequently, a systemic approach to residue data generation was developed using petsai as the example (Magallona et al 1981). The data are expected to be useful for the tropics and, as shown in Table 3 for methyl parathion and mevinphos, the residues obtained are much lower than the FAO/WHO-proposed maximum residue limits at the indicated preharvest interval. Washing and cooking further reduce the residue level in the crop (Table 4).

Table 3. Comparison of preharvest interval (PHI) as basis for FAO/WHO maximum residue limit (MRL) and UPLB[a] data on selected vegetables[b]

	FAO/WHO		UPLB level at PHI (mg/kg)
	MRL (mg/kg)	PHI (days)	
I. Methyl parathion			
Beans	1.0	14-21	0.01
Crucifers	1.0	14-21	0.05
II. Monocrotophos			
Beans	0.2	15-30	0.05
III. Malathion			
Beans	2.0	3	0.04
IV. Mevinphos			
Beans	0.1	1-14	0.01
Cabbage	1.0	1-14	—
Lettuce	0.5	1-14	0.05

[a] University of the Philippines at Los Banos. [b] Source: Magallona 1983.

Table 4. Effect of washing and cooking on the residue level of some organophosphorus insecticides in treated petsay[a]

Treatment	Uncooked			Cooked			
	Unwashed mg/kg	Washed mg/kg	Reduction (%)	Unwashed mg/kg	Reduction (%)	Washed mg/kg	Reduction (%)
Malathion	1.0	0.7	31.7	0.4	65.4	0.3	72.1
Methyl paration	1.8	1.1	37.3	1.1	36.2	0.3	81.4
Mevinphos	1.7	0.5	70.1	0.4	78.2	0.2	90.8
Triazophos	1.0	0.4	56.9	0.6	43.1	0.4	62.7

[a] Source: Magallona et al 1981.

There is a perceptible shift back to botanical pesticides at present. This is premised on the farmer being able to raise his own pesticide or develop small industries based on pesticides produced in the backyard. Extracts containing active principles from several plants have been tested against DBM. Reyes et al (1977) and Reyes (1982) evaluated *Tephrosia vogelii* Hooker, Eroles (1977) evaluated *Tagetes* spp, Carino (1981) tested *Tethonia diversifolia*, Javier (1981) used red and black pepper (*Capsicum annum* L. and *Piper nigrum*, respectively), Alcantara (1981) used *Ageratum conyzoides* while Ferrolino-Calumpang (1983) used *Artemisia vulgaris*.

Some efforts have also been directed to evaluating the more exotic types of chemicals. Morallo-Rejesus and Tetangco-Fabellar (1976), and Tetangco (1976), reported the ED_{25} and ED_{50} of *Attacus* and *Cecropia* juvenile hormones on DBM. Application of the juvenile hormones, reduced larval survival, pupation and adult emergence, larval-pupal intermediates, and increased the proportion of abnormal adults. Sterility effects such as reduced egg production and hatchability were transferred to F_1 and F_2 progenies.

Potentials for a Technology Package

A technology package is taken here to mean the application of viable technology components with flexibility at strategic times; it is not a rigid set of procedures as the term implies. Obviously however, the use of such a package depends on: (1) applicability of the components or their adaptation by the farmer, (2) in-depth knowledge of these components by those transferring the technology to the end user, and (3) willingness to use a technology package in an integrated manner rather than relying on a single component that offers temporary benefits.

From the standpoint of suitability, it is evident that while many components are already known, they have not been adapted sufficiently to be adopted by farmers. This is unhelpful because an aura of preparedness is projected and the end user finds out only later that much still remains to be done. Two examples are often mentioned with much optimism.

1. Tomato-cabbage intercropping: Unfortunately, only the success stories are reported in the published literature while the probably just as numerous unsuccessful efforts have remained unreported. For example, would this approach work at high DBM population levels or under continuous cropping? Under what conditions would it be guaranteed to work?

2. Beneficial organisms: This very promising approach has remained unexploited with the knowledge apparently remaining in research and academic circles. There has been no real effort to apply it in field crop protection.

A requirement for the adoption of a pest management system is also an in-depth knowledge of the components, either on the part of the farmer himself or of those extending the technology to him. This is lacking in the Philippines. Since the stimuli for advancement in knowhow and in extension capability have been absent, the consequence are extension agents who are themselves not satisfied with their careers.

This state of affairs is evidenced in our 1982 insecticide management survey of the Baguio-La Trinidad area (Magallona et al 1982). Of the 155 farmers interviewed 34% relied on the technicians of chemical companies, 26% on government technicians, 23% on pesticide dealers, and 17% on their neighbors. It is necessary, therefore, to give on-the-job training and incentive to the extension agents.

The willingness to use a technology package rather than to rely on a single, temporarily beneficial component should also be present. Already, everybody is aware of the potential of pesticides and their apparent simplicity, which makes them attractive to farmers. Against pesticides, the other components appear too cumbersome and complicated. Clearly then if the farmer is unwilling to take the initiative, government (or non-government) organizations should step in first to illustrate the utility of the other components and later to ensure continuity in their use.

In the case of agribusiness concerns, the problem appears to be one of unwillingness to obtain the services of a pest management specialist. Generalist types of workers appear to be more desirable notwithstanding their limitations in solving serious production problems. Of course, it is also to be emphasized that pest management components have to be worked out but these agribusiness concerns are in the best position to conduct development work (as against research) for the more lasting control of DBM.

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Discussion

C. Y. HSIN: Will the overhead sprinkler system be cost- effective in the dry season when water is precious?
G. FUNASAKI: Watercress is produced in areas where the supply of spring and artesian well water is plentiful. The naturally available water is recycled through the sprinkler system. Therefore, it would be cost-effective even during the dry season.

C. Y. HSIN: Are there any area limitation on the overhead sprinkler system?
G. FUNASAKI: There are no limitations as to locations that I know of. The system does appear to be more effective in large scale operations rather than in smaller ones, however.

P. A. C. OOI: Is there any reason for the difference in aggressiveness between the Taiwan and Trinidad strain of *Cotesia plutellae*?
G. FUNASAKI: Mass-rearing of the Taiwan strain in the insectary was easier because the female *C. plutellae* parasitized more DBM larvae than the Trinidad strain. The Taiwan strain appears to be healthier and more active than the Trainidad strain. It could be that the Trinidad strain had too much inbreeding before we got them from the CIBC insectary, whereas the material from Taiwan was field collected.

D. G. HARCOURT (COMMENT): Regarding the disruption of female activity, it is possible that the cooling effect of sprinkler irrigation is more important than the physical interference.

G. S. LIM: Has the threshold developed by you adapted by the farmers? If not why?
C. N. CHEN: No. Because the sampling method and the counting of insects in the field are still too complicated for the farmers, and the farmers are reluctant to take any risk when they see worms on their vegetables.

H. CHI: According to your results, the spatial distribution of DBM larvae can be described by a negative binomial distribution. It would be interesting to know how many plants with one or more larvae per 100 plants, when the mean is one larva per plant.
C. N. CHEN: About 35 to 50 plants would habor at least one larva each.

H. CHI: You have used Taylor's power law to describe the relation between means and variances. Could you conclude there is a common k or not?
C. N. CHEN: No. We could not detect any common k. In fact, k is unstable over the density range.

O. MOCHIDA: How often do you find DBM population on farmers' field below threshold level?
C. N. CHEN: I would say about 50% chemical applications by farmers are unjustified in their fields according to our control thresholds.

A. SAGENMUELLER: Would you please explain sample size in your paper concerning relationship between population density and sample size.
C. N. CHEN: The sample size (n) is obtained according to the following relationship:

$$n = \left(\frac{t}{D}\right)^2 am^{b-2}$$

where t is the student's t value at $p = 0.05$; D is the precision level chosen (i.e. $D = 0.1$ or 0.2, in this case); m = mean density in terms of number of larvae per plant; and a and b are parameters obtained from fitting to Taylor's power law, $S^2 = am^b$. Therefore, we can see that sample size is determined by several variables. When population density is high, we need less sample size to secure the same level of precision. In other words, sample size needed is inversely proportional to the population density.

A. VATTANATANGUM: How often vegetable growers in Taiwan follow the control threshold as recommended in your presentation?
C. N. CHEN: The control threshold discussed in our paper is recommended to the extension workers as a guidance for deciding the necessity of control in a farmer's field. It is still rather difficult to recommend it to the vegetable growers.

L. C. CHANG: Because the duration of crucifers for seed production is longer than for fresh market production, DBM is usually more damaging to the former. Would you care to comment on the DBM control stragey for crucifer seed production.
C. N. CHEN: I have no experience on crucifers for seed production. But I would think that chemicals with long residual effect will do a good job.

A. SIVAPRAGASAM: What is your sample size to estimate mean and variance of DBM population in the field? I presume you used the Taylor's Power Law to estimate sample size. Recently it has been found that Taylor's estimation could be spurious at low insect densities. On the other hand Iwao and Kuno's model for patchiness regression was a good fit. Why not use the latter model? Any comment?
C. N. CHEN: The sample size was 230-240 plants. As far as optimal sample size is concerned, I think either model is good enough for practical purposes. I have no any preference.

A. SIVAPRAGASAM: Do you think an economic threshold of one larva/plant is a practical threshold considering the fact that DBM population is aggregated in most cases. How about using sequential sampling to estimate critical densitites?
E. D. MAGALLONA: There are practical problems with regards the use of one larva/plant as the economic threshold. In fact, I think it is quite low under practical field situation and if followed may mean more insecticide applications than practical. The work really needs refinement to consider such problems as aggregation, population of natural control agents, stage of the plant infested, among others. The use of sequential sampling may be tried as a part of this refinement effort.

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