BIOLOGICAL CONTROL OF THE DIAMONDBACK MOTH IN IPM SYSTEMS: A CASE STUDY FROM ASIA (INDONESIA)

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ABSTRACT

The most serious pest of cabbage in Indonesia is the diamondback moth (DBM, Plutella xylostella). Since early 1970s, studies on the development of biological control of DBM with the use of ichneumonid parasitoid, *Diadegma semiclausum*, have been conducted in Indonesia. The parasitoid releases were combined with the use of microbial insecticide, *Bacillus thuringiensis*. Result from field studies during the last two decades showed that *D. semiclausum* is well established in almost all of the center of highland cabbage growing areas. Following the success of biological control programme of DBM, the Indonesian National Integrated Pest Management Programme in Vegetables was launched by the Indonesian Government in November 1991. To implement this programme, 42 Farmers Field Schools (FFS) on cabbage were conducted in four major provinces in 1992 and 105 FFS in eight provinces in 1993, involving 68 well trained Field Pest Observers, 165 Field Extension Workers and 3329 farmers. The IPM strategy includes: (1) growing healthy cabbage crop; (2) biological control of DBM using *D. semiclausum* as a core component; (3) control threshold levels as a base for judicious use of selective insecticides.

The benefits of IPM programme is manifested in:

(a) reduction of insecticide applications ca. 61% (1992) to 81% (1993);
(b) rate of parasitism increases, in some locations more than 80%;
(c) marketable yield were ca. 8 to 16% higher in IPM system vs. Conventional system;
(d) increase in profit by ca. $ 834/ha in IPM system over Conventional system;
(e) field workers and especially farmers become more confident on how to properly manage their cabbage crops and overcome pest problems based on IPM system. These significant results encourage the Indonesian government to continue and strengthen the implementation of IPM programme through the whole country using biological control of DBM as a core component of IPM.

INTRODUCTION

The diamondback moth (*Plutella xylostella*) has been recognized as the most destructive insect pest on crucifers in Indonesia since early in the 20th century. Damage by the diamondback moth (DBM) together with the cabbagehead caterpillar (*Crocidolomia binotalis*) on cabbage may reduce crop production to zero, especially under dry condition. The lowest population densities of *P. xylostella* and *C. binotalis*, and the smallest percentage of crop loss are usually found in the February plantings. This is correlated with a maximum of rainfall during the growing period. The suppressing effect of rainfall on *C. binotalis* is clearer than that on *P. xylostella*. Both species occur in the highest numbers on cabbage plants of approximately eight weeks after planting (Sastrosiswojo, 1975).

DBM is a notorious pest, because of its ability to develop resistance against insecticides. Result from the surveys to the center of vegetable growing areas in Java, Bali and Sumatra carried out in late 1970s showed that cabbage growers applied pesticides two three times per week (more than 22 times/season) with dosages far exceeding those recommended. Satisfactory control of DBM has become difficult due to its development of resistance and resurgence to different insecticides. In 1953, Ankersmit reported that DBM had become resistant to DDT in Java (Ankersmit, 1953). In the 1960s, organophosphorous insecticides were used intensively in the highland areas, followed by synthetic pyrethroids in late 1970s. Since then, resistance to most of the commonly used insecticides has been observed in DBM. Levels of DBM resistance to acephate, triazophos and deltamethrin were 1972-fold, 31-fold and 267-fold respectively, compared with permethrin (Sastrosiswojo et al., 1989). Intensive applications of permethrin, acephate and quinalphos on cabbage was reported to increase the fecundity and longevity of *P. xylostella* (Sastrosiswojo, 1988). This situation is not only leads to ineffective control and excessively high pesticide costs, but also to considerable human and environmental hazard and harmful side effects for beneficial insects. At present there are only a few type of insecticides which are still effective against DBM, for example commercial preparations of *Bacillus thuringiensis*, avermectin and insect growth regulators (IGRs).

A possible alternative to chemical control of DBM is biological control. This paper reviews the introductions of an ichneumonid parasitoid (*Diadegma semiclausum*) into Indonesia since 1950 up to the present time and the development of biological control of DBM by using this parasitoid as a core component of integrated pest management (IPM).

DEVELOPMENT OF BIOLOGICAL CONTROL

First Introduction (1950 to 1975)

Efforts to achieve biological control of DBM by introduction of exotic parasitoids were initiated in the 1920s. In 1928, Leefman introduced the ichneumonid parasitoid (Angitia fenestralis) from the Nederlands, but failed to get a laboratory culture established. A second effort by Vos (1953) was more successful. This involved the species Diadegma eucerophaga (*D. semiclausum* or Angitia cerophaga) closely related to D. fenestralis. In 1950, *D. semiclausum* was shipped to Indonesia from New Zealand. In the latter country it had been introduced earlier from England and established itself well as a parasitoid of DBM. As described in detail by Vos, the import and release of *D. semiclausum* in the cabbage growing area around Pacet (West Java), led to its establishment there as an effective biological control agent. Following the success in this original relese area, attempts were made to introduce the parasitoid in other cabbage growing areas as well. These efforts reportedly only succeeded in two locations, in Central Java and West Sumatra respectively, where cabbage was grown from cuttings and few insecticide treatments were applied. The more commonly used practice of growing cabbage from seed entailed heavier use of insecticides, thwarting efforts to get *D. semiclausum* established.

No investigations were carried out on the status and further spread of *D. semiclausum* during the 15-year period following Vos' publication in 1953. Although several releases of *D. semiclausum* have been made in Lembang (West Java), 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. semiclausum* in the vegetable growing area of Lembang, was reported by Sastrodihardjo (1974). An intensive study was conducted from November 1968 up to mid-1969 and from January to July 1970. He reported that less than 60% of the DBM population was parasitized by *D. semiclausum*. 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.

During 1971 to 1975, two different studies were carried by Sastrosiswojo and Eveleens (1977) with the objectives of determining: (1) The distribution of *D. semiclausum* as a DBM parasitoid in Indonesia; (2) Rates of parasitization in two selected vegetable centers (Pacet and Lembang) in West Java.

1. Distribution of *D. eucerophaga* in Indonesia. Surveys were carried out in the 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. semiclausum* 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 indicated that the parasitoid is well established in Java and Bali, and in parts of Sumatra but not in Sulawesi (Table 1).

Table 1. Results of a country-wide survey on the distribution of *D. semiclausum* in Indonesia, 1971-1975

Province with	District	No.of plantings surveyed	No.of plantings with *D. semiclausum*
West Java	Bandung	2	2
	Cianjur	3	3
Central Java		3	3
		3	3
		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

Some observations on the level of parasitism in three larger islands: Java, Bali and Sumatra are as follows:

A. Java and Bali. *D. semiclausum* was widely distributed in all three provinces of Java and in Bali. Despite the widespread occurrence of the parasitoid, DBM was 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. *D. semiclausum* was not found in the districts of Agam and Solok, except in an isolated area near the village of Alahan Panjang, more than 100 km southeast of the original release site. In this field, DBM was scarce and heavily parasitized by *D. semiclausum*. These findings indicate that the parasitoid had spread over the highland vegetable region of West Sumatra, but was of limited effectiveness.

In North Sumatra, no *D. semiclausum* was found. Vos (1953) had already reported failure of release efforts at Brastagi and Tarutung due to excessive use of insecticides. Severe DBM infestation of crucifers was observed in these areas. 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.

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 programme 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.

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

Month	Pacet [a]			Lembang [b]		
	Larvae		Parasitized	Larvae		Parasitized
	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

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 was concluded that *D. semiclausum* was acting 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 ares ranges from 37 to 81% with an average of 70.4%, a little higher than that reported by Sastrodihardjo (1974).

Second Introduction (1976 to 1989)

A. North Sumatra. Although *D. semiclausum* had been introduced to North Sumatra in 1951/1952 (Vos, 1953), from field surveys 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. semiclausum* from Segunung (Pacet, West Java) to Brastagi, North Sumatra, in March 1976. Following mass rearing at Kutagadung (Brastagi), the parasitoid was again released in the vicinity of Brastagi wich is a center of cabbage growing areas in North Sumatra. These efforts were combined with a selective spraying regime of *Bacillus thuringiensis* formulation (Bactospeine, Dipel, Thuricide). According to our studies, *B. thuringiensis* is effective against DBM and cabbagehead caterpillar and does not have any detrimental effects on the parasitoid (Sastrosiswojo *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. semiclausum* (Sastrosiswojo, 1981). The same methods as described earlier were used. Surprisingly, the parasitoid was found widely ditributed and has established by itself very well in all of the vegetable growing areas. 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, appoximately 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. It was concluded 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. semiclausum* in various cabbage fields in North Sumatra (October 1981)

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

[a] No. of larvae sampled were too small, but all were parasitized by *D. semiclausum*.

B. Sulawesi. Using the same method as mentioned earlier, 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 (Bantaeng, Jeneponto and Gowa), infestations of cabbage by DBM were moderate to high and no *D. semiclausum* was found. In these areas, the parasitoid has never been released. 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. semiclausum* was introduced into South Sulawesi from Lembang (West Java) in collaboration with the local university staff and extension service in South Sulawesi. The parasitoid introductions were repeated several times in 1984 to 1986. Following the parasitoid releases, field surveys were made in 1991 and 1992. Results indicated that *D. semiclausum* was established in Gowa and Jeneponto districts, and had become an important biological control agent of DBM.

C. West Java. An intensive survey was carried out in October 1983 with the objective of determining the distribution and effectiveness of *D. semiclausum* as a biological control agent of DBM in West Java (Sastrosiswojo, 1984). Similar research methods to those described earlier were used. During the study, all cabbage growing areas in the highlands of West Java were visited. The results of an extensive survey of the distribution and rates of DBM parasitism by *D. semiclausum* are summarized in Table 4.

Table 4. Rates of parasitization of DBM larvae by *D. semiclausum* in various cabbage fields in West Java (October 1983)

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

a) Population of DBM was very low, due to *B. thuringiensis* spray.
b) Population of DBM moderate to very high, ranging from 3.5 to 24.1 caterpillars/plant. DBM problem was very severe.

Results of the extensive survey indicate that *D. semiclausum* is well established in West Java. 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. semiclausum 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 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. semiclausum* is well established in areas such as in Kuningan and Sukabumi where it has never been released. Presumably cocoons of *D. semiclausum* 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 programme 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. semiclausum* played an important role in the control of DBM. On the other hand, in some other locations, *D. semiclausum* 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.

Third Introduction (1990 to 1995)

Status in the highland areas

Following the success of parasitoid introductions in North Sumatra and South Sulawesi, attempts were made to introduce *D. semiclausum* into the provinces of Aceh, Lampung and Bengkulu in 1993, Irian Jaya in 1993-1994, and North Sulawesi in 1990 to 1993. These provinces are relatively new centers of cabbage growing areas in the highlands. Before the parasitoid introductions were made into those areas, some short trainings on biological control of DBM were held at Research Institute for Vegetables (RIV), Lembang (West Java). The participants of the training were: staff from the Regional Plant Protection Institute (RPPI), Field Pest Observers (FPOs), Field Extention Workers (FEWs), students or junior staff from local universities, staff of local NGOs or even the key farmers. Budget for the trainings were supported by RIV, the Indonesian National IPM Programme (Phase I, 1992 to 1994) and the Asian Vegetable Network (AVNET-AVRDC) Phase I and II (1990 to 1996). In addition, the AVNET Programme also supported rearing facilities for RIV (Phase I) and for RPPI (at the province of Bengkulu, Phase II) by constructing one glasshouse/screenhouse at each location. After the termination of the trainings, the trainees introduced *D. semiclausum* from RIV and then mass produced in the glasshouse, screenhouse or laboratory. Following the mass production, the parasitoids were then released several times to farmers' field in the above mentioned provinces. After about two or three years from the parasitoid introductions, extensive field surveys were made either by the field workers, staff from local universities or researchers from RIV (Lembang) to evaluate the status of biological control of DBM by *D. semiclausum*. The same methods as described earlier were used.

A. North Sulawesi. In 1990, *D. semiclausum* from RIV (Lembang) was introduced into Tomohon (Minahasa) which is one of the centers of cabbage growing areas in mid-level highland (600-700 m a.s.l), at the slope of Mount Lokon. The parasitoids were mass produced in the laboratory of the University of Samratulangi, and at the first time about 200 cocoons were then released to cabbage fields. From the monitoring, it was found that rate of parasitism ranging from an average of 36.5% to 48.7%. Although the parasitoid was temporary established, the eruption of Mount Lokon in 1991 may have dessimated these populations. Therefore,a second introduction of *D. semiclausum* was made in May 1993 and releases to farmers' fields were made in October 1993. From the field survey it was found that *D. semiclausum* occurred in significant abundance and the rates of DBM parasitism ranged from an average of 46 to 58% at Kakaskasen (Tomohon). In the other areas (Paslaten and Rurukan), the rates of DBM parasitism were higher than at Kaslaten, ranging from an average of 64.3 to 90.19%. However, presently the full potential of the parasitoid in North Sulawesi seems insufficiently exploited, due to much interference from the sole reliance of the cabbage growers on chemical insecticides (Wanta, 1996).

B. Bengkulu. In October 1993, *D. semiclausum* was introduced into Sub-district of Rejang Lebong which is one of the center of cabbage growing areas in the province of Bengkulu. From the visit in December 1995, it was found that *D. semiclausum* adults occurred abundantly in farmers' fields, especially in cabbage fields surrounding the screenhouse of RPPI. However, rates of DBM parasitism in farmers' fields were still relatively low, less than 50%. Some efforts are needed to change the farmers' attitude in using chemical insecticides to allow the parasitoid establishes permanently in these areas.

C. Aceh, Lampung and Irian Jaya. Reports were received from the field workers in these provinces, mentioning that D. semiclausum was also temporarily established. Due to some reasons, intensive surveys have never been conducted in these provinces. Therefore, more detail information on the status of biological control of DBM by *D. semiclausum* in those areas is unable to be described.

<u>Status in the warmer areas</u>

In collaboration with AVNET Programme, efforts were made to introduce *D. semiclausum* in the warmer (mid-elevation) areas to suppress DBM populations since 1991. The use of chemical insecticides in the warmer areas is very intensive because the damage on cabbage caused by DBM is economically very important. Following the mass production at the greenhouse of RIV (Lembang), the parasitoids were released in farmers' fields in the district of Majalengka (West Java) and Magelang (Central Java). These districts are two important cabbage production areas in the warmer areas. The parasitoid releases were combined with the use of *B. thuringiensis* formulation when the DBM population surpasses its control threshold level (0.5 caterpillar/plant).

Field surveys were carried out in the cabbage gowing areas of Majalengka and Magelang, from June to October 1995. Four locations were selected from each of these districts, where the parasitoid has been released. The same methods as described above were also used. During three times of observations, *D. semiclausum* was found in all cabbage growing areas visited in Majalengka. The rates of DBM parasitism ranged from an average of 63.29 to 86.44%, indicating that *D. semiclausum* had established. In Magelang, the levels of DBM parasitism ranged from an average of 36.51 to 50% which were lower than in Majalengka. This situation might be due to the use of broad-spectrum chemical insecticides by cabbage growers in Magelang or because cabbage was not continuously grown by the farmers in Magelang (Setiawati and Sastrosiswojo, 1996). Result from this study showed that *D. semiclausum* may become permanently established when this parasitoid was introduced in the warmer areas. In addition, *D. semiclausum* also may become an important biological control agent for the suppression of DBM populations on cabbage in the warmer areas.

BIOLOGICAL CONTROL OF DBM AS A CORE COMPONENT OF IPM

From the foregoing information it is evident that *D. semiclausum* is an important biological control agent of DBM in the centers of cabbage growing areas in the highlands and in the mid-elevation (warmer) areas in Indonesia, especially in the areas where the parasitoid is well established. As indicated earlier, *D. semiclausum* could effectively suppress the DBM populations in cabbage growing areas. Levels of DBM parasitism were relatively high, in some places amounting to more than 80%. Although the rate of parasitism can not always be correlated directly with the success or failure of control of DBM, this component of biological control nevertheless has great potential for developing IPM.

Despite the success of biological control of DBM, results of our surveys have indicated that *D. semiclausum* was 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 (Sastrosiswojo and Eveleens, 1977). The crop is grown in isolated single plantings, in rotation with other crops like paddy rice, especially in the warmer areas. 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 of DBM.

Secondly, in some places farmers tend to spray a variety of insecticides in a calendar system to protect their crops. Spraying is done at least twice a week, often with disappointing results due to the development of resistance by DBM. 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. semiclausum*.

Thirdly, most of the growers are not aware that *D. semiclausum* has already been established in their areas 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, some farmers rely solely on chemical control. As Stehr (1975) has observed, grower understanding and education is essential not only for any biological control programme, but also for an entire pest management programme.

At present *D. semiclausum* has established itself very well in most highland vegetable growing areas and some mid-elevation areas of Indonesia, except in some newly cultivated areas. This fact encourages us to include this parasitoid as a core component of IPM programme on cabbage.

DBM is a notorious pest for its ability to develop resistance against chemical insecticides. For this reason, we need to put less emphasis on chemical control to combat DBM problem. If the insecticides are necessarily should be used, they should give satisfactory control of DBM and other cabbage caterpillars, and be non-toxic or less harmful to *D. semiclausum*. In this regard, some examples of selective insecticides are formulations of *B. thuringiensis*, avermectin and IGRs (Sastrosiswojo, 1984).
The accepted theory of pest management dictates that insecticides should be applied when insect pest populations approach or exceed an economic threshold. In our view the use of an action threshold or control threshold is more practicable. Insecticides should be applied only

when the 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 studies indicated that the control threshold for DBM on cabbage is approximately 0.5 caterpillar/plant (Sastrosiswojo, 1987). Selective use of insecticides based on the population of insect pests might be ideal for developing IPM programmes. In this way, *D. semiclausum* is conserved by applying insecticides to cabbage only if the DBM population reaches the threshold level for control. Another benefit of using thresholds is that the amount of insecticide usage is reduced and the problem of DBM resistance is delayed.

Chiang (1980) stated that the enrichment of natural enemy fauna and flora would be very useful strategy in IPM programmes. Therefore efforts for conservation and further augmentation of *D. semiclausum* are undertaken, such as the use of selective insecticides when the DBM population surpasses its control threshold (0.5 caterpillar/ plant), the use of trap crops (rape for DBM and Indian mustard for *C. binotalis*), and manipulation of cabbage cultivation through cabbage-tomato intercropping system (Sastrosiswojo, 1987).

Since 1970s, the biological control programme for effective suppression of DBM has been developed in Indonesia by introductions of larval parasitoid, *D. semiclausum* into several centers of cabbage growing areas of Indonesia. In addition, considerable efforts were also made to develop other IPM components including: (1) Growing healthy cabbage through balance fertilization, liming to control clubroot disease, and other cultural management such as cabbage-tomato intercropping and the use of trap crops (rape and Indian mustard); (2) Varietal resistance; (3) The use of selective insecticides; (4) Establishment of control thresholds (tentative economic threshold) for *P. xylostella* (0.5 larva/plant) and *C. binotalis* (0.3 egg mass/plant). These components are not only useful to conservation and augmentation of *D. semiclausum*, but they are important components of IPM for other cabbage pests, including diseases.

Monitoring of establishment, conservation and build-up of *D. semiclausum* in various cabbage growing areas has shown that the parasitoid is well established and widely spread, and in most cases providing effective suppression of DBM. It is evident that *D. semiclausum* become an important biological control agent of DBM in cabbage growing areas, especially in areas where it is well established. As indicated earlier, *D. semiclausum* could effectively suppress the DBM population in cabbage growing areas. This component (biological control of DBM) has great potential for developing IPM programme in Indonesia.

DEVELOPMENT AND IMPLEMENTATION OF IPM PROGRAMME

Indonesian National IPM Programme

The main component of IPM programme is essentially human resource development. Field Pest Observers (FPOs), Field Extention Workers (FEWs) and in particular farmers are given intensive practical training in IPM. The objective of the training is to increase their capabilities to make their own decision to overcome pest problems in their own fields based on IPM principles: (1) grow a healthy crop; (2) use and conserve the natural enemies; (3) weekly or routine field observations; and (4) farmers as IPM "experts" or professional "managers" in their farms. The training approach is "the experiential learning" methods, carried out by farmers in their fields. The discussions among the participants are made informal and the function of Field Leaders (FPOs) are only as facilitators, motivators or resource persons. The important part of the discussions is the analysis of agroecosystem and the decision making.

The Indonesian National IPM Programme for highland vegetable pests (on cabbage and potato) was launched in November 1991. The first cycle of the IPM training was directed at training Trainers who will facilitate Farmers Field Schools (FFSs). A training of trainers (TOT) programme was held at Lembang Horticultural Research Institute (LEHRI, now RIV) from January to May 1992 (one growing season). The participants of the IPM training were twenty Field Pest Observers (FPOs), seven Field Extension Specialists, five staff of Agriculture Official Training Institute, twenty staff of Field Laboratory of Regional Crop Protection, one staff of Directorate of Crop Protection and eight staff of LEHRI, all together 60 trainees.

The second cycle of IPM training of trainers was also held at RIV (Lembang) from April to July 1993. 52 DPOs were trained in the implementation of IPM concept and technology on cabbage (also on potato and tomato). The participants receive season-long training, same with the first cycle.

The third cycle of IPM trainer training on highland and lowland vegetables (cabbage, potato, chili and shallot) was held at Research Institute for Vegetables (RIV), Lembang, from June to October 1995. During this training, 20 Field Pest Observers (FPOs) from 10 provinces were intensively trained in IPM concept and technology, especially on lowland vegetables. Since early November 1995, these well trained FPOs (socalled Field Leader II or FL-II) have conducted 72 FFSs in 10 provinces of Indonesia.

During the IPM training, trainers receive season long training, that is about 500 hours for IPM specialists of Field Leaders (FPOs or FL-I, FL-II), and a minimum of 50 hours for farmers.

<u>IPM Components for Cabbage Pests</u>

The IPM components for cabbage pests in the highland areas are briefly summarized as follows :

1) Cultural practices :
   -Cabbage-tomato intercropping and trap cropping (rape or Indian mustard) for DBM and *C. binotalis*, liming (pH above 6.0) to control clubroot, sanitation, balanced fertilization, and crop rotation to control for other soil pathogens.

2) Biological control :
   -Parasitoids, *D. semiclausum* (and C. plutellae) for DBM;
   -*Mortierella* sp. for clubroot (under study).

3) Control threshold level (CTL) :
   - DBM : 0.5 larva/plant.
   - *C. binotalis* : 0.3 eggs mass/plant.

4) Selective insecticides :
   - Microbial insecticides such as : *B. thuringiensis*, Avermectin.
   - I.G.R. : chlorfluazuron, teflubenzuron.

5) Sampling technique and sample size :
   - 10 plants/0.2 ha or 50 plants/ha.
   - Determined systematically : diagonal system or U-shape system.

6) Assessments : Record every week the number of :
   -3 rd/4th instar larvae and pupae of DBM, parasitized DBM larvae and cocoons of *D. semiclausum* from sample plants.
   -Egg masses of *C. binotalis*/sample plant.

7) Control decission :
   - For DBM, use simple equation Y = (1-P).X, where :
   Y = predicted number of damaging larvae.
   P = total parasitism of DBM larvae (expressed in decimal system : 0 to 1).
   X = mean number of DBM larvae/plant.

   Insecticide spray should be undertaken only when the value of Y reaches/surpasses control threshold of DBM (0.5 larvae/plant).

   - For *C. binotalis* :
   Spray with effective, selective insecticide when the number of egg masses more than 0.3 plant (CTL).

Achievements of IPM Implementation on Cabbage

First cycle (1992)

Forty two cabbage FFSs were conducted in North Sumatra, West Sumatra, West Java, Central Java, East Java and Bali provinces, involving about 840 farmers.Two FFS were supervised by one well trained FPO (Field Leader II) and supported by two FEWs. The benefits of IPM implementation on cabbage is very clear as follows (table 5) :

1) Savings by the farmers in terms of pesticide purchases are very significant. The reduction on insecticide and fungicide usage were ca. 61% and 90% respectively in cabbage IPM system over conventional farmers practice.

2) The yields of cabbage was increased in IPM system ca. 16.0% over conventional farmers' practice.

Although a detailed economic analysis has not been undertaken as yet, nevertheless it may be assumed that IPM system can provide a higher revenue when compared to farmers' practice of using chemical pesticides prophylactically. As an example, application of IPM system on cabbage in West Sumatra (Solok), the profit in IPM system was of ca. Rp 6,500,000 or approximately $ 3,095 compared with farmers' practice ca. Rp 1,560,000 or approximately $ 743 (1 US $ = Rp 2,100).

Table 5. Results of IPM implementation on cabbage, 1992

Location (Province/ District)	Efficiency (%) *		Yield (t/ha)*	
	Insecticide	Fungicide	IPM	Conventional
1. N. Sumatra: - Tanah Karo	66.7	No	27.1	29.4
2. W. Sumatra: - Solok	87.5	No	49.0	27.2
3. W. Java:	58.5	83.3	35.5	27.9
- Bandung	62.3	90.0	34.7	28.2
- Garut				
4. C. Java:	52.6	No	37.1	31.3
- Magelang	63.9	100.0	34.0	40.2
- Banjarnegara				
5. E. Java:	62.1	100.0	24.9	24.1
- Malang	52.9	No	16.5	13.0
- Probolinggo				
6. Bali: - Tabanan	42.9	75.0	74.4	66.1
Means	61.0	89.8	37.0	31.9
Yield increased (%)	16.0			

* Means of 42 Farmers Field Schools.

Second cycle (1993)

The result of a further 105 cabbage FFS's scattered in 8 provinces also clearly confirmed the superiority on IPM system over Conventional system practiced by the farmers. Application of the IPM system on cabbage reduced the frequency of pesticide sprays by 80.7% for insecticide sprays and 94.9% for fungicide sprays (Table 6). In addition, the amount of pesticide usage were also significantly reduced by 80.5% for insecticide and 95.6% for fungicide in IPM system vs. conventional farmers practice. The yield of cabbage in IPM system was 7.6% higher over conventional farmers practice (Table 7). The net profit also increased by ca. $ 833.7/ha ($ 1,300.6 in IPM system vs. $ 466.9/ha in conventional farmers practice) and the R/C was 1.6 in IPM system vs. 1.2 in conventional farmers practice

The implementation of IPM concepts and technology on cabbage through 147 FFSs over two years demonstrated that the IPM system can provide a higher net revenue compared to conventional farmers' practice. The IPM system also required less pesticide application, and yet was able to secure healthy and higher quality yields. More importantly, no pesticide residue was left in cabbage crops. In addition, harmful side effects of pesticide use were avoided on beneficial insects such as *D. semiclausum*, an important parasitoid of DBM. Field surveys rates of DBM parasitism increased in IPM systems and in some locations exceeded 80%.

Table 6. Number of pesticide application and amount of pesticide usage during on growing season, and their efficiency in IPM implementation on cabbage, 1993

Province	Number of District	FFS*	Number of pesticide application**						Amount of pesticide usage**					
			Insecticide Sprays			Fungicide sprays			Insecticide (1 or kg/ha)			Fungicide (kg/ha)		
			IPM	Conv.	% Ef.	IPM	Conv.	% Ef.	IPM	Conv.	% Ef.	IPM	Conv.	% Ef.
1. DI Aceh	1	1	3.0	8.0	62.5	2.0	5.0	60.0	1.1	3.4	67.6	2.2	8.4	73.3
2. N. Sumatra	2	17	3.3	14.8	76.0	0.3	8.9	97.7	3.3	14.0	76.4	1.0	25.4	96.8
3. W.Sumatra	3	4	0.8	18.3	95.8	0.0	18.0	100.0	2.7	16.2	83.3	0.0	19.6	100.0
4. W. Java	4	28	3.4	9.8	65.9	0.5	7.8	93.5	4.0	24.8	83.9	0.8	34.0	95.3
5. C.Java	5	27	1.9	7.5	74.2	0.1	4.7	73.8	3.7	19.0	80.5	1.3	32.6	75.4
6. E.Java	4	17	2.4	8.0	70.9	0.3	7.8	72.8	4.0	12.1	66.9	0.4	12.7	72.3
7. Bali	3	6	3.7	32.6	84.1	1.0	27.4	95.1	6.1	31.6	80.7	0.7	12.3	96.4
8 .S.Sulawesi	3	5	2.0	9.1	79.3	0.0	0.0	0.0	2.2	18.4	88.0	0.0	0.0	0.0
TOTAL	25	105	20.6	108.1	-	4.1	79.5	-	27.1	139.5	-	6.4	145.0	-
MEANS	-	-	2.6	13.5	80.7	0.5	9.9	94.9	3.4	17.4	80.5	0.8	18.1	95.6

* FFS = Farmer Field Schools
**IPM = IPM system; Conv. = conventional farmers' practice
Ef.= Efficiency (reduction) IPM over conventional farmer's practice (%).

Table 7. Yield and economic analysis of IPM implementation on cabbage, 1993

Province	Number of		Yield (t/ha)*			Partial economic analysis (US$)**							
	District	FFS *	IPM	Conv.	Diff. (%)	IPM System				Conventional system			
						Value	Cost	Net return	R/C	Value	Cost	Net Return	R/C
1. DI Aceh	1	1	28.6	34.3	-16.6	4,271.0	3,218.7	1,052.3	1.3	5,121.5	4,654.2	467.3	1.1
2. N.Sumatra	2	17	57.2	62.6	-8.6	2,369.2	3,219.4	1,149.8	1.9	1,527.1	1,287.1	240.0	1.2
3. W.Sumatra	3	4	72.4	53.6	35.1	4,609.0	2,112.9	2,496.1	2.2	1,936.9	1,163.1	773.8	1.7
4 .W.Java	4	28	19.6	16.9	16.0	3,282.2	2,039.7	1,242.5	1.6	2,930.8	2,356.1	574.7	1.2
5 .C.Java	5	27	37.1	34.7	6.9	2,598.4	1,579.3	1,019.1	1.7	2,294.4	1,929.0	365.4	1.2
6. E.Java	4	17	38.5	34.5	11.6	2,526.1	1,805.0	721.1	1.4	2,490.7	1,855.1	635.6	1.3
7. Bali	3	5	52.5	63.0	-16.7	3,680.8	3,007.8	67.3	1.2	3,483.5	3,716.8	-233.3	0.9
8. S.Sulawesi	3	6	67.4	47.5	41.9	3,574.8	1,523.7	2,051.1	2.4	2,615.0	1,703.7	991.3	1.5
TOTAL	25	105	374	373.3	-	26,911.5	16,506.5	10,405.0	-	22,399.9	18,665.1	3,734.8	-
MEANS	-	-	43.4	46.7	7.6	3,363.9	2,063.3	1,300.6	1.6	2,800.0	2,333.1	466.9	1.2

FFS = Farmers Field Schools;
* IPM = IPM system; Conv. = Conventional System
** US $ 1 = Rp 2,140 (February 1994)

CONCLUSIONS

Considerable effort has been done to develop biological control of DBM using its introduced larval parasitoid, *D. semiclausum*. The parasitoid become established as an effective biological control agent of DBM in most parts of cabbage growing areas in Sumatra, Java, Bali and Sulawesi. The most important constraint in developing biological control programme of DBM in Indonesia has been geography: the distance between one island/center of cabbage growing area to the others is generally very far.

Experience to date has shown that biological control agents such as parasitoid *D. semiclausum* are key components of an IPM programme for DBM. Training on the development and implementation of IPM on cabbage has made a good start, and significant progress has been achieved. However, there are still many challenges in the future that needs to be overcome such: (1) Many more Field Pest Observers and Field Extension Workers need to be trained to support biological control and IPM programme; (2) Supporting research to strengthen and improve the IPM components is needed in various agroecosystems; (3) Continuity of farmer training must be maintained so that farmers become independent IPM practitioners.

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