# TRAINING u OF DIA *MDBAU J6

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CONTENT

# INTRODUCTION

Among the major traditional plant species that constitute vegetables, members of plant family Crucifereae predominate and are grown widely in tropical and temperate climates. These include cabbage *(Brassica oleracea* var. *capitata L.),* cauliflower *(Brassica oleeaacea* var. *italica),* broccoli *(Brassica oleracea* var. *botrytis),* radish *(Raphanus satiuus L.),* Chinese cabbage *[Brassica campestris* L. ssp. *pekinensis* (Lour.) Olsson] and numerous leafy greens such as kale *[Brassica oleracea* L. var. *albogastra* (Bailey) Musil.], mustard *[Brassica juncea (L.)* Czerniak], pak-choi and spoon cabbage *(Brassica campestris* L. *ssp. chinensis)* all of which are economically important. Like most other vegetable species, crucifers are grown, especially in Asia, in home gardens, periurban environments around cities and in specialized production areas in the highlands and lowlands. The short-duration leafy crucifers are especially suited for periurban agriculture and grown throughout the year which represent an important uninterrupted source of vegetables to consumers and daily ready cash income to farmers. No matter where or when the crucifers are grown, diamondback moth (DBM), *Plutella xylostella (L.),* unfailingly attacks the crop. The larvae of this pest feed on all above-ground plant parts from germination till harvest, and greatly reduce both quality and quantity of the produce. The damage is especially serious in tropics where ideal temperatures and presence of crucifers throughout the year leads to rapid multiplication of pest population.

To control this pest, farmers use large quantities of insecticides. This intensive and often indiscriminate use of chemicals coupled with rapid turnover of generations has resulted in DBM becoming resistant to practically all categories of insecticide used in its control. This- phenomenon is especially serious in intensive vegetable growing areas throughout the tropics and subtropics. The lack of suitable alternative control measures forces farmers to rely on the use of chemicals despite their diminished effectiveness. Desperate farmers are now using tank mixtures of several chemicals and spraying them more often. In addition to being constant health hazards to farmers, who apply the toxic insecticides, and consumers who consume insecticide-tainted vegetables, indiscriminate use of chemicals has resulted in increased cost of production making certain vegetables out-of-reach for average consumer, and degraded the quality of environment. It has recently come to light that indiscriminate pesticide use kill innocent predators like spiders, ants, earwigs and others which in the absence of pesticides, help reduce pest population. This side effect not only results in resurgence of DBM, but it is now held responsible for epidemics of other pests like whiteflies, leaf miners and thrips. It is urgently important to get out of this pesticide dependency treadmill because old pesticides do not work anymore and new chemicals are not coming into market fast enough especially to control DBM.

It is indeed possible to reduce pesticide use drastically and achieve DBM control on a sustainable basis with minimum monetary and environmental cost, if we take the advantage of wealth of knowledge of biology and ecology of this ubiquitous pest. This manual briefly explains the biology and ecology of DBM, formidable array of its natural enemies such as predators and parasites that attack the pest, and highlights the weak points in the life cycle of DBIVI that can be exploited to our advantage in devising an economical and environmental - friendly and sustainable control of this deadly pest.

Most of the information included in this manual is derived from AVRDC's past 24 years' experience in working with DBM and published reports. In the last chapter of this manual we have given details of these reports. We urge readers to read these reports for in-depth information.

Figure 1-1. Indiscriminate use of chemical insecticides for DBM control is common throughout most of tropical to subtropical world

# BIOLOGY OF D ONDBAC. MOTH

Diamondback moth, like most other Lepidoptera, lives through four different life stages; egg, larva, pupa and adult (Figure 2-1). These stages look different, behave differently and have different food requirements.

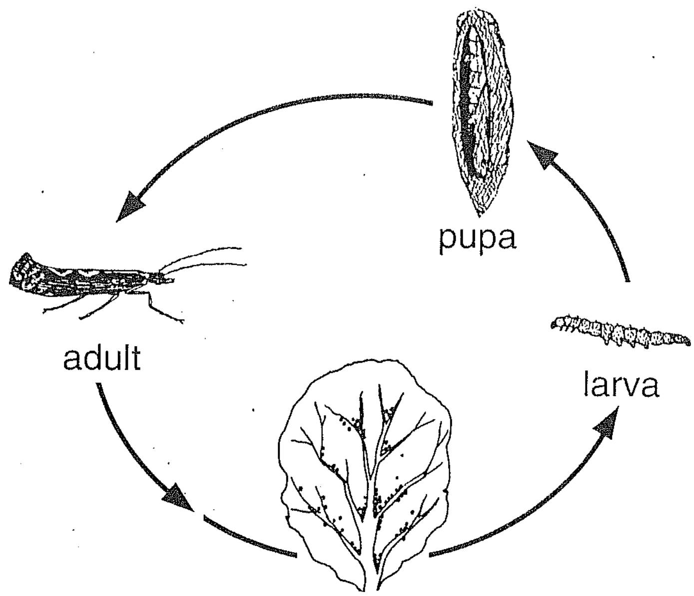



Figure 2-1. Four life stages of diamondback moth

**Egg**

Eggs are laid only on crucifer plants, mostly on the lower leaf surface scattered along the edges of leaf veins (Figure 2-1). DBM adult female lays up to 100 eggs in her life time of 3-7 days. The eggs are very tiny measuring less than 1 mm. When laid the eggs are white, but change to yellow brownish as they mature and ready to hatch into larvae. Eggs do not need any food. Egg stage lasts 4 to 6 days. Eggs then hatch and become larvae.

Eggs although tiny, are attacked by a few species of equally tiny egg parasites which kill some eggs before they hatch into DBM larvae.

**Larva**

Practically every egg hatches into one DBM larva. Soon after eggs hatch, the larvae start feeding on leaves and other above-ground plant parts and continue feeding until they become pupae. The newly hatched larvae are small 2-3 mm long, and translucent. After two days of they molt. Their old skin is cast off and under it a new skin develops. The caterpillar gets bigger and continues to feed on leaves. They are now 5-7 mm long with green body and dark head. Their appetite and feeding rate increases. After 3-4 days they molt again. The old skin is cast off and underneath a new skin develops. The caterpillar gets even bigger and continues to feed on leaves. They are now 8-10 mm long with green body and dark head. Their appetite gets hardier and feeding rate even higher than before. By this time their feeding create 1-2 cm wide cavities in cabbage leaves. These cavities have distinct transparent papery window-like appearance caused by inability of the caterpillar to feed on the translucent waxy layer that covers the crucifer leaves (Figure 2-2). After 3-4 days of voracious feeding they cast off their old skins again. Under the old skin the larvae have a new skin. The caterpillar gets bigger and bigger and feeds on cabbage leaves more and more. At this time the caterpillar is 10-12 mm long. It has green body and dark black head. This is the final larval stage. DBM larvae thus have 4 instars. Most caterpillars feed on the lower leaf surface. Some caterpillars have yellow patch on their body; they develop into male moths (Figure 2-3). Caterpillars in this stage feed for 4-5 days. Towards the end of this stage, the DBM larva becomes lethargic and eats very slowly or not at

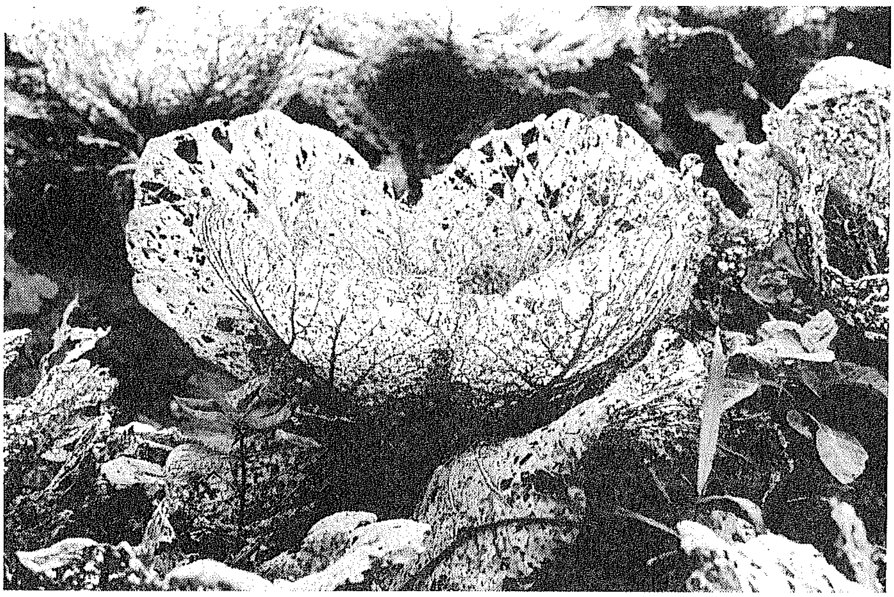


Figure 2-2. Characteristic "window" like appearance of crucifer foliage damaged by diamondback moth

all. It starts making silken cocoon around itself and becomes pupa while hiding inside t:he cocoons.

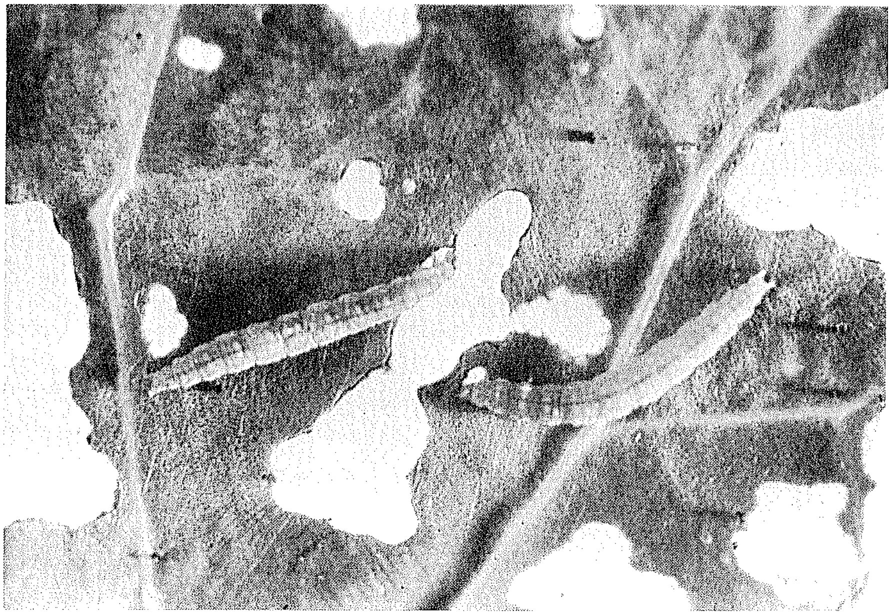


Figure 2-3. Fourth instar diamondback moth larvae; one on the left with light yellow patch on 5th abdominal segment will become male adult, one on the right female adult

Except for a brief period after egg hatch, all caterpillars feed on plant surface. They thus fall easy prey to marauding predators and parasites. Rainfall also drowns or washes off the caterpillars from leaves to ground to certain death. Under high humidity, DBM larvae can fall victim to fungal disease epidemic.

**Pupa**

The pupae are initially green but slowly start becoming brown as the insect inside starts changing to become moth. The pupal cocoon is about 1 cm long and 0.4 cm wide. The pupae are located on cabbage leaves on the same spot where the 4th instar larvae feed. Pupa does not eat. After 4-5 days, it emerges into a moth. Although pupa is harmless, it can fall an easy prey to certain species of parasites, predators and can be drowned by rain.

**Adult moth**

This is the final stage in the life cycle of DBM. The moths are small insects, with body length of 10-12 mm and wing expanse of 14-16 mm with two distinct antennae on the head at the front end. The antennae are made up of several small segments. The two fore wings are dusty and when they are folded in normal position over the insect body, give appearance of 3 or 4 small cubical spots. These spots look like diamonds hence the common name diamondback moth. The moths feed on dew drops or honey dews. They do not eat cabbage leaves. With slight touch or disturbance, they fly away. These insects are not strong fliers and rarely fly more than one meter at one time. Very soon after becoming adults, the female and male moths start mating. This mating usually starts occurring at sunset and continues for 2-3 hours. That is why at dusk these insects fly actively in search of mates. Soon after mating, the females start laying eggs. Characteristic mustard oil smell of crucifer host plant stimulates the insect to lay eggs. Egg laying occurs only at night and continues for 2-3 nights. After 5-6 days, the moth dies leaving behind the eggs which then go through similar life cycle again.

Predators such as spiders and birds are major natural enemies of DBM adults.

**Ecology of DBM**

Diamondback moth feeds exclusively on crucifers. The mustard oil chemicals in these plants are believed to be the cause of DBM's affinity and dependency on crucifers. Without these plants DBM cannot survive and reproduce.

In all crucifers, except for a brief period immediately after hatching from eggs, when first instar larvae bore in petioles and midribs, DBM feeds and pupates on the leaf surface. This exposure of insect on plant surface makes it vulnerable to attack by natural enemies such as predators and parasites and insect pathogens. More the predators and parasites in the field, the lesser will be the DBM menace. At the same time, natural elements such as rainfall, washes off eggs, larvae, pupae and adults from plant to soil where they perish. This factor is the major reason why DBM is not a serious pest during rainy season and is very destructive during dry season.

Temperature does not play any significant role in the biology of this insect except that the higher the temperature the faster is the completion of the life cycle. This results in turnover of several generations in a season in the tropics and consequently greater damage to the crop. This fast turnover of generations also helps in selection of insecticide resistant strains within a very short period, sometimes within one crop season when insecticides are used in its control. Diamondback moth remains active at temperatures ranging from 5 to 40 $^0$C. Temperature does play part in the biology of parasites that attack this insect. The higher the temperatures the fewer will be the parasites. This is one of the major reasons why DBM is so serious in the tropical lowlands.

# DBM IS **SUCH** A SERIOUS PEST?

If one considers the biology and nature of damage by DBM, it should appear to be one of the easiest pest there is to control. The insect lays eggs on plant surface and not inside plant tissue as in certain pests such as thrips or beanflies. The eggs are thus vulnerable to attack by egg parasites or washed away be rain. Except for a brief period in first instar, DBM larvae spend entire larval period on the leaf surface, unlike numerous other pests that bore inside the plant part. DBM never feeds on roots or other underground plant parts making them inaccessible to natural enemies. Thus larvae are exposed to the environmental forces such as predators including small birds and parasites, drowned or washed by rain or blown by strong winds. Diamondback moth pupates on the leaf surface and not in soil or plant debris as is the case with so many other economically important pests. The pupae are enclosed in a very loose reticulation of fiber and not in a hardened impervious cocoon so common with so many other Lepidoptera pests. Diamondback moth pupae are thus subjected to same environmental forces that can affect DBM larvae. Diamondback moth adults, unlike most other lepidopterous moths, are seen in the field hopping from plant to plant with slight disturbance during the day and not in the dark of the night when they will not be seen by predators such as birds, as is the case with most other moth pests. Thus DBM adults are subject to the same adverse forces of nature as the larvae and pupae. Considering these points, DBM should indeed be far easier to control than most other crop pests. However, in the tropics at least, it has become probably the most difficult insect to control.

One of the significant factors that is going for DBM in the tropics, as against temperate climate of Europe, is the availability of very few parasites that will kill the pest in the field. However, large numbers of polyphagous predators that attack other pests are available in the tropics to keep DBM population under check. However, these natural enemies are not keeping the pest under control. Until late 1950s and early 1960s DBM was not a serious pest at all in any tropical country. Its seriousness coincided with widespread use of broad spectrum chemical pesticides which initially controlled DBM but it also killed and possibly eradicated numerous species of innocent predators and parasites who came in the way of insecticide sprays or ate DBM larvae which were poisoned or crawled over insecticide treated plants which killed them. These friendly predators, until insecticide use became widespread, used to keep DBM population in check. Once their number was reduced by indiscriminate pesticide use, DBM population escalated. In the meantime, continuing use of insecticides resulted in DBM developing resistance to insecticides. Here is how DBM becomes resistant to insecticides.

**How DBM becomes resistant to insecticides?**

Insecticide resistance in any insect pest is natural and inevitable consequence of insecticide use to control that pest. Since in DBM only larvae cause all the damage, therefore, the control measures - so far mainly the insecticides - were all aimed at killing DBM larvae. This is but logical. The eggs are too small, and not readily seen to initiate insecticide treatment. Eggs are also covered with thin shell which, to some extent, protects the embryo inside. Pupae are covered with silken cocoon which protect them from insecticides. Both eggs and pupae do not eat cabbage and thus the treated-cabbage pose no harm to them. Adults fly from plant to plant and thus can easily avoid insecticide spray. And like egg and pupa the adult also does not feed on cabbage. So the insecticide treatment of cabbage does not pose any harm to them. It is for this reason that most of the insecticides developed so far are all aimed at killing larvae. Larvae, being surface feeders, are completely exposed. They can be killed by direct toxic insecticide sprays on their bodies or by consumption of insecticide-sprayed leaves or by merely crawling over treated leaves thus allowing entry of toxic insecticides through their tender skin which eventually kills larvae. All this makes it easier for insecticides to kill the larvae. This targeting of only one life stage to kill the pest, coupled with enormous reproductive potential of DBM, especially in the tropics, has resulted in this insect becoming highly resistant.

Here is how DBM becomes resistant (Figure 3-1). In the beginning when DBM started spreading and causing serious damage, farmers used one insecticide that gave good control. It killed may be 99% of the insect population. The few insects that were not killed were strong and probably had inherent ability to tolerate insecticide dose._ They multiplied. Farmers sprayed higher dosages of insecticides which killed may be 99% of them but some even stronger ones survived, they multiplied. Farmers sprayed even greater amount of insecticides and insect become even stronger and more resistant. Farmers then used new insecticides which worked in the beginning but soon, like the earlier chemicals, DBM became resistant. Since, in tropics, due to high temperatures, there is rapid turnover of generations, insecticide resistant strains of DBM are produced much more quickly in this region than elsewhere. This has been going on for the past 30 years and now DBM has become so resistant that none of the insecticides work, even mixtures of several insecticides fail to control the pest.

Incidentally, in the annals of history of insecticide resistance, DBM has the distinction of being the first field crop pest in the world to develop resistance to chemical insecticide when it was reported to be resistant to DDT in 1953 in Indonesia and the first field crop pest to

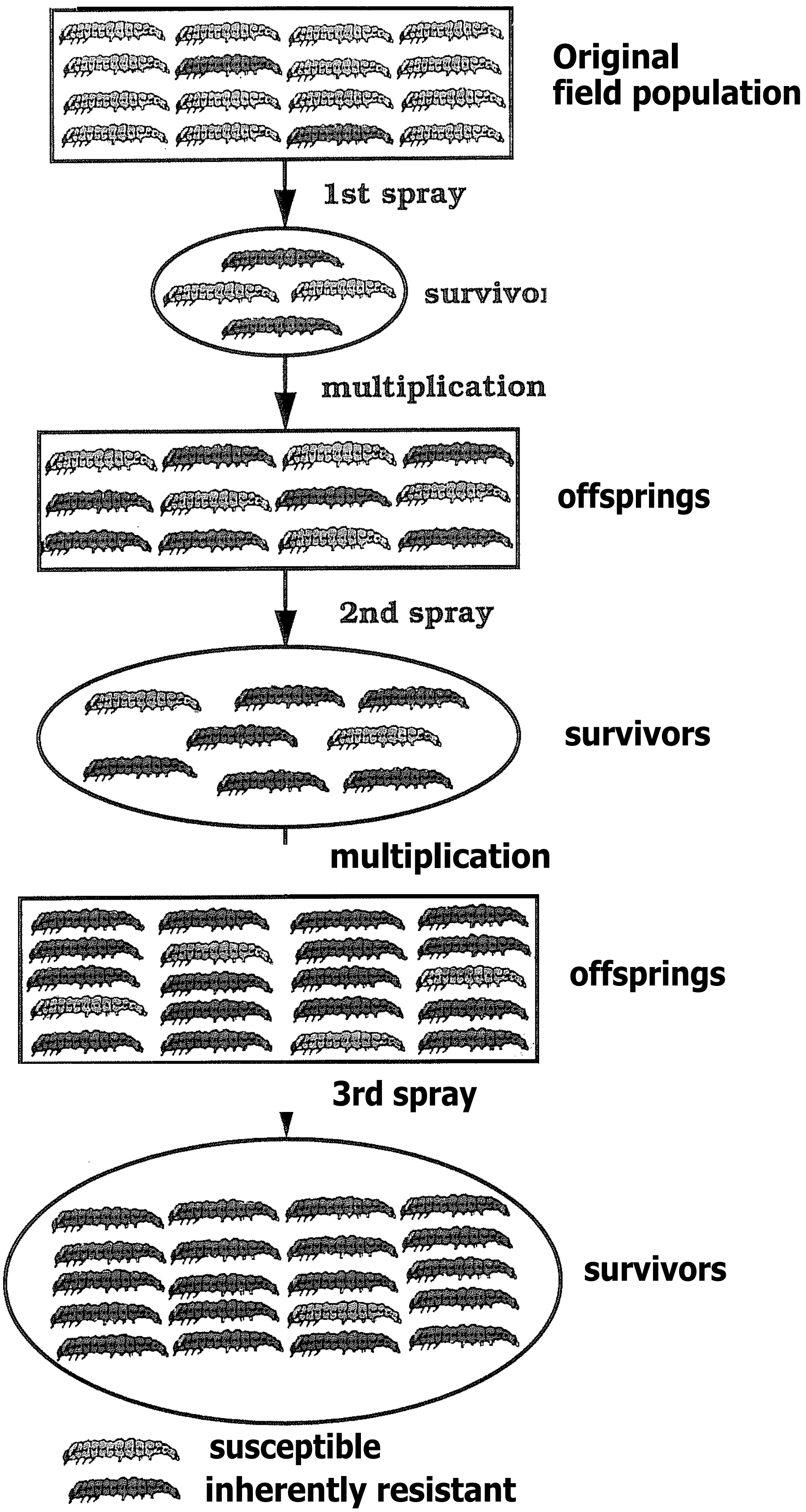



Figure 3-1. Schematic diagram of selection of insecticide-resistant strain of DBM through successive insecticide applications

become resistant to biological insecticide when was reported to have developed resistance to *Bacillus thuringiensis* in 1988 in the Philippines (Kirsch and Schmutterer 1988). It is for this reason that use of insecticide to control this pest is not sustainable. Therefore we will not discuss chemical control measures in this manual.

# PRINCIPLES OF DBM CONTROL

In developing countries of the tropics and subtropics, vegetable cultivation is intensive in outskirts of big cities and in scarce areas in the highlands both of which supply produce on a daily basis to big cities. Cultivation of crucifers is an important source of ready cash income and, in most cases, the sole source of income to the farmers. Production of healthy looking damage-free vegetable for the resource-rich city dwellers, therefore, is an important consideration in all cultivation practices, especially in plant protection. In most of the developing countries, introduction of insecticides, all of which are imported from developed countries, face little, if any, registration hurdles common in the West and Japan. As a results, most insecticides, some of which are never registered in country of its origin, are readily available at reasonable cost. In some countries pesticides are subsidized, especially for staple food like rice and export crop like cotton. Because of absence or poor enforcement of already meager restrictions on pesticide use, the insecticides registered for rice and cotton end up on vegetables. This has resulted in over use and complete dependence on insecticides to control DBM. The ideal climate and availability of host-plant throughout the year support rapid turnover of generations, up to 20 per year, which facilitates selection of resistant strain very rapidly. It is no accident that the first report of DBM developing resistance to insecticides came from one of such intensive production areas in the tropics, Indonesia (Ankersmit 1953, Johnson 1953), decades before the appearance of resistance even in the tropical areas of the U.S., Hawaii (Tabashnik et al. 1987) or Japan (Asakawa 1975, Tokairin and Nomura 1975). To encounter resistance problem, farmers increase doses of insecticides, often use mixtures of several chemicals and spray more often, sometimes once every two days. In most of these areas the insecticide cost amounts to between 30 to 50% of cost of production, well above the fertilizer cost (Lim 1982). Due to indiscriminate insecticide use DBM has now developed resistance to practically all chemicals. Since pesticide residue monitoring hardly exists or is enforced, insecticide contaminated vegetable pass easily through marketing channel onto the dinning tables.

No alternate simple control measures are available because of lack of scientific manpower and disincentive due to relatively cheaper insecticides. In a few countries such as in Malaysia, Indonesia and Caribbean islands, attempts have been made at alternative control measures such as introduction of parasites but the success of these efforts have been thwarted by the continuing indiscriminate use of insecticides. However, this situation cannot go on indefinitely. Since DBM has now developed resistance to all chemical pesticides and even to certain formulations of biological insecticide based on *Bacillus thuringiensis,* it presents us an opportunity to mend our past ways and develop alternate control measures that are economical, environmental-friendly, easy to put in practice and sustainable. Since DBM problem has been building up for the past number of years and farmers are used to the easy solution of insecticide use, sustainable solution of this problem, especially at farm level where it matters most, will be a painful task. Although pesticides are important in plant protection, and in some cases indispensable, their use in DBM control has definitely exacerbated the pest problem throughout tropical to subtropical parts of the world. In the development of any alternate control approach, therefore, drastic reduction in the present level of pesticide use should be the most important priority.

To develop ideal alternative control measures to combat DBM, it is utmost important to consider the characteristics of biology and ecology of the pest. Voluminous information has already been generated and is readily available to those who can make sincere efforts in getting it (Talekar and Shelton, 1993). There are several weak points in the biology of this pest that can be exploited to develop these control measures (Figure 4-1).

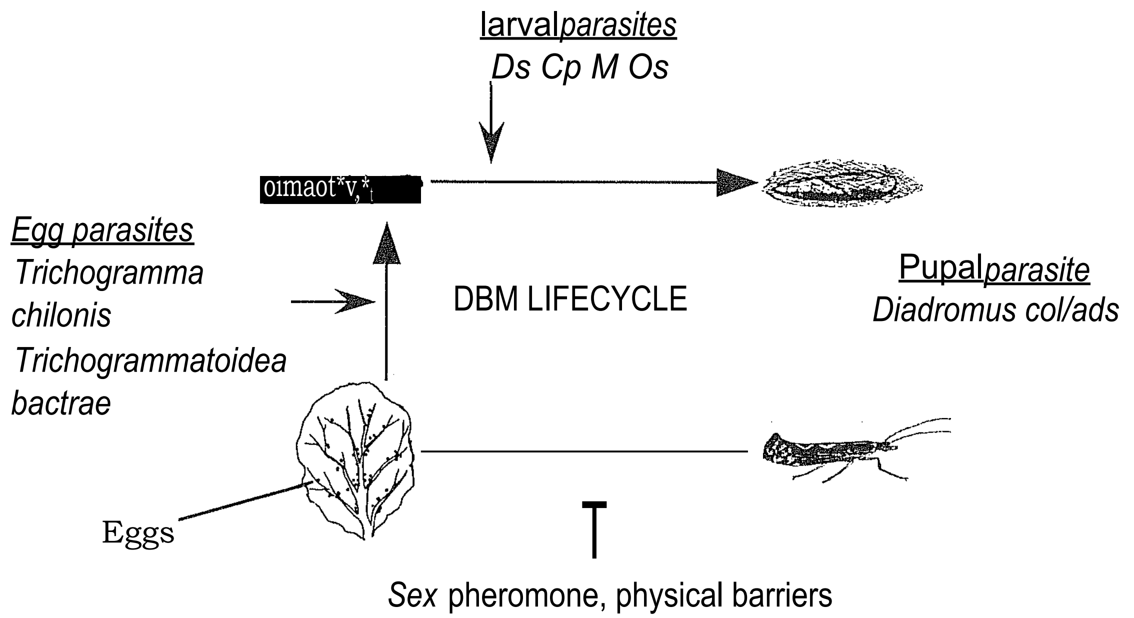



Figure 4-1. Complimentary control measures that can be employed during various life stages to control diamondback moth.
*Ds* = *Diadegma semiclausum, Cp* = *Cotesia plutellae,*
*Mp* = *Microplitis plutellae, Os* = *Oomyzus sokolowskii*

Diamondback moth is a surface feeder and spends its entire life cycle from eggs to adults on plant surface. This make the insect vulnerable to adverse environmental forces such as rain, wind, predators, parasites and even insect pathogens all of which adversely affect survival of the pest. During rainy season, DBM does not pose serious threat partly because of the drowning and or physical removal of the larvae and pupae from the plant surface. The humid weather during rainy season also helps proliferation of insect pathogens which kill the insects, especially larvae.

Presence of all life stages on plant surface also attracts large number of predators and parasites that kill the pest. In fact, this European origin insects is not considered as a pest in Europe because of the large number of predators and parasites that attack larval and pupal stages keeping the pest population always below damaging level. Preservation of native predators and parasites and, where feasible, introduction of new parasites have already given adequate control of this pest in several places outside Europe. Therefore, use of self-sustaining classical biological control should be an important component in the development of any control measure to combat DBM.

Diamondback moth feeds and survives only on crucifers. Its adults may visit other plants but larvae do not survive on non-crucifers for any significant period of time. Denying DBM adults access to crucifer by measures such as prompt destruction of crucifer plant debris from the harvest of old crucifer crop and protecting seedlings by raising them preferably under DBM adult-proof net cover helps in reduction of insect spread. Where feasible, maintenance of crucifer free period in area traditionally planted to crucifers also helps reduce spread of the pest.

Like all lepidopterous moths, DBM female produces sex pheromone. The pheromone chemicals, produced by virgin females ready for mating, help DBM males to locate the female and mate with her. Without mating, fertile eggs are not produced to start a new generation. These chemicals have been identified, synthesized and are available commercially. Pheromone chemicals can be employed to attract DBM males away from the DBM females thus reducing chances of mating and production of new generation.

Diamondback moth is a weak flyer. In case you must plant new crop in the vicinity of old DBM-infested crucifer, erection of a 2 m high net with mesh size small enough to prevent DBM adult passage, will reduce migration of the pest and reduce damage especially in seedling stage when the tender foliage of the crop is especially vulnerable to DBM attack.

In devising suitable control measures, these weak points in the biology of DBM should be exploited to the fullest extent. In subsequent chapters these and other items will be discussed in greater details.

# BIOLOGIC CONTROL OF DBM

Biological control in brief means control of one specific pest by deploying usually an insect or other arthropod that feeds on the pest and maintains the pest population at a lower average density than would occur in the absence of the deployed arthropod. It is a phenomenon which occurs unabated in nature because of which populations of most potential pests are kept below damaging levels. Biological control applies to invertebrates, plant pathogens, nematodes, mites and weeds besides insect pests. However, it is in insect pests and to certain extent weeds, that the biological control is studied and put in practice most.

Biological control organisms fall broadly into three categories: parasites, predators and pathogens. A parasite (also called parasitoid) is an organism of which larva (or other form of juvenile stage) either feed internally (endoparasite) or externally (exoparasite) on the pest's body. The attacked insect pest is called the host. The parasite is destructive only in its immature stages and develops within or upon a single host which is slowly destroyed as the parasite larva completes its development. The parasite adults are free living, feeding on such items as honeydew, nectors and dew drops. Parasites tend to be smaller than the hosts. Parasites may attack any life stage of the host. Those that attack eggs are called egg parasites, those that attack larvae are larval parasites and those that attack pupae are called pupal parasites. There are certain species that attack late larval instars and continue to feed in the host insect emerging as adults from host pupae. They are called larval-pupal parasites. Very few parasites attack adults.

Parasites can be solitary in which only a single individual completes development per host. Many wasps belonging to family Ichneumonidae are solitary e.g. *Diadegma semiclausum* on DBM. A gregarious parasite is one in which more than one individual of the same species normally completes its development in a single host. Many wasps belonging to family Braconidae and Eulophidae are gregarious, e.g. *Oomyzus sokolowskii on* DBM.

Primary parasites are those that develop in or upon nonparasitic host insects. Example, *Diadegma semiclausum is* a primary parasite of DBM.

Hyperparasite is a parasite that develops in another parasite. They can be called secondary parasites if they attack primary parasites. Secondary parasites are harmful since they attack primary parasites which reduces the ability of the latter to control the pest.

Mutiparasitismand superparasitism are important phenomena in biological control. Multiple parasitism or multiparasitism is a situation in which more than one parasite species occur simultaneously within or upon a single host. In most cases only one of these species survives to maturity, the others, less aggressive ones, die in competition. Superparasitism is a situation in which more individuals of a given parasite species occur in a single host. All or some may die and survivors are much smaller than normal. If the parasite species is solitary, physiological suppression of most eggs and early instar larvae result in emergence of only one individual. In some cases host itself succumbs before the emergence of parasites, and all perish.

A predator is a free-living organism throughout its life. It is usually larger than the insect it attacks. In this case the insect attacked is preferrably called as prey rather than host. Predators feed on all stages of their prey. Many predatory species are polyphagous - attacking more than one species of prey. Predatory individuals either actively seek out and capture their prey or wait for unsuspected insect, grabs and devours it. Besides insects, spiders are important predators. Mantids, Coccinelid beetles, chrysopids are typical examples of insect predators.

Pathogens are microorganisms that cause disease in insect pests. They include bacteria, fungi, viruses and protozoa. Nematodes that attack insects are sometimes considered pathogens. They are much larger to be considered microorganisms, but they behave like micorganisms. Bacillus *thuringiensis is* the most important insect pathogenic bacteria whose economic importance far surpasses the importance of all other micorganims combined. This species has long been commercialized. Although theoretically its use constitute biological control, it is a class in its own right and is not considered as a classical biological control agent. It is the use of mostly non-commercialized microbes that are considered as "classical" biological control agents. Parasites, predators and pathogens are collectively called natural enemies.

## Biological control procedures

There are three biological control procedures that can be applied using mainly parasites, especially for DBM. They are:
1. introduction or inoculative release of parasites, 2. agumentation or innundation where parasites are mass reared and released regularly to innundate the field, and 3. conservation of mostly existing parasites and predators.

## 1. Introduction (inoculative release)

This is probably the most common procedure in classical biological control. This involves the introduction of new species of parasites, predators or pathogens into area they did not occur before. Once introduced i.e. released in an area where specific pest exists, they are left to spread and maintain themselves, though its dispersal initially may be assisted by artificial means i.e. by releasing the imported natural enemy in several places to cover an area where the pest needs to be controlled. The introduced natural enemy is considered as "established" when it is found after several generations in an area where it was released. If the pest to be controlled had itself earlier gained entry to the country or area from some other parts of the world, such as DBM in tropical areas from Europe, the chances of success are quite good, since natural enemies have not come with the pest.

**2. Augmentation (innundative release)**

This procedure involves maintenance of the natural enemy in an area in high enough number to give effective control of the pest. It involves mass rearing of the natural enemy and its periodic releases in the fields when there is drop in that natural enemy's population. The drop in population could be due to any reason such as occasional use of pesticide, drought, flooding, harvest of crop etc. The innudative release restores the natural enemy population which helps to reduce target pest population. This practice of use of natural enemy is common in large sugcane plantings where *Trichogramma* species are commonly used to combat lepidopterous sugarcane borer pests. The egg parasites are very small and delicate and their effective use depends on accurate timing of release in relation to egg laying by target pest. The use of egg parasites in DBM control have not been very effective. However, attempts have been made to use innundative release of larval parasites such as *Cotesia plutellae* in subtropical and temperate areas to combat DBM.

**3. Conservation**

This procedure involves better use of natural enemies that already exists in an area. Conservation is defined as the avoidance of use of pest control measures that adversely affect the natural enemies. Use of broad-spectum insecticides to control the pest is the most important factor that affects the population of natural enemies including parasite and predators. The harmful effect of such practice can be minimized by careful selection of pesticide that has minimal toxicity to parasites and predators. *Bacillus thuringiensis is* not toxic to parasites or predators and its use in the control of DBM or other pests does not affect natural enemies. Measures that will increase survival, longevity, fecundity and efficacy of natural enemies also are considered as conservation practices. Adults of many parasites survive better on nectar of certain flowers especially those of plant family Umbelliferae (e.g. carrot). Planting of these species in the vicinity of crop helps survival of the natural enemy population. In long term, conservation of natural enemies may prove to be the most important of all biological control procedures. This is because virtually all pests are attacked to some extent by parasites and predators that provide some control. In this regards, pesticides that are unusually toxic to known natural enemies should not be registered for the control of any pest.

**Parasites and predators of diamondback moth**

Diamondback moth, being the most widespread Lepidoptera in the world, whose life stages are spent on the plant surface making it readily accessible to natural enemies -- has more than its fair share of parasites and predators. Between the two categories of the natural enemies, parasites are by far the most widely studied and some of them are introduced in crucifer growing areas from time to time to control DBM. These parasites attack DBM eggs, larvae and pupae. Adults are most often attacked by polyphagous predators such as birds and spiders. Although over 90 parasite species are reported to attack DBM only about 60 of them are important. Among them 6 species attack DBM eggs, 38 larvae and 13 pupae (Lim 1986). Egg parasites belonging mostly to polyphagous genera of *Trichogramma* and *Trichogrammatodia,* contribute little to DBM control and their commercial use necessitate frequent releases. Larval parasites are by far the most predominant and effective in checking DBM population. Most of the effective larval parasites are host specific and belong to two major genera *Diadegma* and *Cotesia; a* few *Diadromus* species, most of whom are pupal parasites, also exert significant pressure in reducing DBM population. Most of these species are of temperate climate origin being found in Europe where DBM is believed to have originated. In one province of Moldavia in Romania alone, 28 species occur; their combined parasitism exceeds over 70% which is more than adequate to get complete control of DBM thus reducing any need for insecticide or other control means.

In addition to parasites, 25 species of predators are reported to attack diamondback moth. At least 2 viruses, 2 bacteria and 7 major species of fungi are pathogenic to this crucifer pest.

Countries which are constantly plagued by DBM infestation such as those in Southeast Asia, Pacific islands, Central America and Caribbean and most of the sub-Saharan Africa, have one feature in common: they all lack effective larval parasite in contrast to countries in continental Europe which have many *Diadegma, Cotesia* and *Diadromus* species and hardly any DBM problem.

**Attempts at parasite introductions for DBM control**

Introduction of exotic parasites to control pest insects and weeds has been practiced for decades. This approach has considerable promise in the control of DBM, however, it has been practiced only sporadically over the past 50 years. Widespread and often indiscriminate use of insecticides in recent years has frustrated much of recent such efforts and delayed the establishment parasites and their beneficial effects.

One of the earliest attempt was made in New Zealand. Failing to find any significant parasitism of DBM by three native larval parasite species, (Robertson 1939), *Diadegma semiclausum* Hellen was introduced in New Zealand from England (Hardy 1938) and *Diadromus collaris* (Gravenhorst) from elsewhere. These introductions suppressed DBM population and achieved adequate control in subsequent years.

A somewhat similar situation existed in Australia where prior to introduction of effective exotic parasites, DBM was causing serious damage (Wilson 1960). Among the introduced parasites, *D. semiclausum* was established widely in Australia and on the island state of Tasmania. *Diadromus collaris* was established principally in Queensland, New South Wales, Victoria and Tasmania and *Cotesia plutellae* (Kurdjunov) in Australian Capital Territory, New South Wales and Queensland. These introductions resulted in heavy parasitism of DBM (72 to 94% ) and marked reduction in damage to crucifers.

Efforts to control DBM in Indonesia by introduction of parasite was initiated since 1928. However, it was only early 1950s that the exotic parasite *D. semiclausum* was actually introduced from New Zealand in the crucifer growing areas in the highlands of Java. Survey of parasitism soon after parasite introduction revealed that the parasite is established (Vos 1953). However, it was not until mid 1980s that the beneficial effects of this parasite in the control of DBM in the field were realized (Sastrosiswojo and Sastrodihardojo 1986). Indiscriminate use of chemical insecticides in 1960s and 70s probably killed parasites and denied the beneficial effect of this insect to farmers for at least 30 years. Reduction in chemical insecticide use in favor of B. *thuringiensis* in early 1980s resulted in the proliferation of the parasites. This parasite is now introduced from Java to highland areas of other islands in Indonesia.

An identical situation existed in neighbouring Malaysia. In Cameron Highlands of that country where crucifers are grown throughout the year, DBM was a serious pest. Prior to 1977 only one parasite, *Tetrastichus ayyari* Rohwer was present in this area but its parasitism was inadequate to suppress DBM population (Ooi 1979, Lim 1982). Malaysian entomologists in 1977-78 introduced one larval parasite *D. semiclausum* and two pupal parasites *Oomyzus sokolowaski* (Km-djumov) and *D. collaris* in this area (Ooi and Lim 1989). Although these parasites were recovered from DBM in this area one and six years after the release, their parasitism was very low, amounting to a maximum of 6% for both *D. semiclausum* and *D. collaris*. *Oomyzus sokolowski* was recovered in 1978 but was not found in 1984 (Chua and Ooi 1986). Parasitism by C. *plutellae* which entered this area accidently (Lim 1982) amounted to 11% in 1978 and 20% in 1984. Because insecticides were still effective, farmers continued to use them intensively which kept the parasite population very low. Towards the end of 1980s, however, DBM developed resistance to practically all chemical insecticides and Singapore, the major market for vegetables grown in

Cameron Highlands, rejected quantities of insecticide contaminated cabbage which led farmers to start using B. *thuringiensis* (Ooi 1992). Suspension of chemical insecticide sprays resulted in upsurge in the parasite population and increased their contribution to the mortality of DBM; B. *thuringiensis* being harmless to the parasites. Surveys in 1989 showed that *D. semiclausum* has become the major parasite; *D. collar-is* was close behind. *Cotesia plutellae* is now a minor parasite in this area. The combined parasitism has drastically reduced the need for insecticide application and cabbage production in 1990 was increasing (Eyed et al. 1990).

In 1970, C. *plutellae* obtained from India was released in Caribbean islands of Grenada, St. Vincent, St. Lucia, Dominica, Antigua, Montserrat, St. Kitts and Nevis, Belize, Trinidad, Barbados and Jamaica to combat DBM. In some of these release sites, the parasite has been recovered but complete control of DBM was not achieved. Attempts to introduce *Apanteles vestalis* Halliday and *D. collaris* failed likewise (Bennett and Yassen 1972, Yassen 1974). Re-introduction of C. *plutellae* in early 1989 in Jamaica has resulted in its establishment of this natural enemy and its parasitism between the date of introduction till March 1990 ranged from 5.4 to 88.7%. The plant damage reduced from 75% before introduction to 38% in March 1990 (Alam 1992).

On Cape Verde Islands, locally occurring predators and parasites were not able to exert adequate pressure to control DBM and other pests (Lima and van Harten 1985). Among the three parasites introduced specifically to control DBM, C. *vestalis* and O. *sokolowskii* are well established. Occurrence of DBM'now is rare where previously it was very common. In the initial stages, spraying crucifers with B. *thuringiensis* assisted the establishment of the parasites (van Harten 1990).

In Taiwan DBM has been a serious problem since mid 1960s. *Cotesia plutellae* has been reported to parasitize DBM since at least 1972 but it is not able to give adequate control of the pest. *Diadegma semiclausum* imported from Indonesia was released in the lowland crucifer growing areas in 1985 (AVRDC 1986). However it failed to get established. Suspension of chemical insecticide use, however, resulted in appearance of C. *plutellae* whose parasitism ranged from 27 to 100% of DBM larvae. This parasitism along with the use of B. *thuringiensis* gave adequate control of DBM. When *D. semiclausum* was introduced in the highlands, however, within one season parasitism of DBM reached 70% and towards the end of that season DBM was not found in the field (AVRDC 1988). Survey of parasite in two years later indicated that the parasite had spread throughout the highland areas of Central Taiwan with substantial savings in the cost of DBM control (Talekar et al. 1990, Talekar 1992). Establishment of this parasite in highlands and failure to do so in the lowlands appeared to be due to the temperature. Back-up laboratory study indicated that a temperature range of 20 to 30°C is optimum for parasitization of DBM by C. *plutellae* and 15 to 25°C for *D.* semiclausum (Talekar and Yang 1991). At temperatures approaching 30°C, parasitism by *D. semiclausum* drops sharply. In tropical to subtropical areas only in the highlands temperatures are suitable for the establishment of D. semiclausum whereas lowlands are suitable for C. *plutellae*. This was horned out by the successful establishment of D. *semiclausum* in the highlands of Indonesia, Malaysia, and Taiwan and C. *plutellae* in the lowlands of all three countries of the Southeast Asia.

In 1989 D. *semiclausum* was introduced in the highlands areas of northern Philippines. Within one season the parasitism of DBM larvae in the open field where the parasite was released only once at the beginning of the season reached 64% at harvest (Poelking 1992). By 1992, the parasite was well established and spread over 7000 ha of vegetable growing areas of Cordillera region. The insecticide use has dropped from an average of 16 sprays to less than 4 which are actually meant for other pests because DBM damage was too little to require pesticide application (AVRDC 1993). Similarly C. *plutellae* was introduced in mid-level highlands of Indonesia in 1991. This braconid is now established in Java where it is helping in sustainable control of DBM (AVRDC 1993). In highland areas of Tamil Nadu State of India, D. *semiclausum* was introduced in 1994. This parasite is now established in Ooty and Kodaikanal areas of that Indian State.

# BIOLOGY OF DBM P SITES

Crucifer production in tropics falls into two major categories: the cool highlands and hot lowlands around major cities. This has bearing on types of control measures, especially biological control. The major difference in two areas is the temperature and crucifer species grown. Although crucifer species has minor, if any, influence in selection of parasites to be used for biological control of DBM, however, temperature plays a key role in selection of parasites for introduction or innundative release for the control of DBM. In typical tropical highlands, altitude 1200 m and above, temperature ranges between 10 and 26 $^0$C whereas in lowland temperature rarely falls below 20 $^0$C and it can reach as high as 36 $^0$C when certain crucifer species can be grown. These temperature differences require selection of appropriate species of parasites that can survive and give adequate control of DBM. This requires knowledge of biology of available parasite species to judge their suitability in two agro-ecosystem.

## ***Cotesia plutellae*** **(Kurdjumov)**
## **(Order: Hymenoptera, Family: Braconidae)**

**Importance**

*Cotesia plutellae* (also known in the past *Apanteles plutellae) is* the most wide-spread parasite of DBM in lowlands of Asia, being occurring naturally or introduced intentionally, in practically all countries in this continent. It has also been introduced in some countries in the Pacific, Caribbean and Central and South America. Although generally unable to provide full control of DBM by itself, it nonetheless contributes substantially to suppression of DBM. Together with other natural enemies, it often can provide adequate control of DBM in most places. Therefore, conservation of this parasite is crucial for the control of DBM in the lowlands.

**Biology**

**Egg**

The egg of C. *plutellae* which is always laid inside the body of DBM larva, is transparent with rounded ends. The narrower posterior end has a straight short peduncle (stalk) typical of the stalked-type eggs of many insects belonging to family Braconidae. The broader anterior end of the egg measures 0.064 mm and length 0.251 mm at 5 hours after oviposition. The peduncle or stalk is 0.05 mm long. The chorion or the eggshell is transparent, thin and without any definite structure on it (Figure 6-1). Twenty four hours after egg laying, the egg increases to size measuring 0.12 mm and 0.4 mm, respectively.

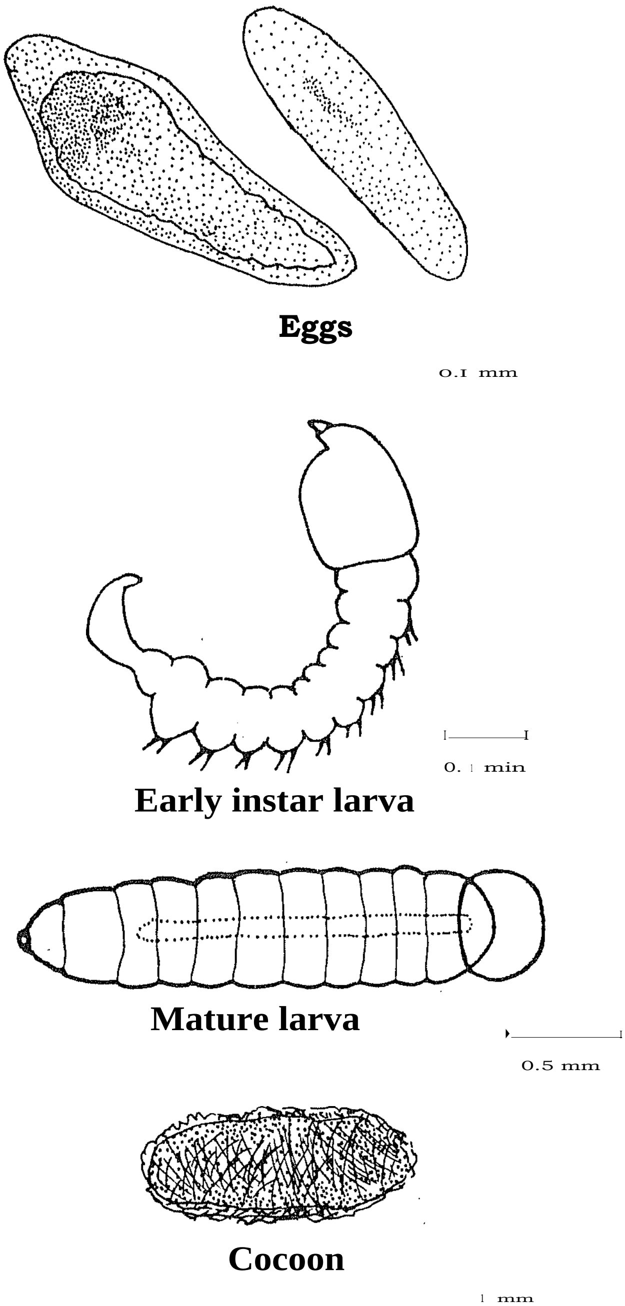



Figure 6-1. Eggs, larva, pupa and cocoon of *Cotesia plutellae.* Eggs and larvae are inside the body of diamondback moth larvae

*Cotesia plutellae* egg is usually found freely floating in the haemocoel. (insect "blood") of the DBM larvae. Soon the embryo developing within the egg is visible through the transparent egg shell. It is possible to find more than one C. plutellae eggs inside DBM larval body, especially when DBM larva is exposed for egg laying by several individuals of *Cotesia* females. However, normally only one mature egg is found per host larva. Others perish in competition. During egg hatching which produces larva, the first instar larva emerges out of the egg at the side towards the anterior (front) broad end of the egg.

**Larva**

Soon after emergence from egg, larva starts feeding on the haemocoel. It undergoes three larval instars before pupation. The first instar larva is transparent and has a caudal appendage (tail) and mandibles. It is found free living (not attached to host tissue) in the posterior (hind) part of DBM larval haemocoel. The caudal appendage is very prominent. Larva has about 10 poorly defined segments with last few bearing short spines. Larva measures 0.45 mm (excluding the tail) long and 0.1 mm wide within 1 day after hatching and 0.7 mm long and 0.2 mm wide on the second day. At times there could be more than one *Cotesia* larvae within one DBM larva but only one survives to pupal stage. First instar lasts 1-2 days.

The 2nd instar larva is white, translucent and differs substantially from the first instar (Figure 6-1). It has clearly segmented and more robust opaque body. Towards the end of 2nd instar, larva may possess a greenish tinge. The 2nd instar larva grows rapidly, trebling from its initial size. The second instar lasts 4 to 5 days.

The 3rd instar resembles a typical hymenopterous larva. It tapers anteriorly and is creamy white to yellowish green. Segmentation becomes more distinct. Body becomes slightly curved and anal vesicle is absent. It is 3.5 mm long and 1.1 mm wide. During this instar the fully grown *Cotesia* larva emerges out from DBM larva killing the host larva in the process. Third instar lasts between 1 to 3 days.

**Parasite emergence**

The full-grown *C. plutellae* larva emerges from the side of DBM larva which is usually in 4th instar. Parasite larva makes a suture on one side usually 3rd - 4th abdominal segment and C. plutellae slowly struggles to get out of the host in 30 to 60 minutes. In some cases larvae emerge completely outside host body before spinning cocoon in preparation for pupation. Some larvae may initiate to form cocoons when head and thorax are barely out of host larva.

**Pupation**

Mature larva soon after emergence from host body starts spinning white silk thread cocoon around itself. The pupal cocoon is spindle-shaped with smooth rounded ends. The cocoon is found generally on the undersurface of host plant leaves. The cocoon is firmly attached to leaf surface and it cannot be dislodged easily. The cocoon measures 3.3 mm long 1.3 mm wide in males and 3.4 mm long and 1.3 mm wide in females. Pupal period lasts 2 to 7 days averaging about 5 days. In general male adults emerge earlier (4.7 days) compared to female adult (5.2 days) from the cocoons.

**Adult**

Adult that is ready for emergence from pupal cocoon, makes a round hole at one end of the cocoon through which it emerges. The adult is black and possess a pair of light-brown mandibles, black or dark brown 18 segmented antennae and transparent wings (Figure 6-2). In general, all legs of the males are usually darker than those of females. It must be pointed out that *C. plutellae* from different parts of world have different shades of body color patterns and the above description may not hold good everywhere. Females have distinct ovipositor towards the end of abdomen. Females measure 2.62 mm long an 0.73 mm wide and males 2.56 mm long and 0.77 mm wide. Without food adult survives for 1.7 days, with availability of food such as honey, adults can survive for more thatn 15 days. They lay over 200 eggs in adult life span. The total life cycle (from egg to adult emergence) averages 13 days.

**Characteristics of parasitism**

*Cotesia plutellae is* a larval parasite and prefers 2nd or early 3rd instar DBM larvae for oviposition. Its lifecycle of 10-15 days is synchronized with that of its host, DBM. The ideal temperature for its multiplication and thereby parasitism is 25 to 35°C. Parasitism goes down as the temperatures drops below 25 $^{0}$C. This parasite is ideal for DBM control in lowland areas of tropics where temperatures are always high, above 25°C, often reaching 35°C. This parasite is not suitable in the highlands where temperatures tend to be below 25°C. This parasite, like other parasites of DBM, is highly susceptible to all chemical insecticides. Therefore, its activity drops whenever chemical insecticides are used. *Bacillus thuringiensis* (Bt) is not toxic to the adults of this parasite. Use of Bt for the control of DBM or other crucifers will not affect *C. plutellae* activities. Since *C. plutellae, is* a specific parasite of DBM which feeds on crucifer only, *C. plutellae* rarely goes outside DBM-infested crucifer fields. Therefore, use of any pesticides on other crops in the vicinity of DBM-infested crucifer does not affect effectiveness of C. *plutellae in* controlling DBM on crucifers. This braconid can control DBM attacking most major species of crucifers.

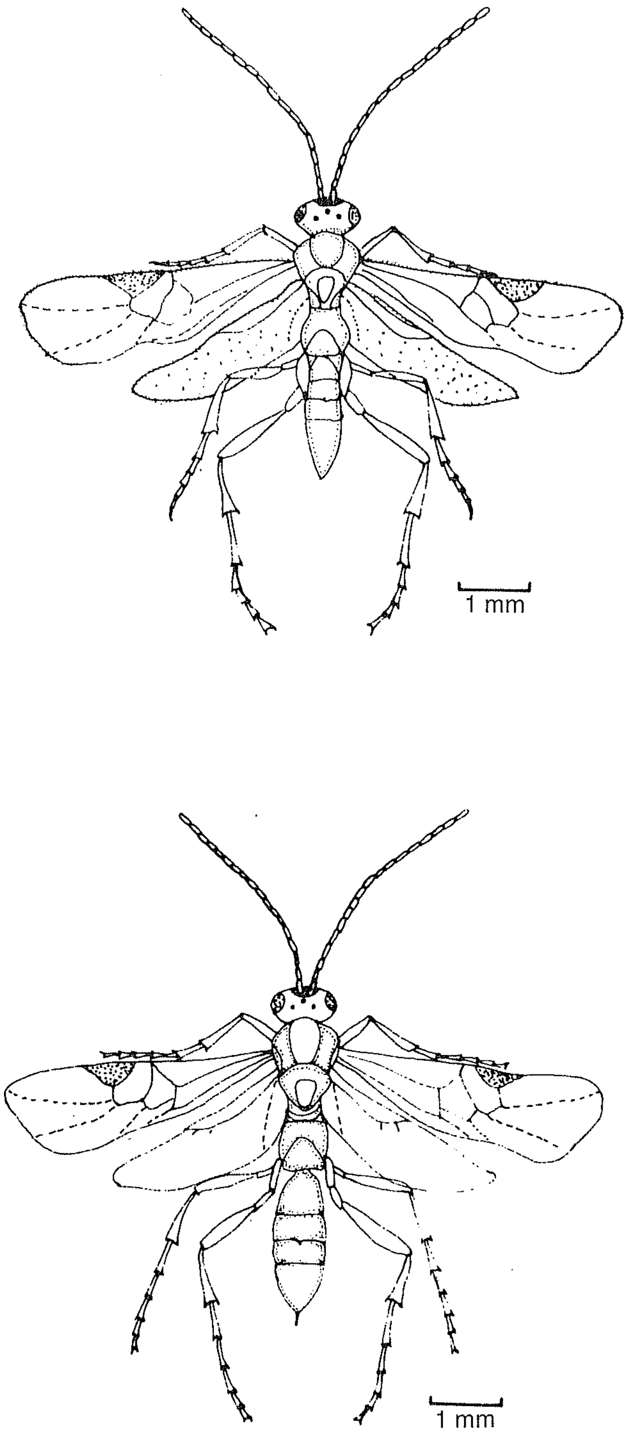



Figure 6-2. *Cotesia plutellae* adults; male (above), female (below).

## *Diadegma semiclausum* (Hellen)
## (Order: Hymenoptera, Family: Iehnenmonidae)

### Importance

*Diadegma semiclausum* (also known in the past as *Diadegma cerophaga, Diadegma eucerophaga, Angina cerphaga) is* probably one of the most effective parasites of DBM being introduced in several countries specifically for biological control of the pest. This European origin insect best survives in temperate climate and only in the cool highlands of tropics where temperature rarely exceeds 27 C for more than 2 weeks. Since, in tropics, major crucifer production areas are in the highlands, and DBM has been serious pest in all these areas, *D. semiclausum* has become a popular parasite for inoculative release. Indeed through such introductions, this parasite has become established in practically all major highland vegetable areas in Indonesia (Lembang), Malaysia (Cameron Highlands), Philippines (Cordillera), Taiwan (Central highlands), India (Kodaikanal, Ooty) and elsewhere. Wherever, this parasite has been established, it is giving control of DBM and there is significant reduction in chemical pesticide use. This parasite can survive at low temperatures reaching below 0 C for any length of time but not high temperature exceeding 27 C over more than 2 weeks. In tropics such temperatures for this parasite's survival can be found at an altitude of 1200 m and above.

### Biology

#### Egg

Eggs are semicircular, cylindrical and are found only in DBM larvae (Figure 6-3). Soon after oviposition, egg is transluscent. Length of egg is 0.22 mm and width 0.05 mm. One day later egg size doubles and the volume quadruples. Egg laying location in DBM larval body is not fixed. Soon after oviposition the eggs could be found in thoracic and abdominal segments. One day later most of the eggs are still free in the abdominal segment. The egg stage lasts for 1.6 days.

#### Larva

After about 38 hours from oviposition, the eggs hatch. Larva graws egg members and enters the haemocoel. Soon after hatching larva is transparent. The body is narrow and long. The anterior end is wider and posterior end is narrow and sharper. The abdominal end has a narrow tubular structure. The body length is 0.67 mm and width 0.14 mm. The length of the tail tube is 0.15 mm. Along the length on both sides of *D. semiclausum* larval pody, there are clearly distinguishable spiracles (Figure 6-3). On 2nd and 3rd day after hatching the larval shape is

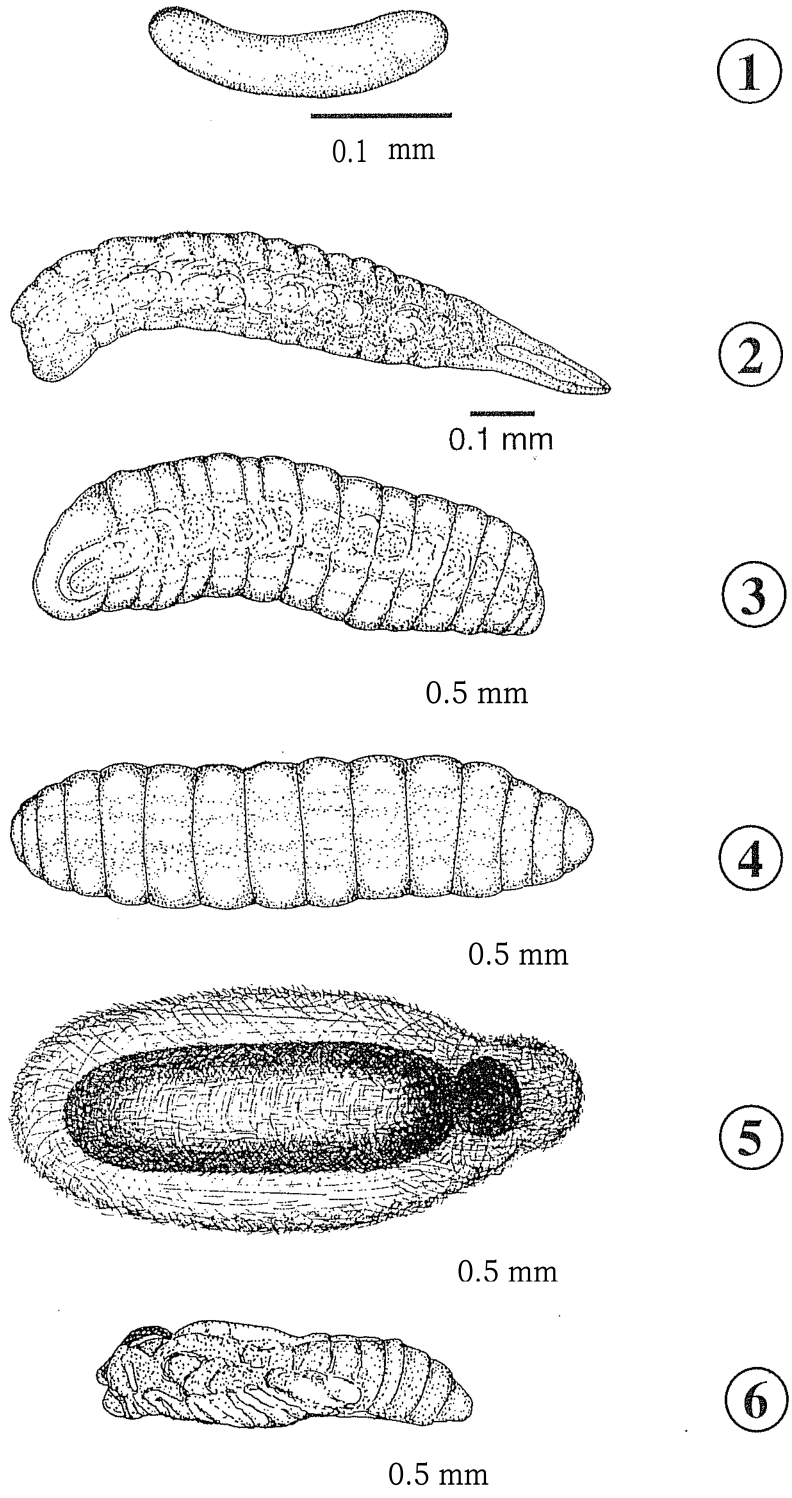



Figure 6-3. Egg (1), larvae (2,3), prepupa (4), cocoon (5), and pupa (6) of *Diadegma semiclausum.* Eggs and larvae are inside diamondback moth larvae, pupation takes place inside diamondback moth cocoon

similar to newly hatched larva. On second day the body length is 1.01 mm and width 0.23 mm. On 3rd, the larva is 1.43 mm long and 0.34 mm wide. The tubular tail is still present on 2nd and 3rd day after hatching. On 4th and 5th day, the larval body is stout and the tail structure at the abdominal end disappears. The digestive cannal is clearly visible because they eat DBM larval body content which is light green. The head, thorax and abdominal segments of the 3rd to 5th day old larvae are clear. Larval stage lasts 5.2 days and there are 4 larval instars.

The larvae become more active and move with ease inside DBM larval body. In older larva the central part of the body becomes bulged and movement is slowed down. At this moment DBM larva occasionally moults into 4th instar. When DBM larva becomes prepupa, the parasite larva eats the prepupa and the larval skin and excreta is pushed to the posterior end at the prepupal body in preparation for *D.* semiclausum to pupate. Later the parasite makes cocoon inside DBM cocoon. The parasite body inside the cocoon becomes shorter and enters prepupal stage.

**Pupa**

The cocoon is cylindrical. It is 5 mm long and 1.64 mm wide. Initially the cocoon is grey but turns dark. Before emergence, the pupa is brown. In the central part, the cocoon has one black ringed area (Figure 6-3). The anal end of the cocoon is black. Soon after the parasite larva becomes prepupa, the parasite body becomes shorter giving it an appearance of a sac. The color' is light yellow. It is 4.6 mm long and 1.32 mm wide. The prepupal stage lasts only one day.

During pupal stage the obvious change is the presence of light yellow wing pads. The antennal segments become distinct. Pupal stage lasts for 6 to 9 days. Before emergence into adults, antennae and legs become darker. Pupal length is 4.5 mm and width is 1.24 mm.

**Adult**

When ready for emergence from cocoon, *D.* semiclausum adults gnaw a small circular hole at the anterior end and climb out from the hole. It flutters the wings and flies away. The body is black. The adults have long antennae (Figuare 6-4). The forewings are transparent, and have dark stigma along the anterior margin. The abdomen is slender long flattened on both sides. Females have long ovipositors and ovipositor length is two third the entire length of the body. Female adults are bigger than male adults. The body lengths are 6.82 mm and 6.05 mm, respectively, for females and males. Female body is 0.9 mm wide and male, 0.87 mm wide.

In laboratory most adults emerge from pupae between 0400 and 0800 hours. The reproductive organs of the newly emerged adults are already developed and they start mating soon thereafter. Adults can survive for upto 3 days without food but the longevity can be as high as 25 days with steady supply of food such as honey.

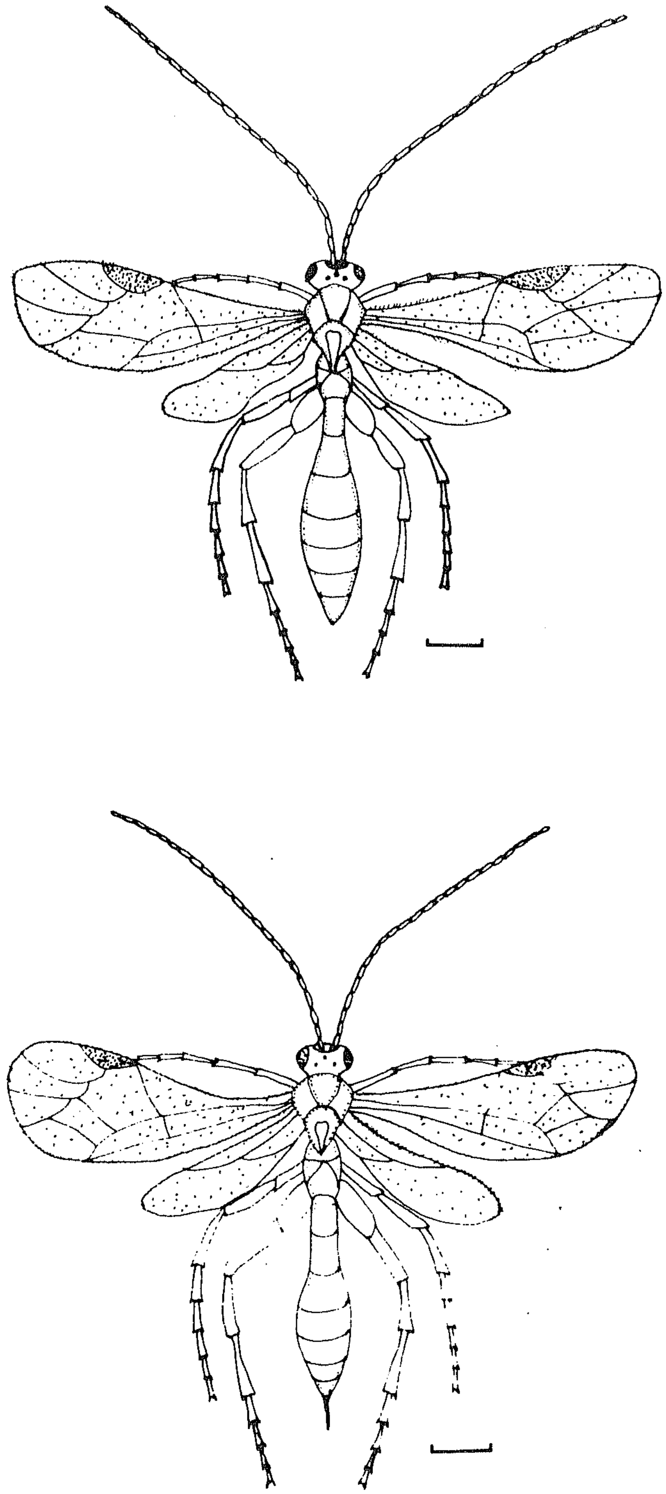


Figure *6-4. Diadegma semiclausum* adults; male (above), female (below). Scale = 1 mm

## Characteristics of parasitism

*Diadeg ma semiclausum* is a specific parasite of DBM and does not attack any other known pests or beneficial insects such as silkworm, honey bees or others. This parasite is suitable for areas where temperatures during crucifer growing season is 15 to 25 $^{0}$C. This parasiste cannot control DBM in areas where temperatures exceed more than 27 $^{0}$C for more than 2 weeks. Its life cycle of about 22 days synchronizes with one generation of DBM in cool highlands. Although small, it is a strong flier and searches actively for DBM larvae. It is thus effective in high and low DBM infestation areas and, once established, keeps the DBM population so low that one need not use any pesticide. This parasite is not suitable for lowlands. Diadegma semiclausum is highly susceptible to chemical pesticides. Its effectiveness drops sharply whenever chemical pesticides are used. Bacillus *thuringiensis* is not toxic to the adults of this parasite. Since D. semiclausum is a specific parasite of DBM which feeds only on crucifers, D. semiclausum rarely goes outside DBM-infested crucifer fields. Therefore use of any pesticide on other crops in the vicinity of DBM-infested crucifer does not affect the effectiveness of D. semiclausum in controlling DBM on crucifers.

## *Oomyzus sokolowskii* (Kurdjumov) (Order: Hymenoptera, Family: Eulophidae)

### Importance

This is a gregarious parasite and attacks 3rd or 4th instar larvae of DBM. Since it attacks even late 4th instar and comes out of DBM pupae, it is often wrongly identified as pupal or larvae/pupal parasite of DBM. Some researchers have occasionally collected this parasite from C. plutellae pupae and have concluded it to be a hyperparasite of DBM. *Oomyzus sokolowskii* never attacks full-grown *C. plutellae* larvae- feeding inside DBM. However, at times, during very brief period when *C. plutellae* larvae leave host DBM larvae to pupate outside DBM larvae, O. *sokolowskii* adults, if present in large number, can lay eggs in *C. plutellae* larvae and develop inside larvae and pupae of this braconid. In such case *O. sokolowskii* rather than *Cotesia* plutellae emerge from the parasite pupae. Under such rare occasions, *O. sokolowskii* can be considered as hyperparasite of DBM. Where *O. sokolowskii* has been established, such as Cape Verde Islands on Africa's west coast, it gives satisfactory control of DBM side by side with C. plutellae (Figure 6-5).

### Biology

Very little information exists on the biology of this parasite. Soon after emergence from their pupae, *O. sokolowskii* adults start mating and start laying eggs in 3rd or 4th instar DBM larvae. The first day's

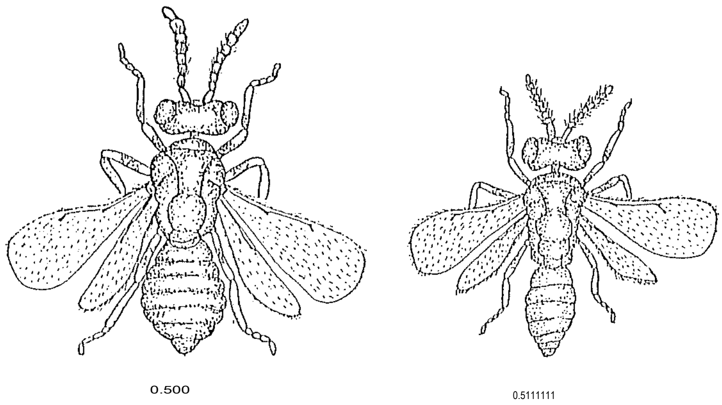



Figure 6-5. *Oomyzus sokolowskii* adults; female (left) male (right)

oviposition amounts to almost 50% of 127-135 eggs laid by a single female. Several females can oviposit in a single DBM larva. Eggs hatch in less than 2 days. Parasite larvae feed inside late instar DBM larvae. Oomyzus *sokolowskii* continues to feed and develop inside DBM pupae when the host larvae form pupae. Eggs and larval stages together last from 5 to 8 days. Pupation takes place inside DBM pupa and it lasts 5-8 days. After 13-19 days from oviposition, several tiny O. *sokolowskii* adults rather than single DBM' adult emerge from DBM pupae. The number of parasite adults emerging from a single host DBM pupa varies from 8 to 39 according to laboratory study. Females can survive upto 4 days without food but can survive for up to 11 to 20 days when fed on dilute honey solution.

**Characteristics of parasitism**

Within the range of 10°C to 35°C, the higher the temperature the higher is the parasitism. When *C. plutellae* oviposited DBM larvae were offered for parasitism by O. *sokolowskii,* the latter parasite oviposited only freshly oviposited DBM larvae. The longer the period that elapsed after *C. plutellae* oviposition of DBM larvae, the lesser is the parasitism by O. *sokolowskii.* This eulophid does not attack either DBM or *Cotesia plutellae* pupae.

### ***Microplitis plutellae*** **Muesebeck**
### **(Order: Hymenoptera, Family: Braconidae)**

This parasite is found mainly in subtropical and temperate areas of the world. However, recent studies at AVRDC indicate that this parasite can survive and multiply normally at temperatures of 25°C to 35°C. It is thus suitable for DBM control in tropical lowlands (Figure 6-6).

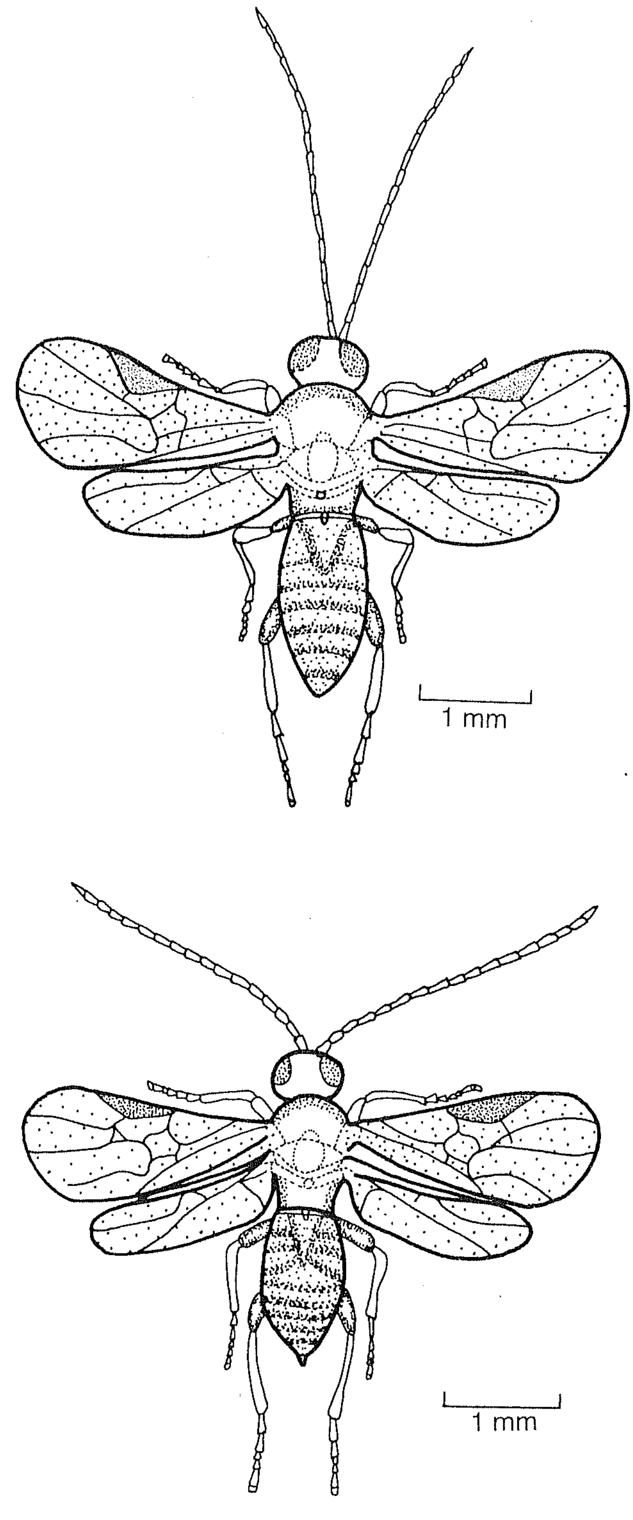



Figure 6-6. *Microplitis plutellae* adults; male (above), female (below)

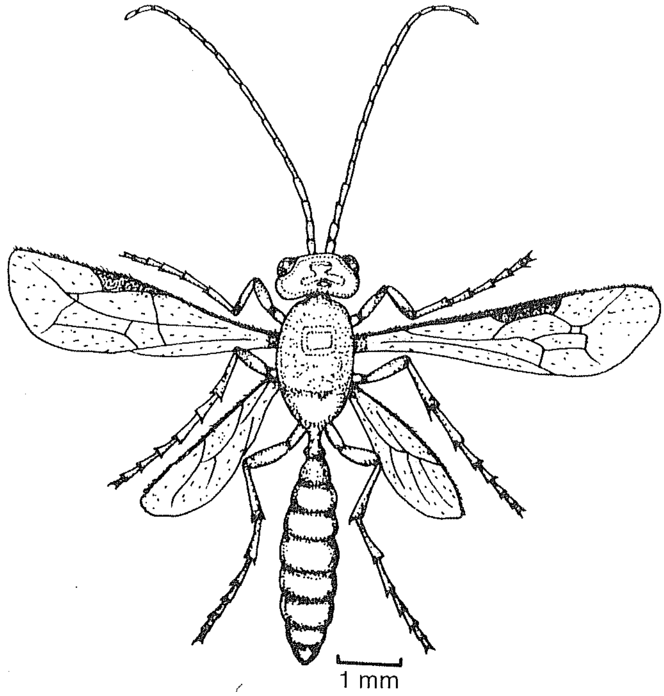
Adults of M. *plutellae* prefer to lay eggs in 2nd or 3rd instar DBM larvae. It can lay more than 230 eggs in its life time. Larval period lasts 15-20 days and pupal period 10-12 days at 26 to 28 $^{0}$C. In temperate climate *M. plutellae* undergoes diapause. In tropics, it multiplies continuously.

### ***Diadromus collaris*** **(Gravenhorst)**
### **(Order: Hymenoptera, Family: Ichneumonidae)**

Unlike the other 4 parasites decribed in this chapter, *D. collaris is* a pupal parasite of DBM. This ichneumonid does not compete with anyone of the earlier described 4 parasites, it supplements their activity in controlling DBM. This parasite is active at low temperatures and is thus suitable for highland areas in the tropics.

*Diadromus collaris* adult is finely punctate and rather brilliant colored. The head is black and palps, mandibles, antennae, pronotum, mesonotum and scutellum are red. The metathorax is black, the legs are reddish. The abdomen is black except for the first few segments which are red (Figure 6-7).

It lays eggs in prepupae or fresh DBM pupae. Each female can parasitize upto 134 DBM pupae, but the number of parasite adults that emerge rarely exceed 50%. *Diadromus collaris* larvae feed inside DBM pupae. It pupates inside DBM pupae. Towards the end of its pupal period *D. collaris* pupae turn dark brown, whereas DBM pupae remain light brown. After a total of 15 days of egg, larval and pupal period, *D. collaris* adults emerge from DBM pupae. Only one parasite adult emerges from single DBM parasitized pupa.



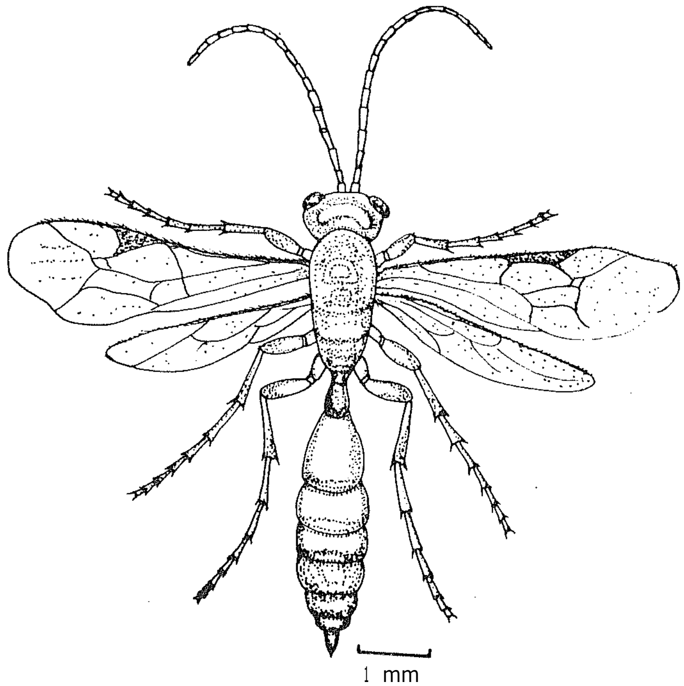




Figure 6-7. *Diadromus* collaris adults; male (above), female (below)

Efficient insect mass rearing procedure is very important in any successful biological control program. In practically all cases, imported parasites need to be reared under controlled conditions to make sure that they do not carry any hyperparasites or pathogens that could be harmful in the new environment. In many countries, quarantine laws require rearing of imported parasite in laboratory or other controlled-environment facilities for three or more generations before they can be released in the field. For parasite introduction, for the first time in the pest-problem areas, the more the parasites the better are the chances of its establishment and spread. Availability of large number of parasites enables one to release it in wider areas thus helping the spread of the natural enemy sooner. For inundative release of parasite, efficient and economical rearing procedure is the most important requirement.

For rearing of DBM parasites, the most important requirement is the temperature control facilities. Most DBM parasites can be reared efficiently at temperature range of 22 to 26 $^{0}$C. This temperature must be maintained uninterrupted as long as the parasites are being reared. Temperatures of over 26 $^{0}$C, in many parasite species, results in production of more males which eventually leads to demise of entire parasite colony.

AVRDC has published an illustrative booklet "Rearing of diamondback moth parasites" which gives details of all aspects of rearing five species of parasites: *Diadegma* semiclausum, *Cotesia* plutellae, *Oomyzus sokolowskii, Microplitis plutellae,* and *Diadromus collaris.* That booklet is available to interested individuals and institutions by writing to AVRDC on address given elsewhere in this publication. The following information is excerpted from that booklet.

In order to rear the parasites, most of which specific to DBM, we must rear DBM first.

## Rearing of DBM

### Growing of cabbage plants

DBM can be reared easily on cabbage plants. Prepare soil or a suitable soil and compost mixture normally used for growing plants in a greenhouse. If possible, use well dried autoclaved soil. Sow cabbage seeds in seedling flats or other suitable medium, placing 2-3 seeds per spot to assure adequate germination. After plant germination and establishment, thin out and maintain 1 plant per spot. Water plants regularly. You should see germination within 1 week.

Allow the plants to grow for 4-5 weeks to have 6-8 leaves. Start applying dilute ammonium nitrate solution once a week soon after germination. Transplant 4-5 week old seedlings, 1 seedling per 15 cm diameter clay or plastic pots. Water plants daily and apply 1-3 grams of ammonium nitrate, depending up on the amount of foliage, once a week after transplanting. Six weeks after transplanting, plants with 10 -12 leaves are ideal for rearing DBM larvae.

**Collection of DBM eggs**

Healthy eggs, larvae or pupae are essential for trouble free rearing of all parasites. Take about 65 grams healthy, pesticide free cabbage leaves, add 500 ml water, and using a suitable blender, blend leaves in water and prepare slurry/juice.

Autoclave the juice ($120^{0}$C, 1.05 kg/$cm^{2}$) for 20 minutes and filter the autoclaved juice through an ordinary sieve and discard plant debris. Dip wrinkled sheets of aluminum foil into the autoclaved juice until the foil is uniformly wet. Air dry the foil, cut in 2 cm x 10 cm pieces (hence forth called "oviposition foil") and store in refrigerator until use.

Cut slit in the lid of a 3-4 liter plastic container and hang 2-3 oviposition foils through it inside the container containing a flask filled with 10% honey solution and small amount of yellow food color to give light yellow/orange tinge to the solution. One end of a 10 cm long cotton wick is dipped in the solution and the other end is exposed over the flask inside the cage (Figure 7-1). Release 200 DBM adults inside the container and allow them to lay eggs for 24 hours. The yellow honey solution absorbed in the exposed portion of cotton wick serves as food to DBM adults. Place the oviposition chamber with DBM adults inside a cabinet away from direct light or cover the chamber with black cloth. Adults readily lay eggs on the oviposition foils.

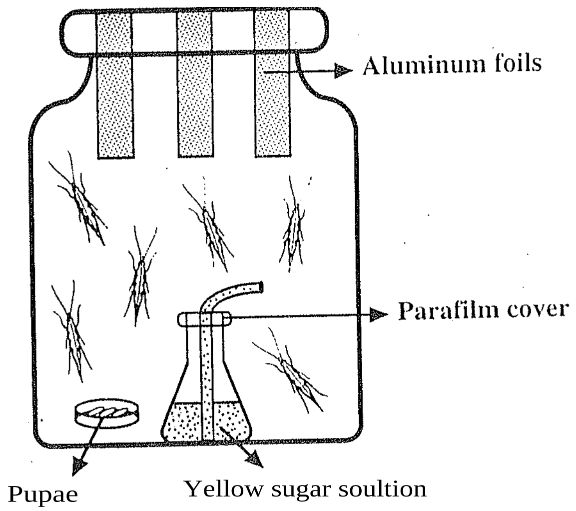



Figure 7-1. A simple plastic container for DBM oviposition

## Collection of DBM larvae and pupae

Dip oviposited foil in 10% formalin for 30 minutes followed by rinsing in running tap water for 15 minutes to wash off formalin completely. Place a 6-week old potted cabbage plant in a nylon net cage (50 cm x 50 cm x 40 cm) with wooden board floor. Cut a disinfected oviposition foil with about 800 eggs in small longitudinal strips and place the strips evenly on cabbage plants. Allow larvae to emerge and feed on cabbage leaves until they are in 2nd or 3rd instars. Second instar larvae are about 3 mm long and third instars, 5.5 mm. These insects are ready to rear any one of the three larval parasites: *Diadegma semiclausum, Cotesia plutellae* or *Microplitis plutellae.*

## Rearing of parasites

### Rearing *of Diadegma, Cotesia* and *Microplitis*

Place about 200 pupae of *Diadegma* or *Cotesia* or *Microplitis* in a cage (50 cm x 50 cm x 40 cm) and allow the parasite adults to emerge. Hang a plastic sheet smeared with 10% honey solution in the cage. Spray the honey solution on the plastic sheet daily. In addition, pour about 40-50 ml honey solution into a petridish and dip an absorbent cotton plug to keep it moist. Change this food source once every 2 days. Hang a black cloth curtain inside at the door side of the cage. This arrangement minimizes escape of parasite adults during opening and closing of the cage.

Parasite adults emerging from pupae feed on the honey solution in the petridish or on the plastic sheet. From this stage onwards all operations should be done at the following temperatures for each species: *Diadegma,* 20-22$^0$*C; Cotesia,* 26-28°C; *Microplitis,* 24-26°C.

Place a potted cabbage plant containing about 800 2nd instar DBM larvae inside the parasite adult cage (Figure 7-2). Cover the exposed soil in the pot with aluminum foil. On the cage floor, surrounding the clay pot, place a single layer of fresh cabbage leaves to trap DBM larvae descending from the plant when parasite tries to oviposit. Let the parasites oviposit in DBM larvae for 24 hours.

Remove the cabbage plant with parasitized larvae from the cage and carefully strip all leaves making sure larvae do not fall down. Place 2 - 3 of these leaves containing about 150 larvae on a fresh 6-week old potted cabbage plant placed in a similar but parasite-free cage (Figure 7-3). At this time transfer all DBM larvae fallen on the leaves placed on the floor of the previous cage on to the fresh cabbage plant. When food supply from the old excised leaves is exhausted, larvae migrate readily to the fresh leaves of the new plant. The biomass of the 6-week old plant provides enough food for larvae until pupation in 15 days.

Collect pupae carefully and store at 8-10°C until use. Pupae can be stored at this temperature for 15-30 days without significant loss of viability. Initially pupae of DBM and *Diadegma* look alike. However, as

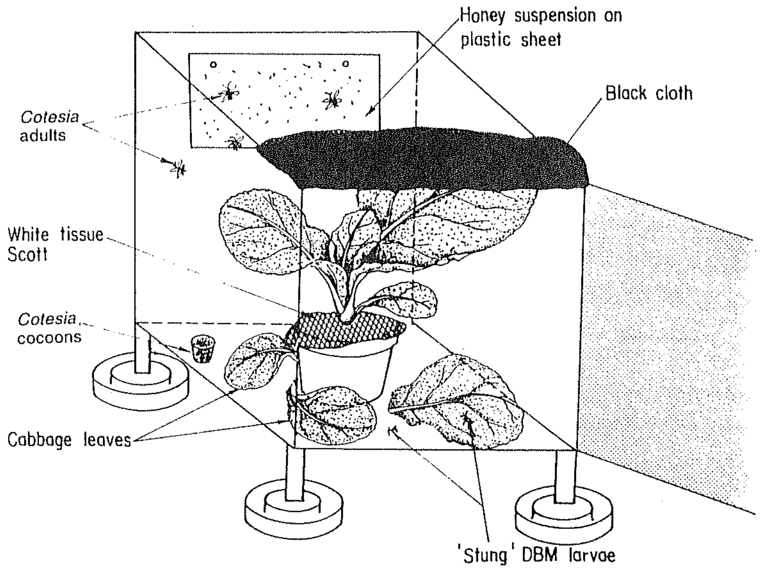



Figure 7-2. Parasite oviposition cage. Adults of *Cotesia, Diadegma,* or *Microplitis* are released inside the cage holding 2nd instar diamondback moth larvae on cabbage plant for parasite adults to lay eggs in

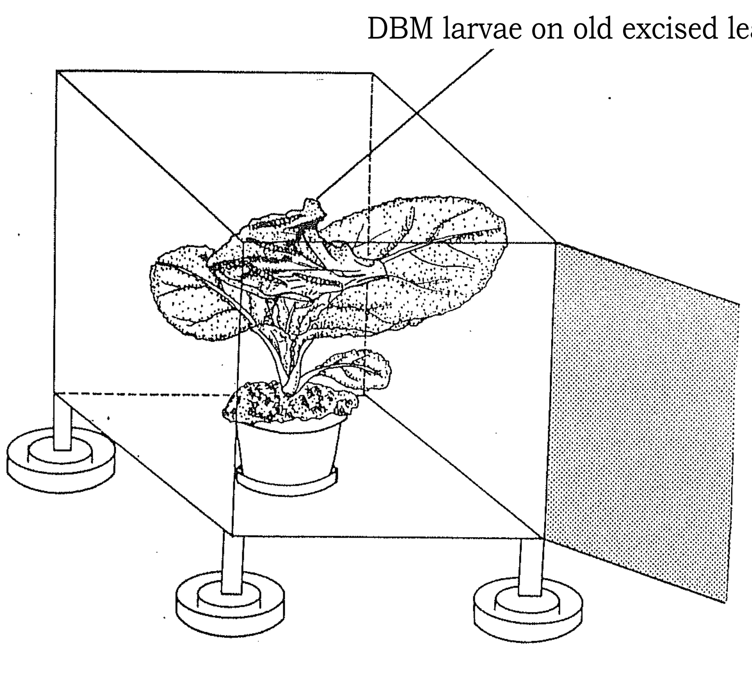



Figure 7-3. Parasite oviposited diamondback moth larvae are transferred on a fresh plant where they can feed -until pupation

the pupal period progresses, *Diadeg ma* pupae darken whereas DBM pupae remain brown. In addition, *Diadegma* pupae are short with blunt abdominal end as against a pointed abdominal end of slightly longer DBM pupae. *Diadegma* pupae are covered with opaque silken web. After about a week at room temperature, parasite adults will start emerging from the pupae. These insects are 0.45 cm long. *Cotesia* pupae are smaller and yellowish white whereas DBM pupae are larger, brown, and covered loosely with a silken cocoon. After 4-5 days parasite adults will start emerging from the pupae. *Cotesia* adults are smaller than those of *Diadegma.* *Microplitis* pupae are smaller and dark brown whereas DBM pupae are larger, light brown, and covered loosely with silken cocoon. After about 2 weeks, parasite adults will start emerging from pupae. *Microplitis* adults are slightly smaller than those of *Cotesia*

**Rearing *of Oomyzus***

*Oomyzus* is a very tiny insect which is also a larval parasite of DBM. Place 100 *Oomyzus* pupae and in a small petridish inside a 15 cm diameter 30 cm long acrylic/plastic cylinder. Also place a cotton plug soaked in honey solution in a small petridish inside the cylinder. *Oomyzus* adults emerging from pupae will feed on the solution. *Oomyzus* rearing can be done at the same temperature as *Cotesia's.* Place about 200-300 4th instar DBM larvae on two fresh cabbage leaves, the petioles of which are wrapped in moist cotton plug covered with aluminum foil. Place the leaf in the cylinder containing *Oomyzus* adults (Figure 7-4). Keep DBM larvae inside cylinder' for 24-48 hours. *Oomyzus* adults will lay eggs in DBM larvae during this time.

After 48 hours, all parasitized larvae will start becoming *Oomyzus* pupae. Initially both *Oomyzus* and DBM pupae are similar. However, after 5 days, *Oomyzus* pupae darken whereas DBM pupae remain light brown until adult emergence. Tiny, black, *Oomyzus* adults, barely visible by naked eyes, emerge from pupae after 15 to 18 days.

**Rearing** *of Diadromus*

Unlike the above 4 parasites, *Diadromus collaris* is a pupal parasite of DBM. This parasite thus supplements the control achieved by the larval parasites.

Place 100 cocoons of *Diadromus collaris* in a 50 cm X 50 cm X 40 cm nylon net cage. Hang a plastic sheet smeared with honey solution inside the cage and also place a cotton plug dipped in 10% honey solution inside the cage to feed *Diadromus* adults emerging from the pupae. *Diadromus* can be reared effectively at the same temperature as that of *Microplitis.* After enough *Diadromus* adults have emerged, place a large number of DBM prepupae or fresh pupae, in a single layer, in a petridish inside the cage. Do not stack up the pupae or else the pupae at the bottom will not get parasitized. Allow *Diadromus* adults to lay eggs in DBM pupae. After 48 hours, remove all DBM pupae and place a fresh lot of DBM pupae for parasitization.

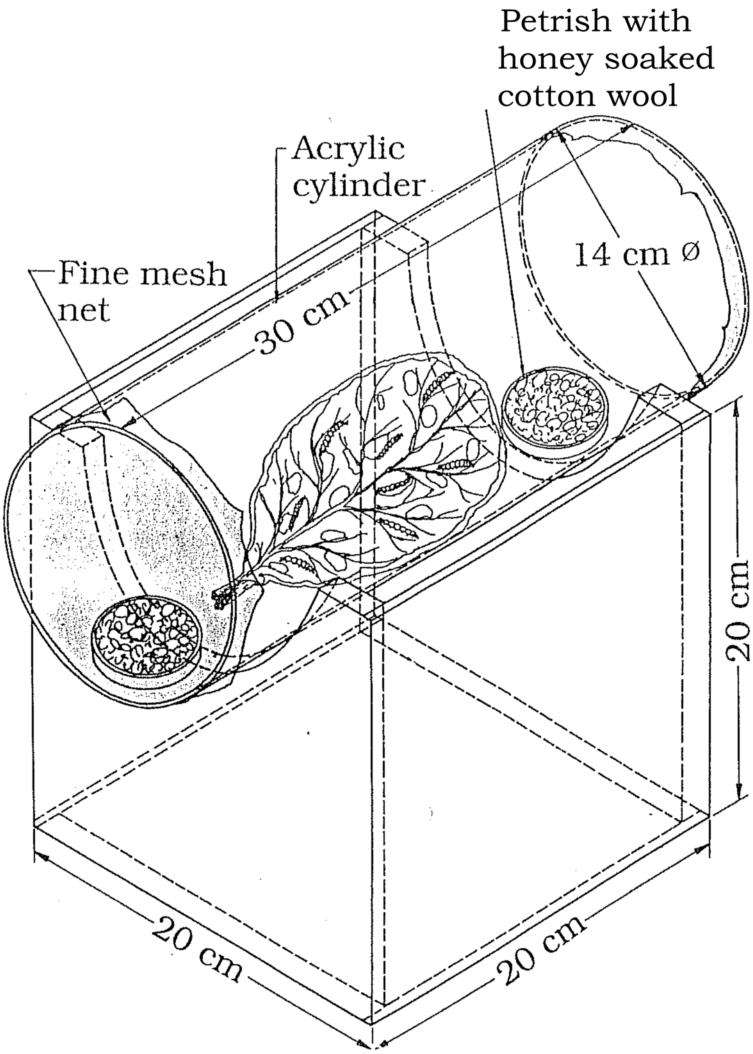



Figure 7-4. *Oomyzus sokolowskii* rearing chamber

Since *Diadromus is* a pupal parasite and spends its egg, larval, and pupal stages inside DBM pupae, it is difficult to distinguish between DBM and *Diadromus* pupae. However, towards the end of the pupal period, *Diadromus* pupae turn dark brown whereas DBM pupae remain light brown. Maintain pupae in the rearing room for 15 days during which time *Diadromus* larvae will pupate inside the DBM pupae. *Diadromus* adults which are of the same size as *Diadegma* adults will come out from pupae starting at the end of 15 days.

## Storage and shipment of parasites

Pupal stage is the most convenient stage to store and ship the parasite. The parasite cocoons can be stored at 10-12 $^{0}$C for about two weeks without significant reduction in adult emergence. After this period the longer the parasites are stored the lesser will be the emergence. Pupal stage is also the ideal stage for shipment over long distances. Pupae should be placed in a small container covered with thin plastic sheet, which in turn is placed in a larger box made up of styrofoam or thick paper. Make several tiny holes in both the inner container and the box to ensure aeration but make sure ants will not pass through the holes. The pupal shipment by air should never pass the X ray source normally used for ordinary check-in baggage or hand carry bags. The X ray source used to check passengers, however, is safe for parasite pupae.

# CULTU CONTROL OF DBM

Cultural control of the insect pest involves manipulation of cultural practices, such as soil tillage, crop rotation, irrigation, sowing date, intercropping etc. to reduce damage by insect pests. In the past when very few control options were available, attention to cultural practices to minimize pest problems was important. However, with widespread use of insecticides, the possibility of use of cultural control was neglected. Now, however, because of the failure of insecticides in controlling DBM, cultural practices that can reduce DBM damage substantially, have potential in adaptation for growing crucifers commercially. Some of the classical control measures that have been tried with limited successes are intercropping, trap cropping, use of sprinkler irrigation, rotation and clean cultivation.

**Intercropping**

Intercropping is a normal cultivation practice in tropics where farm size tends to be small and farmers are forced to make maximum use of available land, especially for vegetable cultivation. This cultural practice is rarely intended to control or even to reduce insect damage and selection of crop species is based more on their economic value than potential influence on pest species. Attempts have been made to exploit this practice to reduce infestation of pest insects. Under certain combinations, intercropping has beneficial effect in reducing certain insect pest damage. The beneficial effects of intercropping are believed to be due to the physical barrier to movement of pest insects produced by intercrop and repelling effects on insect pests produced by certain volatiles emitted by certain intercrops. Intercropping also increases diversity of crop species thereby increasing distance between two adjacent plants of the same species, as compared to monocropping where plants of same species are grown next to each other. This increased physical distance helps to reduce spread of the pest, especially if the pest species is monophagous or oligophagous like DBM, because the moth has to make extra effort to find the new host plant. This cultural practice has been studied with the view to reduce DBM damage.

The earliest documented successful attempts were made in Russia where intercropping cabbage with tomato reduced damage to cabbage by several pests including DBM. This practice, however, had only limited success elsewhere. In an experiment at AVRDC none of the 54 crops tested for their utility in intercropping had any significant impact on the population of DBM on cabbage. Although intercropping with Salvia ofcinalis L., Thymus vulgar-is L. and *Trifolium repens* L. consistently reduced damage to Brussels sprouts from DBM (Dover.1985, 1986), these crops are of questionable importance to the small vegetable farmer who uses his premier land to produce crucifers or similar other vegetables which have high market value.

**Sprinkler irrigation**

DBM larvae are surface feeder and are easily exposed to and influenced by various biotic and abiotic factors. Numerous reports indicate that rainfall is an important mortality factor in DBM biology. Diamondback moth, therefore, is not a serious pest during rainy season. The vulnerability of DBM to rainfall was exploited in its control. Providing irrigation by intermittent sprinkling of water over a cabbage crop at dusk significantly reduced DBM infestation in cabbage (Talekar et al. 1986) (Figure 8-1). This reduction is believed to be caused by drowning of DBM larvae in their feeding holes or physical dislodging of the insect from plant surface. This operation at dusk also reduced mating related flying activity (AVRDC 1988) and presumably oviposition. In watercress, sprinkler irrigation at night alone reduced oviposition as much as sprinkling for 24 hours (Nakanara et al. 1986, Tabashnik and Mau 1986). Sprinkler irrigation technique to control DBM in crops other than watercress, however, is not practical on a commercial farm because of the high cost of infrastructure. Besides such irrigation is likely to induce diseases such as black rot, downy mildew due to high humidity. Watercress is grown in continuous standing water and sprinkler irrigation may not enhance disease incidence. On small scale home gardens, however, sprinkler irrigation, performed at dusk, is practical in controlling DBM.

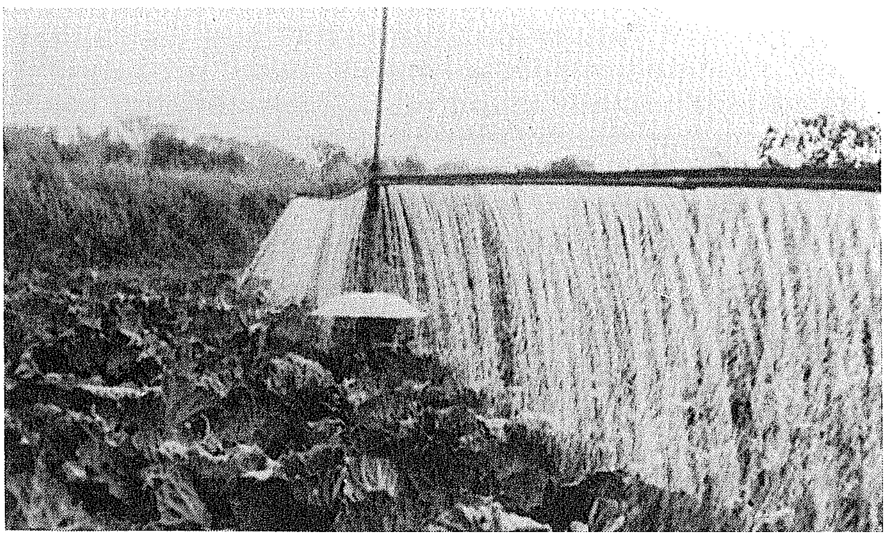


Figure 8-1. Intermittent sprinkler irrigation, especially at sunset helps to reduce diamondback moth infestation -

## Trap cropping

Before the advent of the modern organic insecticides, planting of strips of highly preferred but economically less important species or varieties in the commercial crucifer production area was advocated and practiced. The more preferred crops, mostly white mustard *(Brassica hirta)* or rape *(Brassica juncea (L.)* Czern) attracted DBM to it and spared the commercial crop such as cabbage, Brussels sprouts and others from its attack. Now that the same modern insecticides which made past trap cropping obsolete are made obsolete by insecticide-resistant DBM, the decade-old trap cropping is becoming increasingly attractive, especially in South Asia. Planting of mustard after every 15 to 20 rows of cabbage attracted DBM toward mustard and spared main cabbage crop from its depredation (Srinivasan and Krishna Moorthy 1992). In order to trap all DBM adults that start coming from other areas to the newly planted crop, rows of mustard are planted 12-15 days ahead of cabbage planting and in order maintain mustard foliage available until cabbage is harvested, second set of mustard rows are planted 25-28 days after cabbage planting (Figure 8-2). This trap cropping reduces the need for chemical insecticides to bare a minimum or at times not at all. This cultural control, although not as effective in controlling DBM elsewhere

Figure 8-2. Planting of trap crop like Indian mustard *(Brassica juncea)* after every 15-20 rows of cabbage, as shown here in this Indian Institute of Horticultural Research experiment, may reduce DBM infestation of main cabbage crop. This technique is especially effective against another crucifer pest, *Crocidolomia binotatis,* in Southeast Asia.

as it is reported in India, nonetheless is effective in trapping *Cr°ocidolornia biriotalis,* a serious pest of crucifers in certain tropical countries, and reducing its damage to main cabbage crop.

Rotation and clean cultivation, often mentioned as important in reducing pest population are rarely practiced in controlling DBM. At present selection of vegetable crop species at least in intensive vegetable growing areas of the tropics and subtropics, is determined more by market forces than by the pest problem. If crucifers fetch higher prices as they often do in big cities, the farmers plant crucifers season after season and increase frequency of insecticides to combat DBM - a main cause of insecticide resistance and subsequent DBM problem in tropics and subtropics.

# SEX PHEROMONES IN DBM CONTROL

Sex pheromones are chemicals secreted into external environment by insect females that attract males of the same species for mating. These chemicals, usually a specific mixtures of 2 or more, are produced by virgin females when they are receptive for mating (Figure 9-1). In most Lepidoptera females are receptive for mating at dusk or at night. Pheromone chemicals are active at very low concentration and are highly specific for species concerned. Chemical structure of many insect sex pheromones, including that of DBM, have now been identified and they are synthesized and some even are commercially available. These chemicals can be manipulated in three principal ways in insect control.

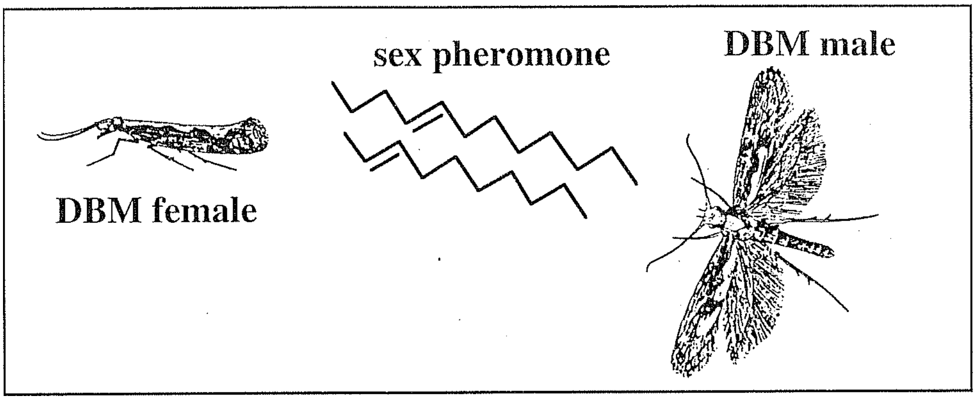



Figure 9-1. Sex pheromone released by DBM female ready for mating, attracts DBM males for mating

**Survey and monitoring**

In this method, small amount (5-10 microgram) of specific pheromone is coated on a rubber septum or held in a permeable plastic tube that allows slow evaporation of the chemicals. The pheromone coated septum or tube is placed in a suitable trap that is coated with sticky glue. Male adults are attracted to the pheromone chemicals and fly actively towards the source of chemicals assuming the chemicals are coming from females ready for mating (Figure 9-2). In the process of flying around pheromone chemical, these adults get trapped on the sticky surface and eventually die. The presence of males in the trap indicate that insect is already present in the field or have started migrating from elsewhere and necessary control measures such as spraying suitable chemical, or release of parasites such as egg parasites, can be initiated to

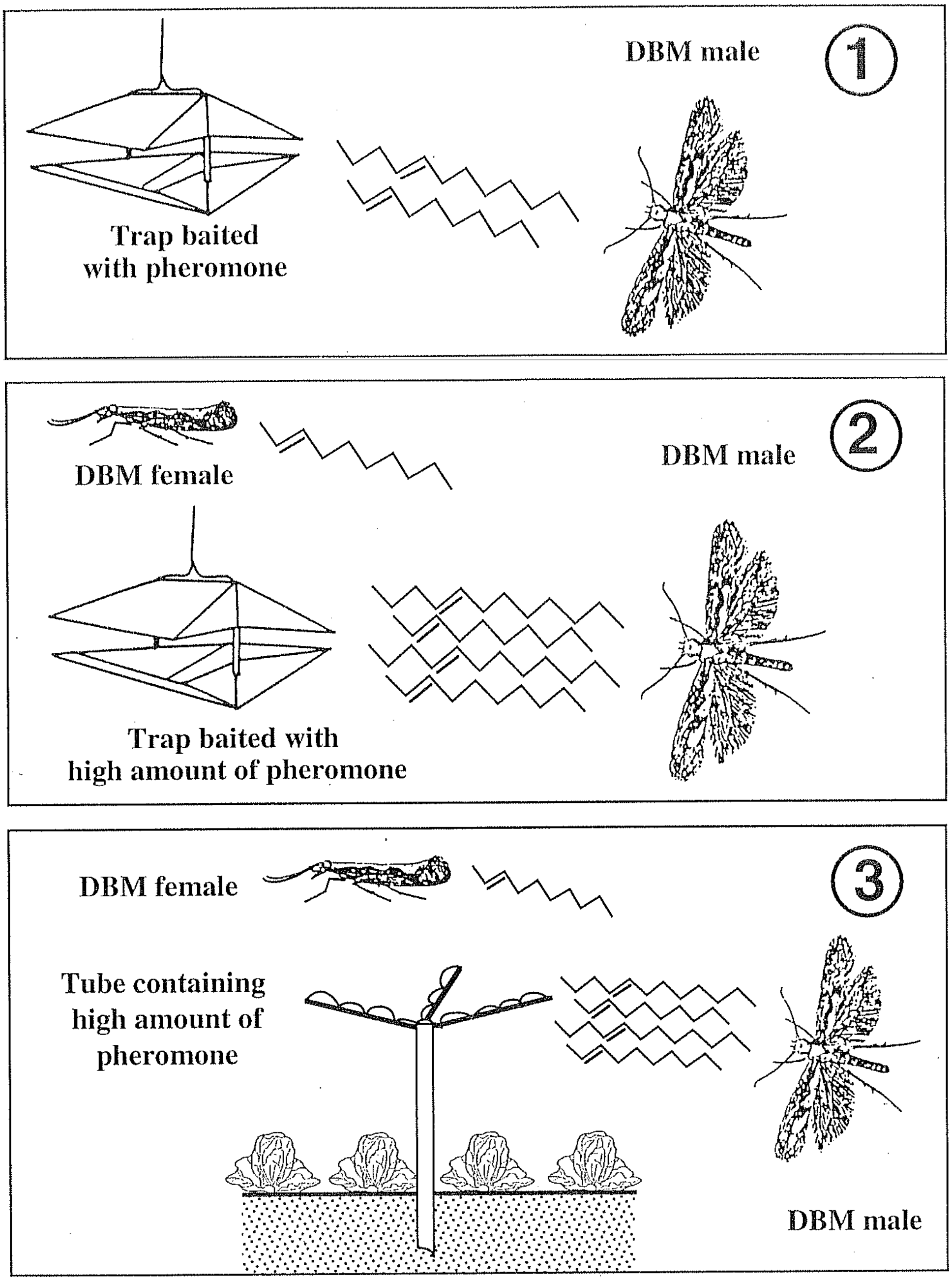



Figure 9-2. Various ways in which sex pheromone can be used for DBM pest control. (1) Synthetic pheromone chemicals are baited inside a trap placed in the field to monitor onset of DBM infestation. (2) Traps baited with higher than normal amount of synthetic sex pheromone attracts males away from females where they are caught continuously. (3) High concentration of sex pheromone placed at a regular interval throughout the field impregnates the air over the crop with sex pheromone and confuses DBM male which fails to detect female- for mating.

have maximum effect. Such monitoring should start soon after crop is planted in the field and at the first appearance of an adult of the target pest in the trap, suitable control measures should be adopted immediately.

**Mass trapping**

In this procedure pheromone chemical, usually in higher than normal concentration, is placed in a trap and insects are trapped continuously. The traps need to be kept in the field throughout the night and day so that insects can be trapped continuously (Figure 9-2). For this purpose, the sticky paper surface of the traps must be replaced as soon as it is covered with insect remains or dust in order to trap newly attracted males. The important aspect of this mode of pheromone use is to trap as many adults as soon as they emerge from pupae as possible before they have opportunity of mating with females. There are very few cases where this method of use of sex pheromone has any great success in controlling the pest.

COOH

**(Z)-11-Hexadecenyl acetate**

CHO

**(Z)-** 1 1-Hexade cenal

Figure 9-3. Chemical structure of two major components of DBM sex pheromone. A 7:3 mixture of upper and lower compounds is ideal for trapping DBM male adults.

**Mating disruption**

In this technique, septa or tubes baited with high concentration of sex pheromone are placed just above plant canopy and no trap is provided (Figure 9-2). High concentration of pheromone evaporates and the air over the field is impregnated with pheromone smell. The principle behind this method of pheromone use is that, if synthetic sex pheromone is released into the atmosphere and maintained at sufficient concentration over long period of time, the natural pheromone scent emitted by receptive females will be masked and males will not be able to locate the receptive females and fail to mate. This failure in mating will stop production of fertile eggs and production of second and subsequent generations of insects. Use of this technique has proven to be successful at least under experimental conditions with several insect species. It is essential that there should be even distribution of high enough concentration of sex pheromone for sufficient length of time. Cost is likely to be high. In some insects instead of complete blend of all pheromone compounds, use of one major chemical has proven to be effective in achieving mating disruption. This reduces the cost.

**Sex pheromone of diamondback moth**

The presence of classical lepidopteran sex pheromone in female adults of DBM was demonstrated for the first time in Taiwan (Chow et al. 1974). Like other Lepidoptera, virgin females of DBM emits the pheromone to attract males for mating. The pheromone consists of three components: (Z)-11-hexadecenal, (Z)-11-hexadecenyl acetate and (Z)-11-hexadecenyl alcohol (Chow et al. 1977, Tamaki et al. 1977, Chisholm et al. 1979) (Figure 9-3). These chemicals are now synthesized and are available for commercial use. The exact proportion of three components in a pheromone blend that will attract the maximum number of male moths is influenced mainly by air temperature but not humidity (Maa 1986) and possible strain differences that might exists at widely spaced locations. Extensive studies have been carried out to determine exact proportion of the pheromone components, effect of environmental factors, effective distance, longevity in the field etc to improve efficacy of the pheromone in order to use this technique for the control of DBM in the field. The ideal mixture is 7 parts of (Z)-11-Hexadecenyl acetate to 3 parts of (Z)-11-hexadecenal. The third compound (Z)-11-hexadecenyl alcohol although present in natural sex pheromone, is not necessary for attracting DBM males. However, until recently for the control of DBM, the pheromone could be used only for monitoring the presence of the pest. This is believed to be mainly due to very short effective distance of the pheromone blend.

During the past few years, however, Japanese scientists have succeeded in achieving mating disruption by the use of high concentrations of the pheromone (250 g/ha) sealed in specially designed polyethylene tube that is hung over cabbage field (Nemoto et al. 1992, Ohbayashi et al. 1992, Ohno et al. 1992). Sex pheromone, a 1:1 mixture of (Z)-11-Hexadecenal and (Z)-11-Hexadecenyl acetate, is diffused out through the polyethylene tube throughout the crop season. The high concentration of pheromone confuses male moth which fails to mate. This reduces production of viable eggs and larval population. This formulation is now commercialized in Japan and collaborative multilocation studies in that country have shown promising results (Ohbayashi et al. 1992), but its use is still not cost effective.

# HOST-PL T RESIST CE IN DBM CONTROL 10

One of the feasible alternatives to insecticide use is the use of crop varieties resistant to insect pests. Resistance can be defined as the ability of the plants of a variety to avoid, tolerate, or recover from the attack of an insect population that causes greater damage to other plants of the same species under the same environmental conditions. Insect resistant varieties are being successfully used in rice, wheat, sorghum and certain other cereals and legumes. These varieties can be used alone or in combination with other control measures in an integrated pest management program.

Although DBM attacks practically all domesticated crucifer species, and some crucifer weeds, the degree of damage varies among different species. Rudder and Brent (1967) in the United States, for example, found that among 10 different crops they tested for resistance to DBM, the most resistant were radish, turnip, and mustard, while the most susceptible were broccoli, rutabaga, Brussels sprouts, and cauliflower. In common cabbage, kale, and collard, some varieties were resistant while others were susceptible. They found that the resistant types had densely compact cells without airspaces, while the susceptible varieties had loosely arranged cells and an abundance of air spaces. Certain varieties of broccoli, cauliflower, mustard, radish, rutabaga, and turnip also show degree of resistance to DBM (Yepsen 1984).

The development of insect pest resistant varieties among crucifers appears to be more difficult than many other crops and past efforts have yielded varied results. This is because insects eat the same fleshy plant parts humans consume and any antibiotic factor that confers genetic resistance to insect pests is likely to be unacceptable for human nutrition. However, there are some notable successes. Researchers at Cornell University's New York State Agricultural Experiment Stations at Geneva have identified resistance factors in one cauliflower accession PI234599 which confers resistance to DBM, cabbage looper, and imported cabbageworm (Eigenbrode et al 1990). The resistance to DBM is caused by certain unknown chemical factors in leaves that adversely affects development of DBM larvae and by amount and type of waxes in leaves that affects the behavior of first instar larvae as a results of which DBM causes much less damage in resistant variety than in susceptible ones (Eigenbrode et al. 1991). The presence of high concentration of waxes imparts glossiness in the leaves of resistant cabbage and cauliflower varieties bred by Cornell scientist using the cauliflower accession PI234599. The DBM resistant cauliflower have slightly yellowish curd or flowers that are consumed as vegetables. Although at present the resistant cabbages and cauliflower are not cultivated to any great extent, these materials are important source available to use when need arises. Cornell scientists will supply small quantities of seeds of resistant source to any researcher seriously interested in utilizing them in their research and development. (Figure 10-1).

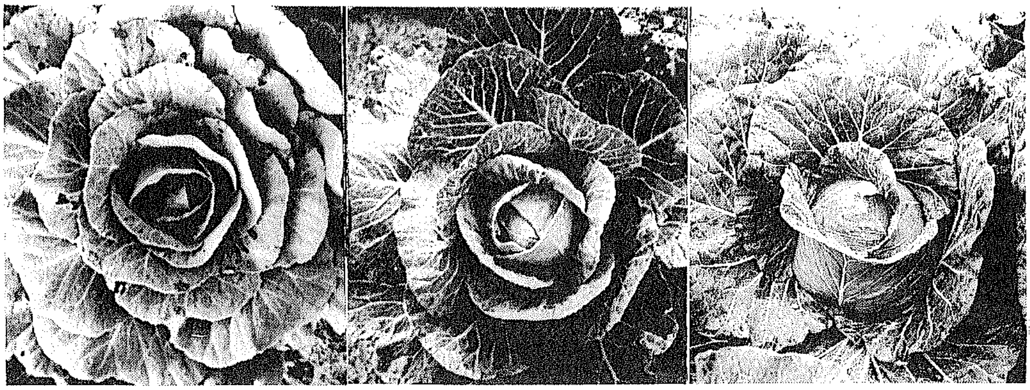


Figure 10-1. Special waxes in the leaf (left) and leaf glossiness (middle) provide moderate level of resistance in cabbage cultivars to DBM. A susceptible cultivar with normal leaf thickness and texture is on the right.

DRAFT

# 11

Integrated pest management (IPM) utilizes two or more control measures together in an integrated manner to make maximum use of natural mortality factors especially native predators, parasites, and then apply specific control measures e.g. insecticides, egg parasites, larval parasties, mechanical means such as erecting suitable barriers or prompt destruction of insect where possible by physical removal, as and when necessary. IPM thus is not a technology, it is a concept of pest control. Therefore, for any successful IPM, one must have the complete understanding of the factors that regulates pest population. Of utmost importance is the knowledge of biology and how physical factors such as temperature, humidity and rainfall affect the pest population. In the case of DBM, in addition to the three factors mentioned above, role of parasites in regulating pest population is of special significance. In Europe, where this insect originated, it is the activity of natural enemies, especially parasites, that keep this pest under check. Outside Europe, where DBM is destructive, it is therefore essential to know the species of parasites that occur locally and their role in regulating DBM population. Since naturally occurring parasites are freely available, an all out efforts should be made to conserve these natural enemies. This implies that chemical insecticides, which are already obsolete in controlling DBM in the tropics, should never be used. Although DBM has developed resistance to certain strains of Bacillus *thuringiensis,* new strains of Bt strains can be employed. Since natural enemies alone have potential in controlling DBM, introduction of as many natural enemies as possible should be a priority of any IPM program. Such biological control-based IPM has been successful in selected tropical to subtropical countries. Here we review some examples of such programs and outline possible IPM measures that can be employed, based on pest biology, to combat DBM and certain other associated crucifer pests in tropical lowlands where this pest is especially serious.

Although farmers in tropical and subtropical areas for the past 30 years have depended exclusively on insecticides to control DBM, the appearance of multiple insecticide resistance and considerable slow down in introduction of new insecticides in the market since mid 1980s, has stimulated research on alternate control measures. These control measures are essentially the same that were discarded in favor of organic insecticides, when the chemicals were first introduced for DBM control in early 1950s. Since parasites, where they are present, play such an important role in checking DBM population, introduction and conservation of these natural enemies is basic to any sustainable IPM. Because of the necessity of use of parasite, the small size of farms, often less than 0.1 ha, and large numbers of farmers,. make it utterely impossible to implement IPM on an individual farm. One needs a community approach to implement sustainable IPM because practices of one farmer influence those of his neighbor. This applies especially to conservation of natural enemies. In this respect establishment of *D. semiclausum* in highlands of Indonesia, Malaysia, Taiwan and the Philippines is already contributing significantly towards the control of DBM (Sastrosiswojo and Sastrodihardjo 1986 , Ooi and Lim 1989, Talekar et al. 1990, Poelking 1992). In all above areas, however, one or two sprays of *B. thuringiensis* or neem during a season may be needed if the DBM activity becomes more prominent. Introduction of a pupal parasite *Diadromus collaris* where it does not occur, is necessary.

In the highland areas such as those of Indonesia, besides DBM, *Crocidolomia binotalis* (Zeller) damages crucifers (Sastrosiswojo and Setiawati 1992). Since presently marketed strains of *B. thuringiensis* are not effective, application of chemical insecticides becomes necessary. This causes occasional flare-up of DBM population presumably due to the insecticide-induced mortality of *D. semiclausum.* In this area, planting of Indian mustard *(Brassica juncea)* trap crop attracts C. *binotalis* away from main cabbage crop. If natural enemies do not keep C. *binotalis* on Indian mustard under control, the trap crop can be sprayed with suitable insecticide to kill *C. binotalis* which will minimize the need to spray cabbage plant and minimize mortality of *D. semiclausum.* Over the period of time, hyperparasites are bound to attack *D. semiclausum* and *D. collaris.* Hence introduction of new parasites, especially those from Europe, need to be continued.

DBM in lowlands remains a serious problem in most of tropics and subtropics. So far *Cotesia plutellae is* the only larval parasite that can survive the high temperature common in the region. Although this parasite has been established in a number of crucifer growing areas in tropics and subtropic, this braconid alone is not effective in controlling DBM and introduction of supplemental parasites such as *Microplitis plutellae* and *Oomyzus sokolowskii is* necessary. AVRDC maintains cultures of both these parasites and they are available to all those interested in their introduction.

The content of damage threshold to adopt control measures has crept in many developing countries of the tropics (Chelliah and Srinivasan 1986, Chen and Su 1986, Rustaparkornchai et al. 1992, Sastrosiswojo 1987, Loke et al. 1992). This useful concept, however, has only limited potential in the tropics in the near future. Its adaptation is hindered by it being laborious, many farmers do not recognize pest from beneficial insect, some farmers have difficulty in counting because of their illeteracy, and in most tropical countries, DBM has already developed resistance to most insecticides, making applications of insecticides for quick suppression of pest population futile. Community wide integrated approach in getting as many DBM parasites released and established as possible is urgently needed. However, it will take time. In the meantime, based on the control options described in this manual, it is possible to integrate the use of some of these options to obtain effctive control of DBM. While exercising the use of these options, it is important that the second most important reason for the severity of DBM problems in lowlands - reliance on chemical insecticide use only - need to be curbed. We not only depend on insecticides but we depend on only those insecticides that kill DBM larvae. This is the crux of the problem. Diamondback moth has four growth stages and each stage has several potential control measures. We need to integrate these control measures. Here is how to integrate these methods and control DBM effectively and inexpensively.

**Step I.**
*conserve parasites and predators*

It is absolutely essential to conserve as many existing natural enemies as possible. In practically every country in the tropics and subtropics, a high temperature-tolerant larval parasite *Cotesia plutellae* is present in lowlands and in some mid level highlands. In cool highlands, one larval parasite; *Diadegma semiclausum* and one pupal parasite *Diadromus eollaris* are present or can be introduced with little efforts. The highland parasites are much more effective than lowland ones. In the lowlands an egg parasites *Trichogrammatoidea bactrae* and *Trichogramma chilonis* could be employed, if their use proves to be economical. Except for the egg parasites, none of the natural enemies can be used like insecticides, i. e. as and when needed. The natural enemies have to be released in large numbers only once or few additional times if the first release did not survive and multiply on its own. In most highland areas of Southeast Asia *D. semiclausum* and *D. eollaris* are established and in lowlands *C. plutellae is* very common. There is no need to release these parasites in areas where they are already present. But these parasites need to be conserved. Intensive use of broad-spectrum chemical insecticides to control DBM, so far has killed the parasites and has prevented the free use of these beneficial insects in controlling the pest. This is because parasites are highly susceptible and chemical insecticides kill them first before they reach DBM. Since most chemical insecticides are useless in controlling DBM anyway, these chemicals should never be used for DBM control which will help conserve the natural enemies.

**Step 2**
*clean cultivation*

Since in tropics and subtropics, because of favorable weather and continuous availability of host plants, DBM is present throughout the year, crucifers planted at anytime are subject to attack by this pest. It is very important, therefore, to reduce DBM damage by all easy to adopt practical means. DBM adult prefers to lay eggs on fresh leaves. Crucifer seedlings, therefore, are especially important target for DBM oviposition. Diamondback moth oviposited crucifer seedlings are natural carriers of pest infestation from one field to the next. Therefore, only seedlings that are free of DBM eggs and young larvae should be used to plant a new crop. Since both eggs and young larvae are too tiny, it is laborious to observe each seedling to see whether they are DBM free. To overcome this, all crucifer seedlings should be covered by protective materials such as fine nylon net or plastic sheet, from germination until the day they are to be transplanted. This will prevent DBM adults finding them to lay eggs on. Crucifer seedlings should never be raised in an open field bordered by DBM-infested crop, no matter how slight is the infestation of the neighboring crop. Seedlings should be grown, if possible under nets in the backyards or other empty places away from any potential DBM source. Although transplanting of DBM-free seedlings alone will not protect the crop completely, it will postpone the onset of DBM infestation and reduce need for undertaking control measures so early in the season. Pesticide-free crop will allow predators and parasites to proliferate and help reduce pest population. The crop should be kept weed-free because DBM can feed on certain weeds especially crucifer weeds. The border and other empty areas should be maintained free of crucifer weeds. In addition, as soon as crucifers are harvested, the field should be cleaned free of plant debris as DBM larvae and pupae may remain on plant debris.

Avoid planting crucifers next to a DBM-infested crucifer crop. However, if you must plant next to other person's DBM-infested crop, erect a 2m-high net barrier between the old crop and the new before you plant your crop. DBM is not an active high flying insect and a barrier suggested above will be useful to' keep the pest away from your new crop for some weeks.

**Step 3**

*watch for DBM arrival but hold back chemical insecticide use as long as possible*

Monitor the onset of DBM infestation. This can be done by daily visit to the field and observing the DBM adults flying around or young larvae feeding on the leaves. Alternatively, traps baited with DBM sex pheromone can be installed in the field. The sex pheromone should be replaced once every 2-3 weeks. The sticky paper trap surface should be replaced as soon as it becomes covered with trapped insects or dust. Sex pheromone attracts DBM males only. Presence for the first time a DBM adult in the trap will indicate initiation of DBM infestation is underway or will soon begin and it is time to take action. If readily available, it is perfect time to release egg parasites to kill eggs and help reduce DBM larval population build-up. There is no hard and fast rule as to how many egg parasites are necessary per unit area to control the pest. However, if amount of parasites is not a constraint, then the more of them you release, the lesser are the chances of DBM becoming serious during rest of the season.

If you are planting the first crucifer crop after rainy season, you should postpone application of chemical insecticides as late as possible to let the natural enemies, especially predators to proliferate and kill DBM. During rainy season, as explained earlier, DBM is not a problem. Frequent rains wash off pesticide residues and help to protect predators and parasites. This will keep the crop DBM free practically until harvest. If this recommendation is strictly adhered to, it will even benefit the second crucifer crop planted in the same field.

**Step 4**

*be vigilant throughout the season*

Observe the plants regularly. If you notice that DBM population is continuously increasing then start applying Bacillus *thuringiensis.* This biological insecticide contains bacteria that cause disease in DBM larvae. It kills DBM but does not affect the parasites. Spray only as required. One week after each spray if you notice DBM population is decreasing stop spraying. Do not spray this product unnecessarily or else DBM could become resistant to this environmental friendly product. Because B. *thuringiensis is* selective against DBM, its use will help to take advantage of parasites' usefulness in controlling DBM. In most countries neem products are becoming increasing available. These products are also selective in killing DBM while sparing the parasites. Use of these products is highly desirable.

If all four steps are followed carefully, DBM damage can be minimized below acceptable level throughout the season. It will conserve natural enemies which will help in sustainable control of this pest.

We realize some of the steps we recommend here are slightly laborious. Vegetable cultivation is already laborious enough. This could discourage some farmers from adopting these control measures. However, in final analysis, the IPM we suggest is still less laborious than spraying chemical insecticides. Our recommendations are certainly cheaper than purchase of pesticides. There is no danger to farmers, consumers and environment when one adopts our suggestions as against present use of pesticides which endangers farmers, consumers and environment.

Our suggestions require community approach. However, most farmers, especially vegetable farmers, are highly individualistic. They spray chemicals as they please - in many cases without consideration as to whether it will control the pest. Once upon a time when insecticides were still effective, the individual farmer's own approach controlled DBM. However, now that the DBM has developed resistance to most chemicals, this approach not only exacerbates the DBM problem on their own field, but their field acts as a source of DBM to the neighboring farmers. Therefore, on small farms in the lowlands, a community approach will go long way in combating DBM on a sustainable basis.

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