EFFECT OF POTENTIAL COMPANION CROPS ON OVIPOSITION, DEVELOPMENT AND INFESTATION BY DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.) ON CABBAGE

BY

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DECLARATION BY CANDIDATE

This Thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

In Loving memory of my brother-in-law Rube who passed away in the course of this study.

I also dedicate this thesis to my parents James and Eunice Raini, my sisters, brother, and Sidney and Nigel (my nephews) for their continued prayers, support and encouragement.

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ABSTRACT

The present study focused on laboratory and field evaluation of three brassica crops (Kale, Rape, Mustard) and three non-brassica crops (Cleome, Coriander and Onion) as potential companion crops in reducing the diamondback moth (DBM) population on cabbage. The effect of the crops on oviposition, development and the survival of DBM were assessed in the laboratory whereas infestation and damage were assessed in the field. Laboratory studies on oviposition by DBM moths showed that when cabbage is available for choice (under choice situation), more eggs were laid on mustard and rape, while very few eggs were laid on the non-brassica crops. Even when no other hosts were available (under no-choice situation), the DBM laid less eggs on the non-brassica crops (43-53 eggs) than cabbage and the other brassica hosts that were tested (80-108 eggs). Mustard appeared to attract the highest oviposition while onion recorded the lowest.

Laboratory studies on the duration of development of larvae and pupae of DBM did not differ significantly among the brassica test host plants. The proportion of first instar larvae surviving to adult stage in rape and kale (27.0-29.5 %) was comparable to that on cabbage (31%), while mustard appeared less suitable (21.5%) and was close to cleome (21.0%). Onion and coriander did not permit the first instar larvae to survive even into second instar stage. The adults that emerged from the DBM larvae fed on

different test hosts did not show any significant differences in their longevity. However, the fecundity was significantly lower (3.6 eggs/ adult) among the adults reared from cleome and this was significantly different from the other test brassica hosts, namely kale (114.9 eggs), rape (71.8 eggs) and mustard (45.8 eggs) and cabbage (115.6 eggs). There was no significant difference among the test brassica hosts.

In the field studies where plots of cabbage were planted with and without the six test plants as companion crops, the DBM larval infestation was significantly low in plots intercropped with coriander (1.35 larvae per cabbage plant), and cleome (1.67 larvae per cabbage plant). Cabbage plots intercropped with the three brassica test crops: mustard, kale and rape also recorded significantly low infestation (1.74-2.22 larvae per cabbage plant) compared to the sole cabbage monocrop plots. The leaf damage severity due to the DBM infestation was also found to be significantly reduced by all the companion crops, compared to unprotected cabbage monocrop plot.

The results have indicated the overall potential of brassica crops (like mustard) to be utilised as a trap (pull) crop and non-brassica crops (like coriander) and cleome as repulsive (push) crops in reducing the oviposition, survival and crop damage by DBM on cabbage. Nevertheless, there is need to further evaluate the optimum proportion and planting pattern of the promising push-pull crops and their relative economic as well as ecological benefit to the cabbage agro ecosystems.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Brassicas are among the most commonly cultivated vegetables in the world and cabbage (*Brassica oleraceae* var. *capitata* L.) is the most grown brassica worldwide (Choudhary, 1967; Nieuwhof, 1969; McCollum and Were, 1980). In Kenya, cabbage and kale (*B. oleraceae* var. *acephala* L.) are the most important brassica vegetables and are grown all over the country (MoA, 1998), from elevations of 800m to 2200m above sea level (Anon., 1989). Cabbage is grown under rain-fed and irrigated conditions. The commonly grown cabbage varieties include Gloria F1 hybrid, Copenhagen market, Sugarloaf, Macanta, Alma hybrid, Golden acre and Prize drumhead (MoA, 1998). In the tropics, cabbage is grown and mostly used for preparing vegetable salads and stews. On the contrary, cabbage is grown as both food and fodder crop in the temperate areas.

Cabbage and kale production in Kenya is predominantly by small and large-scale farmers basically for subsistence with limited commercial objective (MoA, 1998). Particularly, cabbage is a major vegetable in the domestic market, with the advantage of being rich in vitamins and mineral salts. The nutritional importance of the crops has gradually increased over the years even though the supply is limited due to various production constraints. Insect pests constitute major constraints to production and marketing of Brassicas. For example the diamondback moth (*Plutella xylostella* L.) and cabbage aphids (*Brevicoryne brassicae* L., *Lipaphis erysimi* Davis, and *Myzus persicae* Sulzer) are the major pests of cabbage in Kenya (Kibata, 1974; Anon., 1989; MoA, 1998).

In order to minimize both crop damage and loss due to these pests, farmers mostly resort to the use of chemical pesticides. Indiscriminate use of synthetic pesticides is known to lead to problems associated with their excessive use such as environmental pollution, toxic residues, increased pest resistance, and pest resurgence.

The diamondback moth has remarkable adaptations contributing to its worldwide pest status. The insect can reproduce under a wide range of climatic conditions ranging from less than 5ºC to above 40ºC temperature limits (Hardy, 1938). Another remarkable adaptation is the ability of the DBM to develop resistance to insecticides and this resistance has posed an immense obstacle to effective control of the pest. Resistance of the DBM to the major classes of insecticides has been reported in different parts of the world. These include chlorinated hydrocarbons (Ankersmit, 1953; Mo, 1959), organosphosphates, pyrethroids (Liu *et al.*, 1980, 1987) and *Bacillus thuringiensis* products (Verkerk and Wright, 1994). Possible resistance against neem products is also likely (Vollinger, 1986).

The available knowledge on companion crops from elsewhere in the world, suggest that there is some potential for minimizing DBM infestation on cabbage crops. This study was aimed to improve our understanding on the role played by companion crops when intercropped with cabbage, in relation to the DBM populations and its natural enemies. The main aim of the study was to obtain comparative information on oviposition and development of the DBM on selected companion crops under laboratory conditions. The effect of the selected host plants when intercropped with cabbage on the DBM infestation in the field and their parasitoids was also evaluated.

The selected host plants included brassica host plants and non-brassica plants. The brassica host plants were Cabbage (*B. oleracea* var. *capitata*); Mustard (*B. juncea* L.) Czernjaew, Rape (*B. napus* L.) and Kale (*B. oleracea* var. *acephala*) belong to the family Brassicaceae (formerly Cruciferae), whose representative genus is *Brassica*. The family consists about 390 genera and 3000 species. Most *Brassica* species originated in the Mediterranean region. *B. oleracea* L. has a shared northern Mediterranean and Western Europe origin. Mustard *(B. juncea*) is commonly known as Indian mustard or mustard greens or curled mustard. This is a leafy vegetable, which is an important crop in China and South East Asia. It contains glucoside-sinigrin, which gives its bitterness and this increases with plant age. Rape (*B. napus*) is widely cultivated in Asia (mainly in China and India), throughout Europe and Canada as forage for hogs and sheep, and as a cover crop and their seeds are valued for their oil, which is used in cooking and as a lubricant. On the other hand kale (*B. oleraceae* var. *acephala*) is a very popular and widely utilized vegetable all over Kenya. Varieties mostly grown are 'Collards', 'Thousand headed' and 'Marrow stem'.

Cleome (*Cleome gynandra* L.) is commonly known as spider plant, spider flower or African spider flower. Outside of Africa, the name Cat's whiskers is mainly mentioned. It belongs to the botanical family Capparaceae (formerly Capparidaceae) subfamily Cleomoideae (Kuhn, 1988; Kokwaro, 1994). The family consists of about 700-800 species, divided into 45 genera. The genus is phylogenetic near relative of the Cruciferae (Brassicaceae) family (Bremer and Wannorp, 1978). The species are mainly found in the tropics and subtropics, and are well represented in Africa. They are common in dry areas. Synonyms of *Cleome gynandra* are: *Gynandropsis gynandra* (L) Briq., *G. denticulata* DC., *Cleome pentaphylla* L., and *Cleome acuta* Schum. *C. gynandra* is known by various local names in different countries. In Kenya it is commonly known as chisaga, saget, keyo, sake, dek, alot-dek, and mutaka among others.

Coriander (*Coriandrum sativum* L.) belongs to the family Apiaceae (formerly Umbelliferae). It is commonly known as 'Dhaniya'. It is a small aromatic herb (0.3 to 1 m high), and is native to the Mediterranean region where it has been used since ancient times. It still grows wild or semi-wild in some parts of Sudan and Egypt. It is extensively cultivated in Russia, Central Europe, India, Turkey, Morocco, Argentina and the United States of America. India, Morocco and Romania are the largest exporters of coriander in the world.

Onion (*Allium cepa* L.), is the common name for this genus of biennial herbs, native to Asia but cultivated in temperate and subtropical regions for thousands of years. Onion cultivation has extended to all parts of the world and half of it comes from the Asian continent. Onions make up the genus Allium, of the family Alliaceae (formerly Liliaceae). Onions are one of the most versatile vegetables and by far the most important bulb crop.

1.2 LITERATURE REVIEW

1.2.1 Origin and distribution of the diamondback moth

Linnaeus first described the diamondback moth in 1758, and named it *Plutella xylostella* (Moriuti and Linnaeus, 1986). Since that time, various changes in the nomenclature have taken place, resulting in several synonyms. Curtis (1860) described the insect and renamed it *P. maculipennis*, but Brandley (1966) while gazetting some changes in the nomenclature of the British lepidoptera proposed *P. xylostella* to be the new specific synonym of *P. maculipennis*. Furthermore this insect which belongs to the family Plutellidae is occasionally treated as a member of the Yponomeutidae by some authors (Miyata *et al.*, 1982; Okada, 1989; Talekar *et al.*, 1990). However, Ripper (1928) using Fracker's classification described the details of distinguishing features of *Plutella* larva and assigned it to the family Plutellidae. Comstock (1950) distinguished *P. xylostella* from Yponomeutidae by their longer prolegs. The Plutellidae also have short porrect maxillary palpi and have the tendency of resting with their antennae held straight forward (Scholtz and Holm, 1985).

Although it is impossible to definitely state the original habitat of the diamondback moth, a certain amount of circumstantial evidence exists to show that it originated in Europe. The insect is oligophagous and may have originated together with its host plants mainly brassicas within the family Brassicaceae. Some authors (Strusburger, 1921; Choudhary, 1967; Purseglove, 1968; Nieuwhof 1969) attributed the occurrence of numerous wild forms of brassicas along the coasts of Mediterranean Sea, South western Europe and Southern England as the evidence that brassicas originated from those areas. While studying the biology of the diamondback moth in England, Hardy (1938) found that the most favourable conditions for multiplication were those within temperatures of 30°C and these correspond to sub-tropical and warm temperate zones. He thus suggested that the moth may have originated from the Mediterranean region. Other authors (Robertson, 1939; Annecke and Moran, 1982) also supported this idea. The diamond back moth is able to migrate for long distances (Shaw, 1962; French, 1967; Lempke, 1981; Lorimer, 1981), and this has evidently contributed to the distribution of the insect, which has become virtually cosmopolitan.

The diamond back moth was reported to have established itself in some parts of East Africa by 1912. Morstat (1913) observed the insect at Usambara and Amani areas of Tanzania (German East Africa). In Kenya, several entries of diamondback moth specimens were received from farmers for identification around 1914 (Anon., 1986). Le Pelley (1959), Wheatley and Crowe (1967) and Nyiira (1971) have reported other records of its early distribution in East Africa. Presently, the moth is a common pest in all areas where brassicas are grown. In Kenya these areas fall within 800m and 2,200m above sea level (Anon., 1989).

1.2.2 Host range and host specificity

The host range of DBM is limited to crucifers that contain mustard oils and glucosides (Thorsteinson, 1953; Gupta and Thorsteinson, 1960; Nayar and Thorsteinson, 1963; Hillyer and Thorsteinson, 1971). Talekar and Shelton (1993) have listed the cultivated and wild crucifer weed species on which DBM feeds. Various studies have demonstrated the attraction of *P. xylostella* adults to volatiles emanating from host plants (Palaniswamy *et al.,* 1986; Pivnick *et al.,* 1990). Glucosinolates are necessary for host plant selection and larval phagostimulation, but other factors may be involved (Gupta & Thorsteinson, 1960; Reed *et al.,* 1989; Renwick & Radke, 1990; Spencer, 1996; Hughes *et al.,* 1997). Other reports also indicate that DBM is more attracted to plants that contain higher levels of the volatile chemical stimulants (Mitchell *et al.,* 1997). The practical value of understanding ovipositional behaviour is that it can be used to direct insects to inappropriate hosts (Prokopy & Owens, 1978). Oviposition preference, however, does not by itself relate to the fate of eggs and larvae (Ampong-Nyarko *et al.,* 1994).

Diamondback moth does not choose non-host plant species based on the absence of inhibitory substances, but rather on the presence of these oviposition stimulants. The chemical that serves as a stimulant to diamondback moth dually serves as an inhibitory compound to other insects (Olsson and Jonasson, 1994).

Crucifers are grown in tropical and temperate climates and in a variety of cropping systems from backyard gardens to large-scale fully mechanized farms. The 1990 Food and Agriculture Organization (FAO) production figures indicate that, on a worldwide basis, cruciferous vegetables are grown on 2.2 million ha, with half the production occurring in Asia (FAO, 1990). Members of this diverse plant group are cultivated for various edible plant parts, such as roots of radishes and turnips, stems of kohlrabi, leaves of cabbage and kale, and seeds of mustard and rape, which are consumed as fresh, cooked, or as processed vegetables.

1.2.3 Biology

1.2.3.1 Life cycle

The diamondback moth adults are slender, small, 1/3inch (8mm) long, grayish-brown moths with folded wings flaring outward and upward at their posterior ends. Duration of the lifecycle is temperature dependent; it may be completed in 20 days or less in warm climates (25ºC) but may be longer (20-30 days) in cooler temperatures (Finch and Thompson, 1992). Eggs are oviposited singly or in clusters of 2-4 along the leaf veins on the upper and /or lower leaf surfaces and have an incubation period of 4-10 days. There are four larval instars and the total larval period varies from 10-28 days depending on the environmental conditions (Hsu and Wang, 1971; Salinas, 1986; Sarnthoy *et al.*, 1989). First instar larvae mine into the leaf where they feed on the spongy mesophyll for two days and then emerge as second instars. The second, third and fourth instars each lasts for 2 days followed by pre-pupal period of one day. Pupation may last 5-15 days. Mating takes place soon after emergence and oviposition can occur on the day of emergence. The pest has 3 to 6 generations each year depending on geographical area and seasonal conditions (Harcourt, 1957; Abraham and Padmanaban, 1968; Lu and Lee, 1984; Chelliah and Srinivasan, 1986; Hoy, 1988).

1.2.3.2 Damage

The actual damage caused by the diamond back moth on cruciferous plants results from the first and second instar larvae feeding and mining on the outer leaves and moving into the center, where they damage the young leaves. The third and fourth instars generally feed on the underside of leaves making small irregular windows, while leaving the upper leaf surface intact, thus causing the greatest damage (Talekar and Shelton 1993). Early crop damage reduces the photosynthetic capacity, yield, and may result in headless plants or plants with multiple undersized heads. Late damage may not affect yield, but the perforated outer leaves lower the aesthetic quality and hence the market value of the crop.

1.2.4 Pest status

Plutella xylostella is the most destructive pest of cabbage and other brassicas throughout the world, and it continues to present one of the greatest threats to crucifer production worldwide (Jussoh *et al.*, 1992; Talekar, 1992; Syed & Loke, 1995). Among the criteria that make DBM one of the most cosmopolitan pests is its ability to migrate and disperse over long distances. Studies indicate that DBM can remain in continuous flight for several days and cover distances of 1000 km per day, but how the moths survive at low temperatures and high altitudes is not known (Harcourt, 1986). Although the diamondback moth is believed to have originated from the Mediterranean area (Harcourt, 1954), which is also believed to be the source of some of the most important crucifers, it is now present in all areas where crucifers are grown or growing as wild plants. This insect is believed to be the most universally distributed of all the Lepidoptera (Meyrick, 1928).

Host plant abundance and natural enemies are two key factors that regulate DBM populations in the field (Harcourt, 1986; Fox *et al.*, 1990; Ooi, 1992). Absence of effective natural enemies, especially parasitoids and predators, is believed to be the major cause of the DBM pest status in most parts of the world (Lim, 1986). The absence of parasitoids in a particular area may have occurred because DBM is better able than its natural enemy complex to become established in newly planted crucifers. Reports on the ability of DBM to migrate over long distances are numerous (French, 1967; Bretherton, 1982), but there is no record of migration of any of its parasitoids.

Another reason for the lack of effective biological control in an area may be destruction of natural enemies by the use of broad-spectrum synthetic pesticides. Prior to the introduction of synthetic pesticides like DDT in the late 1940s, DBM was not reported as a major pest of crucifers. However, with wide spread use of synthetic insecticides on crucifers beginning in mid 1950s, its important natural enemies appear to have been affected. Continuous use of synthetic insecticides leading to eventual development of insecticide resistance among the pest population has been a major cause of control failures. In 1953, DBM became the first crop pest in the world to develop resistance to DDT (Ankersmit, 1953), and now in many countries including Kenya it has become resistant to most synthetic insecticides used against it in the field (Talekar *et al.,* 1985; Talekar *et al.,* 1990). In addition, DBM has earned the distinction of being the first insect to develop resistance in the field to the bacterial insecticide *B. thuringiensis* (Tabashnik, 1985; Kirsch and Schmutterer, 1988; Hama, 1992; Shelton and Wyman, 1992). Pesticide resistance and control failures are now common on this pest in the tropics. Chemical pesticides used to minimize crop loss due to the diamondback moth are estimated to cost U.S. $1 billion annually (Talekar & Shelton, 1993; Shelton *et al.,* 1993a).

1.2.5.0 Current management practices

1.2.5.1 Biological control

Biological control is a strategy, which is widely recognised component in *P. xylostella* management, particularly where control failures have previously occurred as a result of insecticide resistance (Loke *et al.,* 1992). Numerous parasitoids and predators are known to attack all life stages of DBM. They have been suggested to be important stabilizing agents for diamondback moth populations (Ullyett, 1947; Yamada and Yamaguchi, 1985). Parasitoids play a dominant role in the population dynamics of diamondback moth (Lim, 1986; Waterhouse and Norris, 1987), and their integration with other measures of control is now sought after. The key control agents have been endolarval parasitoids, especially of the genera *Diadegma* (Ichneumonidae), and *Cotesia* (=*Apanteles*) (Braconidae), *Tetrastichus* (=*Oomyzus*), (Eulophidae) and *Microplitis* (Braconidae). These have been reported as the most predominant and effective especially where pesticides are used judiciously (Talekar and Shelton, 1993; Anon., 1995; Verkerk and Wright, 1996). A few species of *Diadromus* (Ichneumonidae), a pupal parasitoid, may exert significant control, while egg parasitoid of the genera *Trichogramma* and *Trichogrammatoiea* contribute little to DBM control (Talekar and Shelton, 1993).

The introduction of parasitoids is of considerable promise in the control of DBM, but it has been practiced only occasionally over the past 50 years. Their establishment has been frustrated by indiscriminate use of insecticides (Sweetman, 1958; Huffaker, 1971; DeBach, 1974). *Bacillus thuringiensis* (Bt.) offers hope for diamondback moth control because of its relative specificity and the fact that no serious control failures have been documented (Georghiou, 1990). However, Kirsh & Schmutterer (1988) found low efficacy of *B. thuringiensis* in the control of diamondback moth in Philippines and speculated that it could be due to development of resistance. Predators have also been suggested to be important stabilizing agents for diamondback moth populations (Ullyett, 1947; Yamada and Yamaguchi, 1985). They include generalist predators like birds, earwigs, ladybird beetles, ants, syrphids and spiders (Makumbi, 1996) which often attack various DBM stages.

Chemical and morphological plant attributes can directly influence survival, fecundity, and foraging success of natural enemies on hosts or prey. They may do so by affecting qualities of an herbivore that in turn affects the physiology, behavior, or development of natural enemies (Cortesero *et al.*, 1999). Key parasitoids of DBM have been found on alternative food sources and shelter plants, which may also increase the lifespan of parasitoids (Lim, 1992).

1.2.5.2 Chemical control

Insecticides have dominated attempts to control *P. xylostella* for over 40 years (Ho, 1965; Syed, 1992a). Compounds from virtually all classes of insecticides have been used, including organochlorines, organophosphates, carbamates, pyrethroids and botanicals (Talekar & Griggs, 1986; Talekar, 1992). DBM has a long history of eventually becoming resistant to every insecticide used extensively against it. Factors that influence the development of resistance in diamondback moths include high fecundity and reproductive potential, rapid turnover of generations, a long growing season and extensive acreage of crucifers, and frequent insecticide application (Magaro and Edelson, 1990). Understanding the genetics, field dynamics, mechanisms and stability of resistance is necessary for resistance management to succeed, but too often these studies are undertaken after resistance has already developed.

1.2.5.3 Cultural control

Various cultural control methods have been used for DBM control and include inter-cropping, sprinkler irrigation, trap cropping, rotation and clean cultivation. Endersby & Morgan (1991) provided a thorough review of cultural methods of control against *P. xylostella*, including physical barriers, physical toxicants, intercropping and companion planting.

1.2.5.3.1 Crop rotation

Crop rotation has seldom been researched upon for the DBM control, probably because of the high prices of crucifers in the market. Nevertheless, continuous planting of crucifers would tend to favour continuous breeding generations of DBM, which could result, in need for more frequent use of pesticides. With DBM being prone to the development of pesticide resistance (Hama, 1992; Shelton and Wyman, 1992), and the possibility of resurgence of DBM in the fields due to destruction of natural enemies, crop rotation may offer some relief. However, the biological and economic dimensions to this option have not been adequately assessed.

1.2.5.3.2 Intercropping

Intercropping is the practice of raising two or more crops in the same field at the same time (Soule, 1992). Intercropping has many benefits, such as enhancing the efficiency of land use (Soule, 1992); offering benefits in the management of detrimental insects, diseases and weeds (Root, 1973; Smith, 1976; Kroll *et al.,* 1984; Rice, 1984; Liebman, 1988). Intercropping offers a habitat management approach strategy where the environment is modified in such a way that the pest population densities are lowered below economic injury levels (Amoako-Atta *et al.,* 1983; Ogwaro, 1983; Omolo and Seshu Reddy, 1985; Minja, 1990). This results from the enriched biodiversity of plants and the pest's natural enemies in and around the cropping environment

(Van Emden and Dabrowski, 1994). Crop and non-crop plant species affect colonization of pests by their visual appearance and smell, or by acting as physical barriers or diversionary hosts (Risch, 1981; Sheehan, 1986).

A number of ecological hypotheses have been offered to explain lower pest-population loads in multispecies plant associations (Altieri, 1994; Vandermeer, 1989). These include: the enemies hypothesis, disruptive-crop hypothesis (associational resistance), the trap-crop hypothesis, resource concentration and plant "apparency" hypothesis. The enemies hypothesis mechanism operates in intercropping systems where the components attract, for whatever reason, more predators and parasites than the monoculture, thus reducing the pests through predation and/or parasitism. This proposition predicts that there will be a greater abundance and diversity of natural enemies of pest insects in polycultures than in monocultures (Root, 1973), and consequently more yield (Russell, 1989). The disruptive-crop hypothesis mechanism proposed by Vandermeer (1989) operates where a component species disrupts the ability of a pest to efficiently attack its proper host. This works in the two ways either by disrupting host finding or after finding host plant the insect leaves that patch because of frequent encounters with non-host plant individuals. Monophagous insects (specialists) are more likely to decrease in abundance in intercrops as a result of disruptive-crop mechanisms. For instance, webworms in sesame appear to be regulated in sesame-cereal intercrops by shading from the companion crop; several squash pests are less effective at finding hosts in squash-maize intercrops. This effect has been demonstrated with collards interplanted with tomatoes or tobacco on the flea beetle, *Phyllotreta cruciferae* (Root, 1973) and *P. xylostella* (Litsinger and Moody, 1976) and carrot fly on carrots interplanted with onions (Uvah and Coaker, 1984). The diamondback moth has been reported to be repelled by tomato in cabbage-tomato intercrops (Buranday and Raros, 1973). This hypothesis has also been termed as associational resistance by other authors (Tahvanainen and Root, 1972; Root, 1975).

The trap-crop hypothesis mechanism operates where one component species attracts a pest that would normally be detrimental to another component species. Risch *et al.,* (1983) included the latter two hypotheses as a single hypothesis called the resource concentration hypothesis. In their review of the literature they concluded that the resource concentration hypothesis accounted for more of the reductions in pest numbers than did the enemies hypothesis.

The plant "apparency" hypothesis (Feeny, 1976) is based on crop apparency which can be increased or decreased either by intercrop diversity or by high-density cropping (Feeny, 1977). For instance *Pieris rapae* and *B. brassicae,* occur mainly in open succession habitats and are more attracted to host plants that stand out against a bare soil. In contrast, the fruit fly occurs in dense stands and would be less attracted to open plantings of grasses and cereals (Burn *et al.,* 1987).

Two or more of the mechanisms can operate simultaneously, and hence, there is still considerable controversy about how diverse backgrounds affect host-plant selection by insects because reports published so far have not been consistent (Andow, 1991; Altieri, 1994). Unfortunately none of the above hypotheses have been developed into a robust general theory and universal validity of the above hypotheses have been questioned (Sheehan, 1986; Russell, 1989). None of the proposed hypotheses really include all of the mechanisms that are known to operate in the general area of diversity and pest attack (Vandermeer, 1989). However, Finch and Collier (2000) have developed a general theory based on detailed observations of insect behavior. This theory is based on the fact that during host plant finding the searching insects land indiscriminately on green objects such as the leaves of host plants (appropriate landings) and non-host plants (inappropriate landings), but avoid landing on brown surfaces such as soil. The complete system of host plant selection involves a three-link chain of events, these are: volatiles from plant chemicals; the central link by visual stimuli and the final link by cues from non-volatile plant chemicals. They have further described as 'appropriate/inappropriate landings' (Finch, 1996), as the previously missing central link in host selection by insects.

Intercropping is not presently being practiced for the management of DBM, possibly due to other horticultural and economic reasons. An improved understanding of the influence of the companion crops and associated arthropod species diversity on DBM populations is likely to lead to the development of suitable options for utilising the companion crops for DBM management.

1.2.5.3.3 Trap cropping

Trap crops are usually sacrificial plants sown at the edges of fields earlier than the main crop area in order to attract insects or other organisms with the intention of protecting the crop of interest from pest attack (Van Emden and Dabrowski, 1994). Trap cropping came as a result of developments in ecology and agriculture, particularly with respect intercropping to (Andrews and Kassam, 1976; Andow, 1983), crop diversification (Cromartie, 1981; Altieri and Gliessman, 1983;), and integrated pest management (IPM) (Flint and van de Bosch, 1981; Kogan, 1986). Before the advent of modern organic insecticides, strips of economically less important but highly preferred crops were planted within commercial crucifer field (Kanervo, 1932; Ghesquiere, 1939). Effective trap cropping may limit the use of insecticides because DBM larvae are retained in the trap crop and become heavily parasitised (Talekar and Shelton, 1993). However, careful consideration must be given to the particular plant species to be added. It is also important to observe and understand the biology and ecology of the potential crop pests and their natural enemies (Hokkaneen, 1991).

Farmers are motivated to utilize trap cropping because of the difficulties in coping with the pest situation in other ways. This could be brought about by the cost of the chemicals, resistance to pesticides (Saxena, 1982; Swezey and Salamanca, 1987) or simply lack of effective alternative control methods (Hokkanen *et al.,* 1986). Trap cropping has also been used to study the ecology of certain pest species (Castro *et al.,* 1988). Another use is by agronomists to facilitate pesticide efficacy testing (Hill and Mayo, 1974), and also in obtaining pest survey information (Castro *et al.,* 1988). Another use of trap crops is to attract natural enemies of the insect pests to the fields and concentrating them thus enhancing naturally occurring biological control agents (Adashkevich, 1974a). Finally, trap crops may sometimes also contribute through some yields, although their main role is to attract the devastating pests from the main crop.

There has been contradicting reports on the efficacy of the various trap crops that have been used. For instance, use of Indian mustard [*Brassica juncea* (L.) Czern] as a trap crop for the management of DBM on cabbage has been reported to be successful in India and South Africa (Srinivasan & Krishna Moorthy 1991; Charleston and Kfir, 2000). However, Bender *et al.* (1999) have reported that the use of mustard as a trap crop showed no significant effect on the number of lepidopterous larvae in cabbage. Other reports from Malaysia have suggested that Indian mustard could be manipulated as a hedgerow in the cabbage ecosystem to provide habitat diversity to dilute the pest population on cabbage in addition to helping conserve the natural enemies within the ecosystem (Srinivasan and Krishna Moorthy, 1992).

Collard (*B. oleracea* var. *acephala*) has also been shown to have potential as a trap crop of DBM in cabbage fields in Florida, USA, and that it can play an important role in the maintenance of the natural enemy, *Diadegma insulare* (Cress) (Mitchell *et al.*, 1997).

1.2.5.3.4 Companion cropping

Companion cropping schemes are designed to mask the smell of crop plants by interplanting them with other strong-smelling plants on the basis that insects often locate their host plants by smell. Morallo-Rejesus (1986) reports that 88 plants have insecticidal properties against *P. xylostella* most of these belonging to the Asteraceae, Fabaceae and Eurphorbiacae. Many such botanicals also have repellent properties although their potential in this role has yet to be exploited. Intercropping trial on cabbage with garlic or tomato in Central America (Andrews *et al.*, 1992), showed no substantial reduction of DBM infestation in cabbage. On the other hand, there are other reports that showed that interplanting cabbage with tomato resulted to significant reduction of DBM larval density in cabbage (Bach & Tabashnik *et al.*, 1990; Facknath *et al.*, 1998). It has further been reported indicated that the population of *P. xylostella* is regulated by the chemical repellence or masking of cabbage by intercropping them with tomatoes (Buranday & Raros 1973; Facknath *et al.*, 1998). Similarly, garlic in interows of cabbage led to a decrease in *P. xylostella* numbers (Talekar *et al.*, 1986). Planting onion sets (bulbs) and coriander seed between cabbage has been shown to repel cabbage lepidopterous pests (butterflies and moths), and the smell of the intercrop has been reported to be responsible by confusing the brassica pest (Facknath *et al.,* 1998).

1.3 JUSTIFICATION OF THE STUDY

In Kenya, cabbage which is a leading vegetable crop is most severely damaged by diamondback moth (DBM) (MoA, 1998). Resistance to pesticides has been observed in DBM in Central Province (MoA, 1998). Cabbage farmers also find it uneconomical to apply pesticides for several number of times. These problems have prompted the need for a more rational approach, namely Integrated Pest Management (IPM), which seeks to maximize the use of safer alternatives. These include cultural methods such as trap and companion cropping systems. Nevertheless, these methods will depend on adequate knowledge of the pest's life history, host plant interactions and other aspects of its biology. While studies on DBM so far carried out have focused either on brassica host as diversionary trap ('pull') crops or non-brassica crops as 'repulsive' ('push') crops, there is need to evaluate both groups of plants as potential companion crops based on a further vision for developing a 'push-pull' strategy for managing DBM. A major setback to such an approach in Kenya is lack of information on the role of potential hosts and non-hosts that can contribute to DBM control measures such as trap and companion cropping. The study was focused to investigate the potential of companion crops on reducing incidence of DBM on cabbage. Ultimately, it is aimed at evolving a control strategy that selectively uses plants, which are 'attractive' ('pull') and 'repulsive' ('push') simultaneously in the management of DBM.

1.4 NULL HYPOTHESES

1. Companion crops have no effect on the oviposition, survival and development of the DBM.
2. Companion crops do not influence the rate of infestation of cabbage by DBM larvae.
3. Companion crops have no effect on the activity of diamondback moth's natural enemies.

1.5 OBJECTIVES

1.5.1 General Objective

To evaluate the potential of companion crops in reducing infestation and damage of cabbage by DBM

1.5.2 Specific Objectives

1. To evaluate the diamondback moth adult oviposition response to selected companion crops.
2. To assess the survival and development of the DBM on the selected test crops

3. To evaluate the effect of companion crops on the infestation and damage of cabbage by DBM.
4. To investigate the influence of companion crops on the activity of the parasitoids of the diamondback moth.

1.6.0 GENERAL MATERIALS AND METHODS

1.6.1 Test plants

The test crops, which were used in this study, included Cabbage, Mustard, Rapeseed, Kale, Onion, Cleome and Coriander. These crops were used both as intercrops in the field and as study materials in the laboratory for bioassays. The plants were grown in a screen house within ICIPE (Duduville). Because onion takes the longest period of time among the test crops to establish in the nursery, it was planted in the nursery three weeks before cabbage, rape and kale. Two weeks after planting of the three latter crops in the nursery, mustard, cleome and coriander were directly seeded in pots. During the transplanting of onion, cabbage, kale and rape, the mustard plant was directly seeded because of its relatively faster developmental growth. Synchronization of planting dates was necessary for optimal utilization of the plants especially in their most leafy and succulent stage. Cabbage, kale, rape and onion seedlings were used four to six weeks of age of transplanting. Mustard was used four to six weeks after planting while cleome and coriander were used when they were six to eight weeks old. After each planting, a tag was pinned beside each batch of crop showing the date of planting for records. To ensure an adequate and constant supply of the test plants, ten pots of each host were established weekly.

1.6.2 DBM rearing technique

Pupae were collected intact with the leaves from JKUAT cabbage field in petridishes lined with moist filter paper to prevent them from dehydration. As described by Yamada (1979), the emerged adults were released into a cage (50x50x70 cm) containing the potted plants in the ratio 1:5 male: female. The adults were maintained on a 10% honey water solution as described by Hardy (1938) which was provided to them on a piece of cotton wool. The plants were replaced by fresh ones after 48hours to maintain uniform development of insects. The colony was maintained at 21±2°C, and 70% relative humidity (RH).

CHAPTER TWO

2.0 LABORATORY EVALUATION OF THE DIAMONDBACK MOTH (DBM) OVIPOSITION RESPONSE TO SELECTED COMPANION CROPS

2.1 Introduction

Oviposition is important in insects because mobile adults find host plants for their relatively immobile offspring (Tabashnik and Slansky, 1985). The contrast between a moth's orientation towards a preferred and non-preferred plant has been used to identify attractants involved in pre-oviposition behaviour. Certain host plants are found to be more attractive than others (Palaniswamy *et al.,* 1986). For *P. xylostella,* involvement of specific components of crucifers has long been suggested in the stimulation of feeding by larvae or oviposition of adults (Gupta and Thorsteinson, 1960; Thorsteinson, 1953). The strong correlation between the presence of glucosinolates and host range of cabbage pests has led to numerous studies based on the assumption that these compounds are responsible for host recognition. However, contradiction or inconclusive results from behavioural experiments exist. Nevertheless, Tabashnik (1985) has demonstrated that DBM adults use visual and mechanoreceptor cues to locate host plants. This study aimed to investigate the relative attraction of the test plants for oviposition by diamondback moth.

2.2 MATERIALS AND METHODS

The DBM adults used in this test were reared in the standard conditions described in section 1.6.2. A day-old mated female moth was released at the center of a cage measuring 40cm (l) x 30cm (w) x 30cm (h). The cage had an opening at the front fitted with a cloth (15cm diameter) and another small opening from behind (10cm diameter). Detached leaves of equal sizes of each test host plant (cabbage, mustard, rape, kale, cleome, coriander and onion) were kept in the cage individually. To keep them fresh, the leaves were inserted through a lid of a vial containing water as described by Charleston and Kfir (2000). In the case of cleome and coriander, a number of leaves equal to the size of the leaves of other plants compared, were used. The leaves were placed in a vial with their petioles dipping into the water so that they could remain fresh during the 24h-oviposition period. The plants were arranged in a completely randomized block design within the cage and the experiment in each group of plants was replicated four times. After 24h exposure, the eggs laid on the leaves and the vial surface were counted and the data obtained was subjected to a log transformation for stabilization of variances (Bowerman, 1990).

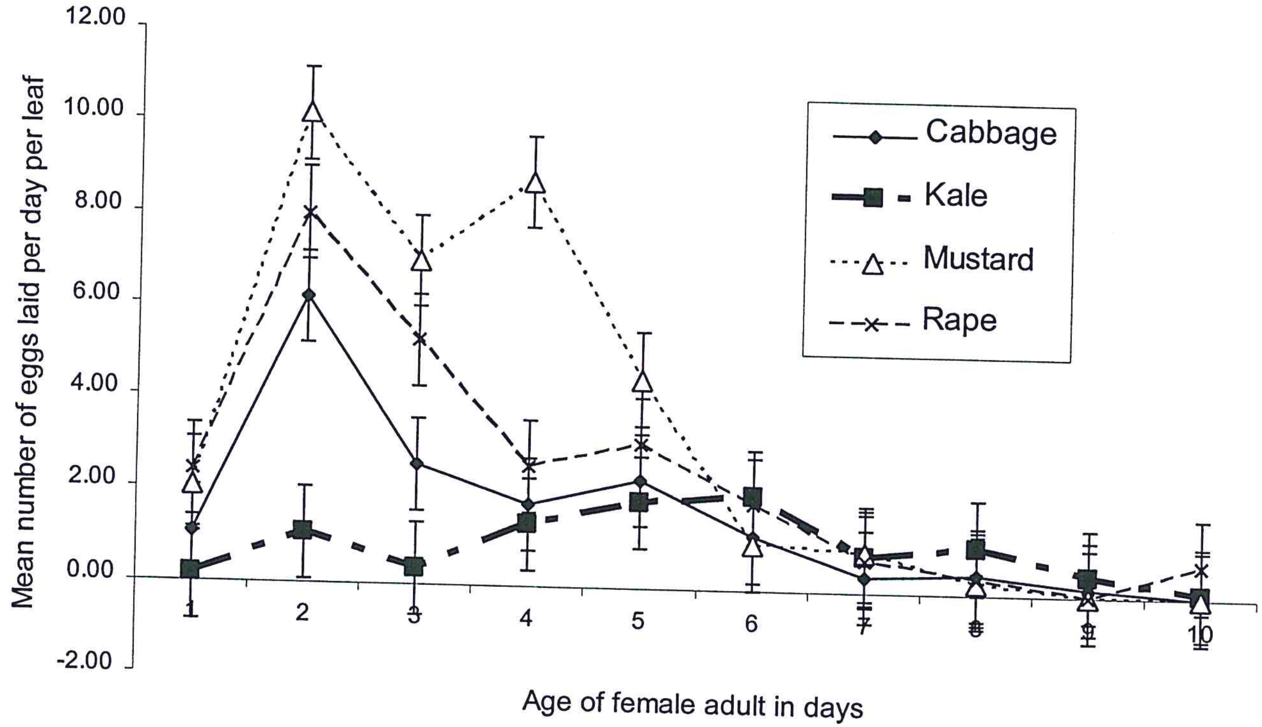
Three types of choice oviposition test and one no choice oviposition tests were carried out. In the first choice test, the known brassica host plants (Kale, Mustard and rape) along with cabbage were compared. In the second choice test, a comparison of the non-brassica host plants (cleome, coriander and onion) along with cabbage was undertaken. In the third choice test all the test plants (three favorable hosts and the three apparent unfavorable plants) were together set up in a single cage. The no-choice test involved setting up a single test plant in a cage separately. The numbers of eggs laid in each test plant were recorded in ten consecutive days.

2.3 RESULTS

2.3.1 Oviposition by DBM among three brassica host plants compared with cabbage under choice situation

The overall oviposition trend (Figure 2.1) showed that on average, mustard recorded significantly more eggs (3.46 ± 0.61) than cabbage (1.60 ± 0.33). The mean egg number laid on the other two hosts (kale and rape) was not significantly different from that on cabbage. Mustard accounted for the highest proportion of eggs (41%), followed by rape (29%), cabbage (19%) and kale (11%). On the daily oviposition pattern, the major peak in oviposition on cabbage, mustard and rape occurred during days 2 and 3, while on kale it peaked on day 6. During days 1-5, mustard recorded consistently the highest number of eggs laid daily followed by rape. Beyond day 6 till day 10, very few eggs were laid on all the host plants.

Figure 2.1: Daily oviposition trend by DBM on three brassica host plants compared with cabbage under a choice test



2.3.2 Oviposition by DBM among non-brassica hosts compared with cabbage in a choice situation

The overall number of eggs oviposited by DBM on cabbage (3.18 ± 0.64) was significantly higher than those on coriander (1.26 ± 0.34), cleome (0.51 ± 0.14) and onion (0.11 ± 0.04) (Table 2.1). The overall number of eggs laid on coriander did not differ significantly from those laid on cleome, but was significantly more than those laid on onion. The latter three crops accounted for 24, 10 and 4 percent of the total number of eggs laid respectively, compared to 62 percent recorded on cabbage. The pattern of daily oviposition (Table 2.1) showed that cabbage and coriander recorded the highest number of eggs on day 2, though this was not significantly different from the number of eggs laid on cleome. Onion recorded a significantly less number of eggs on day 2, which was not significantly different from the number of eggs laid on cleome and coriander. During days 1 to 5, the three test crops recorded consistently less daily oviposition compared to cabbage.

2.3.3 Comparison of DBM oviposition among all the six test host plants under choice situation

For this study, the oviposition preference by DBM adults was studied when all the six test host plants (three brassica host plants plus three non-brassica plants) were availed for egg laying in the same chamber along with cabbage. There was no significant difference among the host plants (cleome, coriander and onion (Table 2.2). However, cleome

Table 2.1: Mean number of eggs laid per day on the non-brassica host plants compared with cabbage

Day	Cabbage ± std error	Cleome ± std error	Coriander ± std error	Onion ± Std error
1	3.92± 2.36abc A	0.33 ± 0.33b AB	0.17±0.17ba AB	0.00 ± 0.00a B
2	9.75 ± 4.11a A	1.83 ± 0.82a AB	6.08 ± 2.49a AB	0.38 ± 0.38a B
3	6.00 ± 1.90ab A	1.83 ± 0.70a AB	2.17 ± 1.34ab AB	0.13 ± 0.13a B
4	6.58 ± 2.87ab A	0.92 ± 0.51ab AB	1.42 ± 0.67ab AB	0.00 ± 0.00a B
5	2.58± 0.93abc A	0.17 ± 0.17b B	2.17 ± 1.09ab AB	0.25 ± 0.16a B
6	1.00 ± 0.58bc A	0.00 ± 0.00b B	0.17 ± 0.17b AB	0.00 ± 0.00a B
7	1.33 ± 0.59bc A	0.00 ± 0.00b B	0.00 ± 0.00b B	0.00 ± 0.00a B
8	0.58 ± 0.31c A	0.00 ± 0.00b A	0.00 ± 0.00b A	0.38 ± 0.38a A
9	0.08 ± 0.08c A	0.00 ± 0.00b A	0.00 ± 0.00b A	0.00 ± 0.00a A
10	0.00 ± 0.00c A	0.00 ± 0.00b A	0.42 ± 0.42b A	0.00 ± 0.00a A
Mean	3.18 ± 0.64 A	0.51 ± 0.14BC	1.26 ± 0.34B	0.11 ± 0.04C

Means within a column followed by same lower case letter (s) or in row followed by same upper case letter (s) are not significantly different by Student-Newman Keuls (SNK) test at p=0.05.

(0.98 ± 0.23) recorded significantly more eggs than coriander (0.19 ± 0.06) and onion (0.10 ± 0.06). Out of the total number of eggs laid, rape, mustard and kale accounted for 26, 26 and 18 percent respectively compared to 20 per cent on cabbage, while cleome, onion and coriander had 8, 1 and 1 percent respectively. The analysis of daily oviposition patterns of DBM adults (Table 2.2) indicated that active egg laying occurred during day 1 to day 6. Among the brassica host plants rape and mustard received significantly more eggs than cabbage and kale during day 1. Coriander, cleome and onion recorded a significantly less number of eggs on day 2 and 5 as compared to the brassica host plants. The number of eggs recorded during days 6 to 10 did not differ significantly among the test plants.

2.3.4 Egg laying on different test host plants under no choice situation

The extent to which DBM adult moths laid eggs on individual host plants in the absence of choice is illustrated in table 2.3. The brassica host plants were significantly more preferred for oviposition than the non-brassica host plants. The overall daily oviposition by DBM on cabbage was 2.82 ± 0.37 eggs, and this was not significantly different from the number of eggs laid on kale (2.19 ± 0.29) and mustard (2.80 ± 0.38) but was significantly greater than those laid on rape. Among the non-brassica host plants, coriander recorded significantly

Table 2.2: Daily mean number of eggs laid on six test host plants in comparison with cabbage under choice test

Day	Cabbage ± Std error	Cleome ± Std error	Coriander ± Std error	Kale ± std error	Mustard ± Std error	Onion ± Std error	Rape ± Std error
1	3.00 ± 1.99ab B	2.25 ± 0.99a B	0.00± 0.00b B	3.20 ± 1.83ab B	9.50 ± 2.85a A	0.25 ± 0.16a B	10.83 ± 4.33a A
2	9.50 ± 4.53a A	1.83 ± 0.80a BC	0.83 ± 0.41a BC	7.25 ± 2.72a A	7.33 ± 2.92a A	0.00 ± 0.00a C	7.58 ± 2.40a A
3	2.00 ± 0.75ab AB	2.50 ± 1.26a AB	0.50 ± 0.34ab AB	5.50 ± 2.28a A	5.33 ± 2.63ab AB	0.130 ± 0.13a B	4.17 ± 2.04abc AB
4	2.33±1.09ab AB	0.08 ± 0.08a AB	0.25 ± 0.18b B	3.92 ± 1.76ab A	4.92 ± 2.22ab A	0.00 ± 0.00a B	7.58 ± 2.53ab A
5	5.08 ± 1.84a A	0.58 ± 0.40a B	0.08 ± 0.08b B	2.75 ± 0.85ab A	4.42± 1.73ab A	0.00 ± 0.00a B	2.83 ± 1.21bcd A
6	3.17± .51ab A	1.92 ± 1.16a AB	0.08 ± 0.08b B	0.58 ± 0.36b AB	0.92 ± 0.36bc AB	0.50 ± 0.50a AB	1.08 ± 0.53cd AB
7	0.75 ± 0.49b A	0.25 ± 0.18a A	0.00± 0.00b A	0.17 ± 0.11b A	0.33 ± 0.33bc A	0.13 ± 0.13a A	0.33 ± 0.23cd A
8	0.08 ± 0.08b A	0.17 ± 0.17a A	0.00± 0.00b A	0.58 ± 0.40b	1.00 ± 0.62bc A	0.00 ± 0.00a A	0.17 ± 0.11cd A
9	0.00 ± 0.00b A	0.25 ± 0.18a A	0.00± 0.00b A	0.17 ± 0.17b	0.00 ± 0.00c A	0.00 ± 0.00a A	0.00 ± 0.00d A
10	± 0.00b A	0.00 ± 0.00a A	0.17 ± 0.17b A	0.00 ± 0.00c	0.00 ± 0.00c A	0.00 ± 0.00a A	0.00 ± 0.00d A
Mean	**2.59 ± 0.60A**	**0.98 ± 0.23B**	**0.19 ± 0.06C**	**2.42 ± 0.49A**	**3.38 ± 0.62A**	**0.10 ± 0.06C**	**3.46 ± 0.68A**

Means within a column followed by same lower case letter (s) or in row followed by same upper case letter (s) are not significantly different by Student-Newman Keuls (SNK) test at p=0.05.

more eggs (1.85 ± 0.32) than cleome and onion with 1.58 ± 0.29 and 1.56 ± 0.36 eggs respectively. The proportion among the total number of eggs laid across all hosts, mustard, kale, and rape recorded 20, 15 and 13 percent respectively compared to 21 percent laid on cabbage, while coriander, cleome and onion received 13, 11 and 7 percent respectively. The daily oviposition pattern (Table 2.3) showed no significant differences among all the test crops during days 1 and 2. Mustard received significantly more eggs than onion on day 3; however this was not significantly different from the number of eggs laid on the rest of the test plants on day 3. The three non-brassica hosts (cleome, coriander and onion) received significantly less number of eggs than cabbage on day 8 and 9.

2.4 DISCUSSION

Female DBM moths were generally found to lay significantly more eggs on the brassica hosts as compared to non-brassica hosts, thus indicating oviposition preference of females on *Brassica* leaves (Charleston and Kfir, 2000). In the choice experiment among the suitable brassica host plants, DBM laid significantly more eggs on mustard than on the other host plants. This indicated that mustard contained more oviposition stimuli, as previous studies have indicated that DBM is more attracted to plants that contain higher levels of volatile chemical stimulants (Mitchell *et al.*, 1997). This is consistent with the results from previous studies reported by Andrahennadi and

Table 2.3: Daily mean number of eggs laid under no choice test

Day	Cabbage± Std error	Cleome± Std error	Coriander ± Std error	Kale ± Std error	Mustard ± Std error	Onion ± Std error	Rape ± Std error
1	4.54 ± 1.89a A	0.75± 0.56bc A	1.29±0.53abc A	3.58±1.30abc A	0.58 ± 0.36c A	1.63 ± 1.43a A	2.88 ± 1.19abc A
2	2.25 ± 0.91a A	4.50 ±1.29a A	4.50 ±1.49ab A	4.46 ±1.39ab A	5.42 ± 1.65ab A	1.13 ± 0.82a A	3.33 ± 1.64abc A
3	5.79 ±1.97a AB	3.63 ±1.66ab AB	4.50 ±1.52a AB	4.96 ±1.24a AB	6.04 ± 1.43a A	1.69 ± 1.31a B	3.29± 0.97ab AB
4	3.29±0.94a AB	1.75 ±0.56bc AB	1.38±0.85abc B	2.92±1.02abc AB	6.50 ± 2.01a A	2.88 ± 1.48a AB	1.33 ± 0.43abc AB
5	2.33 ±0.62a A	2.38 ± 1.18bc A	3.00±1.33abc A	2.00 ± 0.62abc A	2.63 ± 1.01bc A	3.44 ± 1.51a A	2.08 ± 0.56abc A
6	1.71 ±0.60a A	1.33 ±0.92bc A	1.54 ±1.13bc A	1.54 ± 0.62bc A	3.00 ± 1.18bc A	0.63 ± 0.32a A	2.58 ± 0.67a A
7	1.92 ±0.61a A	1.08 ±0.78bc A	1.38±0.55abc A	1.38 ± 0.47bc A	1.71 ± 0.84c A	1.81 ± 1.62a A	1.50 ± 1.41c A
8	3.17 ±1.30a A	0.29 ±0.20c B	0.25 ±0.17c B	0.29 ± 0.13c B	0.58 ± 0.32c B	1.00 ± 0.77a B	0.63 ± 0.24abc B
9	2.46 ±0.96a A	0.08 ±0.08c B	0.04 ±0.04c B	0.29 ± 0.15c B	1.00 ± 0.57c AB	1.25 ± 0.81a AB	0.54 ± 0.21bc AB
10	0.75 ±0.33a A	0.00 ± 0.00c A	0.67 ±0.67c A	0.45 ± 0.33c A	0.54 ± 0.46c A	0.13 ± 0.13a A	0.75 ± 0.38bc A
Means	2.82 ± 0.37A	1.58 ± 0.29C	1.85 ± 0.32BC	2.19 ± 0.29AB	2.80± 0.38A	1.56 ± 0.36C	1.89 ± 0.29BC

Means within a column followed by same lower case letter (s) or in row followed by same upper case letter (s) are not significantly different by Student-Newman Keuls (SNK) test at p= 0.05.

Gillot (1998), Lin *et al.* (1983), Eckenrode *et al.* (1986), Srinivisan and Krishna Moorthy (1992) and Yu *et al.* (1998). In the choice test involving brassica and non-brassica hosts, the mean number of eggs laid on mustard, did not differ significantly from those on rape, kale and cabbage. This was an indication that ovipositing females expressed their preference among the brassica host plants when limited choices are availed, rather than when too many or none are offered. This was clearly clarified by the choice test where 62% eggs were laid on cabbage leaves when cabbage was compared with the non-brassica plants. The comparatively large number of eggs laid by DBM adults, under no choice experiment on the non-brassica host plants suggests that the inhibitory oviposition stimuli from these hosts did not fully 'repel' the hosts from laying, but discouraged oviposition to considerable extent.

These results are in general agreement with those by Renwick and Chew, (1994) who reported that a compound allyl- isothiocyanate characteristic constituent of cabbage and other brassicas stimulates DBM for oviposition. Secondary plant compounds, coumarin and rutin, which inhibit oviposition by DBM are not in substantial amounts in brassica and are relatively found in high levels in many non-brassica herbs (Leung, 1980). This could have been responsible for the low number of eggs recorded on non-brassica host plants and need to be investigated further. Recent discovery of some non-polar oviposition stimulants that do not appear to be related to the glucosinolates suggest that additional stimuli responsible for host selection by DBM have been overlooked (Hughes *et al.,* 1997).

In this study the most number of eggs were laid between day 1 and day 5, indicating that the DBM adults completed their major oviposition after about five days when the insect was most responsive to host plants. There are reports that most females start to lay eggs on day 1 (Pivnick *et al.,* 1990; Kandoria, *et al.,* 1994; Uematsu and Sakanoshita, 1989). The understanding of daily patterns and ontogeny could make it easier to investigate host plant location behaviour because reproduction is known to be closely tied, albeit temporarily, to the location of hosts (Pivnick *et al.,* 1990).

CHAPTER THREE

3.0 EVALUATION OF THE EFFECT OF COMPANION CROPS ON DIAMONDBACK MOTH SURVIVAL, DEVELOPMENT AND PROGENY PRODUCTION

3.1 Introduction

Plutella xylostella has demonstrated varying development periods when reared on different food plants (Dube and Chand, 1977; Singh and Singh, 1982). Studies on host preference have revealed that on the most preferred hosts, the insect had higher survival rate, larvae consumed more foliage, completed larval stage in less time, had heavier pupae, and higher fecundity (Anon. 1987; Abro and Wright, 1989; Eigenbrode and Shelton, 1990; Wakisaka *et al.,* 1991). Optimality theory suggests that ovipositing females should choose plant species that maximize larval fitness (Thompson and Pellmyr, 1991; Barker and Maczka, 1996). The sensory cues that elicit or inhibit oviposition clearly play an important role in the survival of most phytophagous insects (Renwick and Chew, 1994). Hillyer and Thorsteinson (1969) showed that food quality during larval stage may influence the age at which sexual maturity is attained. The chemical that serves as a stimulant to the diamondback moth dually serves as an inhibitory compound to other insects (Olsson and Jonasson, 1994).

More than one cue apparently plays a role in the host plant acceptance by the diamondback moth. Glucosinolates are necessary for host plant selection and larval phagostimulation and many stimulate feeding in DBM (Nayar and Thorsteinson, 1963). The host range of DBM is limited to brassicas that contain mustard oils and glucosides (Thorsteinson, 1953; Gupta and Thorsteinson, 1960; Nayar and Thorsteinson, 1963; Hillyer and Thorsteinson, 1971). Preference has been consequently coincident with botanical distribution of the phagostimulants (Gupta and Thorsteinson, 1960). This study was aimed at evaluating the potential of the test crops in supporting the larval survival and development of the DBM.

3.2 MATERIALS AND METHODS

Cabbage, kale, rape, mustard, cleome, coriander and onion were used in this study. Fifty eggs per replicate per test plant were placed on fresh leaves of each test plant in a petri dish lined with a wet filter paper. This was kept in a growth chamber (23±2°C), 50-75% relative humidity till the eggs hatched. Twenty-five hatched first instar larvae were transferred using a camel brush to the respective test plant leaves held in transparent plastic glasses. These glasses had small vials containing water to maintain their freshness. The leaves were replaced with fresh ones after every 48 hours during the first four days and after day 4, they were replaced after every 24h. The number of larvae in the 2^{nd} through the 4^{th} instar and their weights were recorded daily. After pupation, they were transferred to a petri dish. When the adults emerged, they were allowed to stay for 24h to ensure mating; then a pair (male and female moths) was transferred to a cup for egg laying.

The eggs laid by a female per day were counted and recorded and female longevity was assessed. The data was subjected to ANOVA, and chi-square analysis.

3.3.0 RESULTS

3.3.1 Developmental period of DBM on the different test plants

Larvae fed on cleome had the longest developmental period of 15.44 ±0.41 days which did not differ significantly from that which was fed on cabbage (14.88 ± 0.57 days), kale (14.56 ± 0.56 days), mustard (15.00 ± 1.34 days) and rape (14.44 ± 0.41) days. The five host plants also did not have significant effect in the duration of the pupal stage (Table 3.1). Onion and coriander did not support full development of DBM, and survival was limited to the first instar.

3.3.2 Survival trends of DBM larvae on the host plants

The overall survival of DBM from first instar to adult stage differed significantly among the test plants (Table 3.2). The maximum overall percentage survival was recorded in cabbage (31.0%), followed by rape (29.5%), kale (27.0%), and mustard (21.5%) while cleome recorded the lowest (21.0%). No significant difference in survival was recorded among the above test plants (χ^2 =4.9670, df = 4, P = 0.2907) (Table 3.2). Coriander and onion recorded the highest (100%) mortality. Out of the initial number of 25 first instar, on average, only 7.8 ± 1.2, 5.3 ± 0.5, 6.8

Table 3.1: Developmental duration (days) of the various stages of DBM as influenced by the test crops

Crop	Egg ± SE*	First instar ± SE	Second instar ± SE	Third instar ± SE	Fourth instar ± SE	Pupae ± SE	Total ± SE
Cabbage	2.00 ± 0.00a	1.94 ± 0.15a	2.06 ± 0.11a	2.00 ± 0.16a	2.36 ± 0.16a	4.50 ± 0.40a	14.88 ± 0.57a
Cleome	2.00 ± 0.00a	2.00 ± 0.00a	2.38 ± 0.18a	2.00 ± 0.28a	2.13 ± 0.13a	4.94 ± 0.20a	15.44 ± 0.41a
Kale	2.00 ± 0.00a	2.31 ± 0.16a	1.94 ± 0.18a	1.69 ± 0.25a	2.00 ± 0.10a	4.63 ± 0.28a	14.56 ± 0.56a
Mustard	2.00 ± 0.00a	2.13 ± 0.13a	2.06 ± 0.20a	2.14 ± 0.09a	2.36 ± 0.18a	5.57 ± 0.47a	15.00 ± 1.34a
Rape	2.00 ± 0.00a	2.00 ± 0.00a	2.00 ± 0.16a	2.13 ± 0.16a	1.94 ± 0.11a	4.38 ± 0.28a	14.44 ± 0.41a
Coriander	2.00 ± 0.00a	2.19 ± 0.25a	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b	4.19 ± 0.26 NA
Onion	2.00 ± 0.00a	1.50 ± 0.21b	0 ± 0b	0 ± 0b	0 ± 0b	0 ± 0b	3.50 ± 0.25 NA

Means within column followed by same letter are not significantly different, (Student-Newman Keuls (SNK))-test, P=0.05.
*SE- Standard error

± 2.3, 5.4 ± 1.1 and 7.4 ± 1.4 on cabbage, cleome, kale, mustard and rape respectively reached the adult stage.

Table 3.2: Percent survival of DBM larvae reared on different host plants in the laboratory

Host Plant	Total larvae observed	Percent Overall survival (Instar to adult)
Cabbage	200	31.0
Cleome	200	21.0
Kale	200	27.0
Mustard	200	21.5
Rape	200	29.5
Onion	200	.
Coriander	200	.

(χ^2 =4.967, df = 4, P = 0.2907)

3.3.3 Influence of test plants on the weights of DBM developmental stages

The third and fourth instar larvae and pupae (Table 3.3) reared on cleome recorded significantly less weight than those recorded on cabbage. Comparison of weights of those reared on kale and rape were at par with those of cabbage; mustard resulted in significant reduction in weight only during the third larval instar stage.

Table 3.3: Weight (g) variation in DBM developmental stages as influenced by test crops

Host plant	Second instar ± Std error	Third instar ± Std error	Fourth instar ± Std error	Pupae ± Std error
Cabbage	0.00127 ± 0.00062a	0.00184 ± 0.00026a	0.00510 ± 0.00020a	0.00465 ± 0.00021a
Cleome	0.00020 ± 0.00001a	0.00059 ± 0.00020b	0.00363 ± 0.00038b	0.00306 ± 0.00034b
Kale	0.00059 ± 0.00002a	0.00210 ± 0.00024a	0.00569 ± 0.00029a	0.00509 ± 0.00018a
Mustard	0.00014 ± 0.00003a	0.00063 ± 0.00018b	0.00425 ± 0.00066ab	0.00432 ± 0.00028a
Rape	0.00109 ± 0.00012a	0.00211 ± 0.00023a	0.00563 ± 0.00022a	0.00510 ± 0.00020a

Means within column followed by same letter (s) are not significantly different (Student –Newman Keuls (SNK)) test, P=0.05.

3.3.4 Adult longevity and fecundity

The DBM adults resulting from larvae fed on the five test host plants did not differ significantly in their longevity (Table 3.4). Fecundity was significantly low in adults resulting from larvae reared on cleome (3.62 ± 2.4 eggs per female) compared to a very high fecundity in the adults resulting from larvae reared on cabbage (115.63 ± 21.50 eggs per female). The adults reared from kale laid 114.88 ± 37.31 eggs per female, while the rape and mustard-reared adults recorded moderate fecundity of 71.75 ± 18.65 and 45.75 ± 20.29 eggs, respectively. However, the latter three brassica host plants did not differ significantly from the fecundity of adults reared on larvae fed on cabbage (Table 3.4).

Table 3.4: Host plants effects on the adult longevity and fecundity

Treatment	Adult longevity in days		Eggs laid per female
	Female	Male	
Cabbage	9.29 ± 1.84 a	2.5 ± 1.09a	115.63 ± 21.50a
Cleome	2.92 ± 1.67a	4.04 ± 2.07a	3.62 ± 2.38b
Kale	6.00 ± 2.02a	8.42 ± 2.19a	114.88 ± 37.31a
Mustard	4.50 ± 1.57a	1.83 ± 1.08a	45.75 ± 20.29a
Rape	7.79 ± 1.99a	4.50 ± 2.01a	71.75 ± 18.65a
Coriander	.	.	.
Onion	.	.	.

Means followed by same letter, in each column are not significantly different means separated by SNK test, P=0.05.

3.4 DISCUSSION

Results from the laboratory studies showed that there was a higher rate of survival of the first instar larvae on the brassica host plants compared to those reared on the non-brassica host plants (coriander and onion). However, substantial survival was recorded on cleome, which is a non-brassica plant. The failure to feed and subsequent lack of early larval survival on the coriander and onion suggests the unsuitability of these plants for feeding and development of the DBM larvae. This is consistent with previous studies that indicated that DBM stayed away or refused to feed on leaves of certain plants which are non-host species (Idris and Grafius, 1996). The mechanism of DBM resistance on unsuitable host plants is rejection of the plants by the first instars, which results in protracted searching behaviour resulting in higher net movement rates and reduced feeding.

Additively, feeding of the first instars normally results in the creation of mines. Failure to establish shelter within the mines on host plants results in larvae remaining exposed on leaf surfaces, which is likely to increase the risk of desiccation, predation and other causes of mortality (Salinas, 1984). These behavioural differences may have led to the total larval mortality on coriander and onion as a result of starvation and desiccation.

The development time of larvae was not significantly different among host plants which supported full development. This indicated an apparent lack of any distinct beneficial or adverse effects of the test plants on the rate of development of the immature stages of the pest. This is in general agreement with a previous study carried out by Xu *et al.,* (1997) which indicated that development period of DBM immatures reared on *B. juncea* (Mustard), *B. chinensis* and *B. napus* (rape) was constant irrespective of host plants. However, in this study the resulting weight of the successive stages was significantly low on cleome, indicating that, the host crop did not have the desirable food quality for supporting optimum larval development. This conforms with a previous study by Idris and Selvi (1997), who reported that wild host plants may have higher concentrations of feeding attractants or stimulants, but are of poor host quality.

The involvement of specific components of brassicas on *P. xylostella* has long been suggested for the stimulation of larval feeding or for oviposition of adults (Thorstein, 1953; Gupta and Thorsteinson, 1960). However, certain host plants are more attractive than others (Palaniswamy *et al.,* 1986). The strong correlation between the presence of glucosinolates and host range of cabbage pests has led to numerous studies based on the assumption that these compounds are responsible for host recognition. Host range of DBM is thought to be essentially correlated with botanical distribution of glucosinolates (Gupta and Thorsteinson, 1960). Although cleome differed significantly from the conventional hosts in the number of eggs deposited on it, it was noted that larval survival took place on it. This could be attributed to the fact that cleome belongs to the genus, which is phylogenetic near relative of the Cruciferae (Brassicaceae) family (Bremer and Wannorp, 1978). Hence, it is most probable that cleome possesses some attributes which can support the survival of DBM larvae. However, the low pupal weight and low number of eggs laid on this non-host plant indicate poor host quality. Idris and Selvi (1997) reported a similar observation working on host suitability of *Cleome rutidosperma* and concluded that the crop may be considered as a component of an integrated pest management program.

Larval survival in cleome and mustard was significantly lower than it was in the other brassica host plants. The results of low survival on mustard are consistent with previous reports by Charleston and Kfir (2000), which showed that DBM preferred to lay more eggs on the Indian mustard leaves although it did not suit its larval survival as compared to cabbage, kale and rape. The poor correlation between adult oviposition preference and larval survival on mustard may be explained by a variety of factors. For instance, ovipositing females may prefer ovipositing on host plants that are nutritionally sub-optimal but that are not visited by some of their natural enemies, therefore providing enemy free space (Thompson, 1988; Fox and Eisenbach, 1992; Gratton and Welter, 1998). Results from studies by Charleston and Kfir (2000), Fox and Eisenbach (1992), indicated that *P. xylostella* prefers plants of low nutritional quality because they are not frequented by natural enemies. Possibly, DBM adults in this study selected mustard as a potentially enemy-free space plant.

The poor correlation could also have been due to physiological factors such as leaf wax characteristics, which are believed to influence oviposition (Spencer, 1996). Glossy leaves have reduced wax load (Andrahennadi and Gillot, 1998; Stoner, 1992; Eigenbrode and Shelton, 1992), which improves the adhesiveness of eggs (Uematsu and Sakanoshita, 1989), but reduces larval survival (Eigenbrode and Shelton, 1992) possibly through increased predation on *P. xylostella* (Eigenbrode *et al.,* 1995). In this study, the low survival of larvae reared on mustard could have been brought about by a reduced wax load on this plant. Charleston and Kfir (2000) reported that mustard did not have the right haze for normal leaf wax of bluish-white found on the preferred host plant for survival.

Fecundity of the resulting moths was low on cleome in comparison to other test plants which showed no significant differences.

This indicates that cleome (a non-brassica host of DBM), apparently affects the reproductive ability of DBM. Fecundity is one of the most important factors affecting population dynamics of DBM (Harcourt, 1985). Hence, severe reduction in eggs deposition would be sufficient to cause population decrease (Tabashnik and Mau, 1986). There are no previous records on the survival and development of DBM on *Cleome gynandra*. However, survival and development on cleome in this particular study can be explained on the basis of 'appropriate/inappropriate landing' theory put forward by Finch and Collier (2000). This theory tries to explain why pest insects rarely decimate wild host plants growing amongst other plants in natural vegetation due to inadequate stimuli for host selection and acceptability. However, certain proportions of the insects do develop on wild-host plants, and this explains the limited development of DBM on the cleome observed in the laboratory, most probably due to concentrated stimuli in the experimental chambers.

CHAPTER FOUR

4.0 THE EFFECT OF COMPANION CROPS ON LAR INFESTATION AND DAMAGE OF CABBAGE BY DBM IN FIELD

4.1 Introduction

Intercropping and mixed cropping are widely applied as reg cultural practices in the tropics for a variety of reasons. Because of economic importance, interest in vegetable intercropping is ma centred around brassica crops (Theunissen *et al.,* 1995). Plant dive affects the population dynamics of insect herbivores in agricult habitats (Risch, *et al.,* 1983; Andow, 1988) and their nat communities (Kareiva, 1983). Specialist insect herbivores exhibit lo population densities in diverse habitats containing host and non-h plants compared with simple habitats containing host plants ((Kareiva, 1983; Risch, *et al.,* 1983; Andow, 1988). Although m studies have demonstrated effects of non-host neighbours on herbiv population densities, few studies have examined possible mechanis responsible for their population dynamics. Hence, it has been difficul establish a generalised and reliable protocol for deploying diversity crop fields (Åsman *et al.,* 2001).

The negative impacts of pesticides and increasing pestici resistance have increased the interest in alternative control methods. Kenya, where most small-scale farmers are practising subsisten farming, the involvement of companion planting towards the development of an IPM package would be beneficial. Although the successes of various crops as companion crops (Facknath *et al.*, 1998) have been reported from various parts of the world no major efforts have been made in Kenya with respect to brassica farming. This study was aimed at improving our understanding on the role played by companion crops when intercropped with cabbage in relation to the DBM populations and its natural enemies

4.2 MATERIALS AND METHODS

4.2.1 Assessment of DBM infestation and damage on cabbage in the field

The field trials were conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Thika district, Central province, Kenya. It is located 32 km north of Nairobi at latitude 1'05"S, and longitude 37'00"E and approximately 1,525 m above sea level (ASL). Rainfall is bimodal; over 55% of the total rain falls in the long rains season between March and July, while the short rains fall between October and December. Temperatures are moderate between 13°C and 26°C. The region has clay soils. Market gardening is practiced in the area because of the high demand for cabbage from the urban population. The assessment of infestation and damage caused on cabbage was carried out in three growing seasons between May 2000 and March 2001. The treatments comprised of six test plants (mustard, rape, kale, cleome, coriander and onion) intercropped with cabbage at the ratio of 1:4 (one row test plant to four rows cabbage) (Plates 1-3). The control experiments consisted of a cabbage monocrop sprayed with Dipel (a *Bacillus thuringiensis* product) and another cabbage mono crop which was not sprayed.

Using the recommended agronomic practices described by Nieuwhof (1969) and Anon (1989), cabbage, kale and rape seeds were sowed in well-raised nursery beds 1x3 meters to prevent water logging. Shallow drills of about two centimeters deep were made across the nursery bed at a spacing of about 10 cm apart. The plants were watered daily using a watering can. Kale and rape were sowed in the nursery three weeks after the onion had been sown in the nursery. Cabbage was sown in the nursery two weeks after the sowing of kale and rape. After four weeks the seedlings of the companion crops-Kale, rape and onion were transplanted into a well-cultivated piece of land. The other three companion crops cleome, coriander and mustard- were directly seeded at the time when Kale, rape and onion were transplanted. Cleome, coriander and mustard were planted on a raised row bed (approx. 30cm), and a swallow drill of about 2-3 cm made across the bed. Cabbage was planted 14 days after the planting of the companion crops. Rape, Kale, mustard as well as cabbage were planted at a spacing of 60 cm between rows and 30 cm between plants. Onion was planted 60 cm away from the cabbage row and 10cm between the plant. Cleome, mustard and coriander were directly seeded by broadcasting. During planting, one teaspoonful (approximately 20 grams) of Diammonium Phosphate (D.A.P) (18.5%+48% P_2O_5) fertilizer was applied in each planting hole and in the drills in all the plots and was well mixed with the soil. A nematicide (furadan) was applied prior to planting. Calcium Ammonium Nitrate (CAN) 23%N fertilizer was applied as top dressing in two splits, three and eight weeks after the planting of cabbage, at a rate of 20 grams per hole. Manure was applied two days before planting. Hand weeding was done two and five weeks after transplanting cabbage. The sole cabbage control plot sprayed with Dipel was sprayed once a week, the day after sampling. Plot sizes of 7.8 x 2.2m were marked with 1.5m path separating each individual plot and 2.5-meters strip separated each block (replicate) from another. A Randomized complete block design (RCBD) with eight treatments replicated four times was used (Appendix 1).

The field plots were used to assess the population of the immature DBM stages on the cabbage and the damage caused by the DBM on cabbage plants by larvae. To estimate the population of the DBM's immature stages on cabbage, the recording of larvae numbers per plant started four weeks after transplanting cabbage and continued weekly thereafter until the onset of harvesting time of the cabbage. Two randomly selected cabbage plants per row from thirteen rows out of the total fifteen rows were sampled. The first and last rows in each plot were not sampled. A total of 26 plants per plot were examined. The number of larvae observed was recorded weekly for eight weeks until harvest. The pest damage for cabbage heads were rated using the following scale: 0= no feeding damage; 1= outer leaves slightly damaged; 2= considerable damage; 3= heavily damaged heads (Dreyer, 1986). At crop maturity, no yield data was collected on the feeding damage due to interference by sudden late stage disease incidence.

The data on variation of DBM larval counts and damage score ratings was analysed using analysis of variance (ANOVA). Significant differences between the means were separated using Student-Newman-Keuls test (SNK-test). Appropriate models using SAS software (SAS institute, 1995) were applied to the results of the experiment. The data was log transformed to remove dependence on the variance (Snedecor and Cochran (1972).

The results presented here are from the first season field trial data during May to September 2000. The second experiment was unsuccessful due to a total crop failure, which occurred three weeks after planting. This was due to an attack by cutworms, which left a very poor crop stand and 'forced' the start of yet another trial from November 2000 to March 2001. The third trial had a good plant stand but the unexpected rains in the months of January and February adversely affected DBM population. Hence, there was very low DBM population in the whole season, resulting in lack of useful comparison of the treatments.

4.2.2 Investigation of the influence of companion crops on the DBM larval parasitism

The crops in section 4.2.1 above were used for this study. Observations were made fortnightly from the fourth week after transplanting and involved assessing the effect of companion crops on the parasitoids of

DBM. Immature stages were collected in petri dishes which were kept in the laboratory and were observed for emergence of any parasitoids after two weeks. Their abundance was evaluated as the total number of parasitoid species that emerged from the entire collection. Percentage parasitism was calculated from the ratio of the total number of parasitised DBM to the total number of hosts collected forthrightly over the crop period as described by (van Driesche, 1983; Poeliking, 1992). No statistical analysis was carried out as the parasitoid natural incidence was very low across all the treatments.

4.3.0 RESULTS

4.3.1 DBM larval infestation in the field

The overall larval infestation on the cabbage monocrop (2.42 ± 0.13) did not differ significantly with the onion (2.37 ± .16) and kale (2.22 ± 0.13) intercrops (Table 4.1). Coriander-cabbage intercrop recorded a significantly less larval infestation (1.35 ± 0.08 larvae per plant), than in the cleome-cabbage intercrop (1.67 ± 0.10). The dipel-protected cabbage monocrop recorded significantly least mean larval infestation (0.78 ± 0.05) per plant. Among the suitable brassica intercrops, no significant difference was observed between mustard and kale intercrops and between rape and mustard intercrops. In the cabbage unprotected monocrop, the infestation was significantly low during the first three weeks but increased from the fourth to the eighth week. A similar trend was observed in the kale, mustard and rape intercrops. Although the onion- and cleome-intercrops demonstrate a

Plate 1: Field trial intercrops with cleome –cabbage intercrop in the foreground and coriander and mustard intercrops in the background

Plate 2 Field trial with mustard cabbage intercrop in the background and cabbage monocrop in the foreground

Plate 3 Field trial intercrops with the onion cabbage intercrop in the foreground and coriander and mustard intercrops in the background

similar trend, a marked reduction in larval infestation between the seventh and eighth week was observed. The coriander cabbage intercrop recorded a significantly high infestation (1.02 ±0.16) in the first week but substantial reduction occurred between week 2 and week 4 and it continued to record a significantly less infestation compared to the cabbage monocrop unprotected treatment and other intercrops treatments till harvest.

4.3.2 DBM damage score assessment in the field

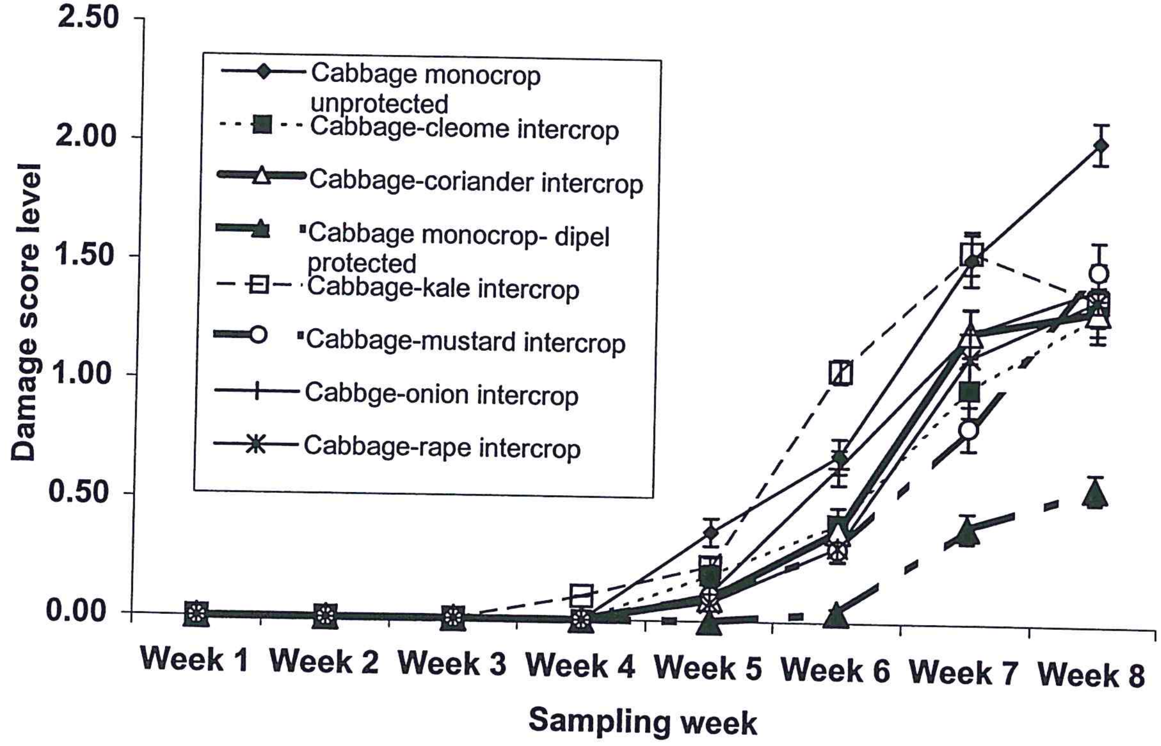
In the overall, the cabbage monocrop had a damage score of 0.58 ± 0.03 per plant which was significantly higher than in all the intercrops. The Dipel protected crop recorded the lowest damage score (0.13 ± 0.01) (Figure 4.1) and there was no significant difference between all the other intercrops. In the overall weekly trend, the seventh week had a score of 1.05 ± 0.04, mostly on the outer plant leaves. By the eight week the damage was still increasing. In the cabbage unprotected monocrop, the damage increased gradually from week 1 at 0 (no feeding damage) to reach 2.04 ± 0.09 at week eight which was considerable damage.

Table 4.1: Mean number of larvae in the eight crop combinations over a period of eight weeks

Week	Cabbage monocrop unprotected	Cleome-cabbage intercrop	Coriander-cabbage intercrop	Cabbage monocrop Dipel protected	Kale-cabbage intercrop	Mustard-cabbage intercrop	Onion-cabbage intercrop	Rape-cabbage intercrop
Week 1	0.43 ± 0.10d	0.43 ± 0.10d	1.02 ± 0.16c	0.52 ± 0.08c	0.88 ± 0.14d	0.55 ± 0.11c	0.74 ± 0.14d	1.18 ± 0.20b
Week 2	0.48 ± 0.09d	0.19 ± 0.04d	0.45 ± 0.07d	0.23 ± 0.05d	0.54 ± 0.07d	0.39 ± 0.07c	0.75 ± 0.12d	0.64 ± 0.09b
Week 3	0.24 ± 0.06d	0.32 ± 0.06d	0.23 ± 0.06d	0.15 ± 0.04d	0.79 ± 0.11d	0.65 ± 0.09b	0.30 ± 0.08e	0.13 ± 0.04c
Week 4	1.26 ± 0.19c	0.83 ± 0.13d	0.37 ± 0.08d	1.03 ± 0.13b	1.55 ± 0.18c	1.51 ± 0.22a	0.86 ± 0.14d	0.72 ± 0.11b
Week 5	4.35 ± .45ab	3.57 ± 0.41a	2.49 ± 0.34b	1.71 ± 0.25a	3.62 ± 0.64b	3.38 ± 0.45a	4.89 ± 0.83b	3.02 ± 0.35a
Week 6	3.28 ± 0.30b	3.12 ± 0.32a	2.64 ± 0.28a	0.60 ± 0.10c	3.29 ± 0.40ab	3.10 ± 0.33a	4.62 ± 0.52ab	3.16 ± 0.35a
Week 7	4.40 ± 0.36a	2.94 ± 0.37a	1.64 ± 0.20b	0.66 ± 0.12c	4.12 ± 0.41a	2.46 ± 0.27a	4.46 ± 0.41a	2.98 ± 0.34a
Week 8	4.93 ± 0.52a	1.97 ± 0.25b	1.93 ± 0.27b	1.30 ± 0.15ab	2.97 ± 0.32ab	3.34 ± 0.33a	2.38 ± 0.30c	2.10 ± 0.20a
Mean	2.42 ± 0.13A	1.67 ± 0.10E	1.35 ± 0.08F	0.78 ± 0.05G	2.22 ± 0.13BC	1.92 ± 0.10CD	2.37 ± 0.16AB	1.74 ± 0.09DE

Means within a column followed by same lower case letter (s) or in row followed by same upper case letter (s) are not significantly different by Student-Newman Keuls (SNK) test at p=0.05

Figure 4.1: Damage score on all treatments over eight weeks



4.3.4 Parasitoid occurrence

The recovered parasitoids of the diamondback moth included *Diadegma sp.*, (Hymenoptera: Ichneumonidae); *Cotesia* sp., (Hymenoptera: Brachonidae) and *Oomyzus sp.* (Hymenoptera: Eulophidae). *Diadegma sp.* appeared singly and had the highest level of 4.4% parasitism. *Cotesia sp.*, appeared in numbers ranging from 3-7per individual host. On the other hand, *Oomyzus sp.*, appeared in numbers ranging from 3 to 12 per individual host (Table 4.2). On overall the parasitoids accounted for 9.4% mortality of DBM. No parasitoids emerged from any of the field collected DBM immatures in the laboratory during the first three weeks of sampling

Table 4.2: Observed parasitoids and number that emerged from DBM pupae and larvae collected from the field

Insects collected	Number of insects recorded after every fortnight				Total number of DBM	% parasitism
	Week 1	Week 3	Week 5	Week 7		
DBM immatures	40	40	40	40	160	
Diadgema sp.	-	-	3 (3)*	4 (4)	7	4.4
Cotesia sp.	-	-	-	17 (3)	3	1.9
Oomyzus sp.	-	-	12 (2)	27 (3)	5	3.1
Number of DBM parasitised	0	0	5	10	15	9.4

*Figures in parenthesis represent number of parasitised DBM

4.4 DISCUSSION

Field results showed that among the treatments, the unprotected cabbage monocrop harboured the highest number of larvae on average and consequently recorded the highest damage. Among the intercrops with non-brassica host plants, it was clearly shown that the coriander-cabbage intercrop reduced infestation and cabbage damage to a greater extent compared to the onion and cleome intercrops. On the other hand, no significant difference in the overall infestation was observed among the suitable host crops. These results suggest that coriander has a potential for use as a companion crop in reducing DBM infestation and damage on cabbage. The specific mechanism employed in reducing the infestation is difficult to ascertain because it has been reported that intercropping results in pest attack have not been unequivocal (Andow, 1991, Tonhasca and Byrne, 1994). Using meta-analysis, Tonhasca and Byrne (1994), reported that the effects of diversity had at most a low to moderate effect on herbivores. However, Vandermeer (1989), proposed the disruptive crop hypothesis, which is equivalent to Root's (1973) resource concentration hypothesis and suggests that a second plant species disrupts the ability of an insect to efficiently attack its major host. It is assumed to work either by some kind of confusion or due to frequent encounters with the non-host plant individuals. Intercropping has also been reported to lower pest densities by reducing immigration into the crop or increasing emigration from the field (Åsman *et al.,* 2001). In the coriander- cabbage intercrop, at the start of sampling, the infestation was high but reduced drastically one week later. This suggests that a certain kind of disruption may have taken place. Taking into consideration the aromatic nature of coriander, it may be speculated that certain volatiles may have caused a disruption, which led to a reduction in DBM population. However, it should be noted that there is no scientific evidence that odors from highly aromatic plants can actually deter pest insects (Dover, 1985). Previous studies indicate that coriander has been effectively used as a companion crop in reducing the incidence of various pests (Varun *et al.,* 1994) and as an alternative resource fauna for hoverflies (Morris and Li, 2000). From the results obtained in this study, it can be suggested that coriander may have camouflaged the host plant and this supports the first part of the disruptive crop hypothesis. A more vertical plant morphology has been suggested to be a more efficient deterrent than recumbent one (Renwick and Chew, 1994), and since coriander grows up more vertically compared to other crops, this could have contributed to its barrier effect.

Previously published results on the diamondback moth and intercropping have been variable (Åsman *et al.,* 2001). Some studies have shown that where the companion crop may have hidden the host plants, significant reductions in egg and larval density were found (Horn, 1987; Theunissen and Schelling, 1996; Finch and Kienegger, 1997). In other studies where no larval reduction was found with companion plants of several different species (Latheef and Irwin, 1979), the companion crops were grown around the perimeter of plots containing cabbage and thus could not visually hide the crop. This mechanism of visual camouflage, where host plants are hidden by taller non-host plants (Finch, 1996), seems to explain further the reduction in the larval infestation in the coriander cabbage intercrop as compared to the onion intercrop which could not hide the cabbage crop. The same reason may apply to the limited effect of cleome-cabbage intercrop.

If a trap crop, such as mustard is to be used, then it must be more attractive to the pest than the main crop (Hokkanen, 1991). But the ability to support higher densities than a main crop does not make a preferred crop a trap crop; the trap crop actually must reduce pest densities on the main crop when the two are interplanted (Ali and Karim, 1989). Mustard apparently combines the quality needed for trap crop, in being able to attract oviposition away from the target crop, but not permitting options for the development of the pest. The mustard intercrop consistently showed a significant reduction in infestation in the field. Indian mustard has been successfully used as a trap crop for *P. xylostella* in some places (Srinivasam and Krishna Moorthy, 1992; Pawar and Lawande, 1995; Facknath, *et al.*, 1998), while it has failed (not been effective) in some other locations (Charleston and Kfir, 2000; Bender, *et al.,* 1999). In this particular study, mustard and rape showed reduction in DBM infestation on cabbage, while kale did not. The reason for the variations in response with respect to kale was perhaps the variety used which may have played an important role and this warrants further investigation.

Though insects colonize monocultures and polycultures to the same extent, there is a higher emigration rate from an intercrop compared with a monoculture (Bach, 1980a; 1980b; Risch, 1981; Kareiva, 1983; Elmstrom *et al.,* 1988; Rämert and Ekbom, 1996; Roda *et al.,* 1997). The inability to explain arthropod response to vegetational diversity with few broad hypotheses has been attributed, in part, to the many adaptive variations that characterize arthropod behavior (Smith and McSorley, 2000).

In this study effect of some of the companion crops like coriander (as 'push') and mustard (as 'pull') crops in reducing larval/ pupal infestation was also reflected in form of reduced leaf damage severity. As evident from the results of this study, these crops will divert DBM oviposition and feeding activities away from the cultivated crop. Although yield records could not be recorded, it could be presumed that the reduction in leaf damage would have enhanced the market price of the cabbage. Future studies should focus on assessing the yield value in relation to the cosmetic quality of the produce.

Diadgema sp., *Cotesia* sp., and *Oomyzus* sp. were the three parasitoids which were recorded in the present study. Various authors have recorded a number of parasitoids, some of which were not observed in this study (Le Pelley, 1959; Waiganjo, 1996). The three parasitoids attacked only pupae and larvae and this conforms to a study carried out by Waiganjo (1996) which did not also record any egg parasitoids. Although *P. xylostella* parasitoids occurred in low percentages, this was an indication that they could contribute in checking the DBM population build-up when they occur in large numbers which is in agreement with a previous study by Waiganjo, (1996). The low rate of parasitism observed in this study may have been brought about by disruption of host finding by the specialist parasitoids. This is consistent with a previous study by Ivey and Johnson (1998), who reported emergence of a negligible number of parasitoids when they were assessing the effect of an IPM package and companion cropping on DBM. As with specialist herbivores, specialist natural enemies such as host-specific parasitoids may rely on sensitive visual, olfactory, and tactile cues to find hosts (Smith and McSorley, 2000). The cues are more likely to be obscured in polyculture than in monoculture (Sheehan, 1986). Further studies to understand the role that companion crops play on the survival and activity of natural enemies of DBM would throw more light on this important component of population dynamics of DBM. Ullyett (1947) stated that other factors such as the mode of attack and plant characteristics might modify even potentially effective parasites and minimize their effect so as to become almost negligible in importance.

CHAPTER FIVE

4.0 GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion and conclusions

This is apparently the first study on DBM which has undertaken a combined evaluation of both the brassica host (as potential 'pull' crops) and the non-brassica plants (as potential 'push' crops) as potential companion crops for reducing DBM infestation on cabbage. Among the different factors that can affect the potential of the brassica crops, the oviposition preference for mustard over cabbage was confirmed and this suggests that it could divert/ dilute the onset of infestation (by egg laying) of DBM on cabbage. Further, mustard did not favor the optimum survival of larvae and even affected the fecundity of the resulting adults. These attributes render mustard as a preferable choice for a trap crop. The benefit of companion cropping with mustard was also evident in the reduction of DBM infestation and crop damage in the associated cabbage crop. Nevertheless, it is important to verify if there are no risks due to the planting of mustard in the vicinity of cabbage in the incidence of other pests such as aphids and diseases such as black rot, though during the present study no such evidence was found.

Among the non-brassica crops tested, coriander and cleome showed good potential, as they reduced the DBM infestation and damage in the associated cabbage crop. Besides their direct benefit in reducing DBM infestation, they had a secondary benefit of supporting the activity of beneficial insects such as parasitic wasps, syrphid adults and pollinators. This was due to odours which they produced for several weeks during the crop season and this odour may be quantified. While coriander and cleome have some potential for being also sold in the local market, it is preferable to optimize the land area assigned to them as companion crops for DBM control in the context of the socio-economic considerations. In particular, different planting arrangements of some of the 'push' crops need to be tested in order to identify combinations that would offer 'highest' returns with least area being required for planting them. Although onion intercrop did not show a significant reduction in the DBM infestation, different varieties need to be further evaluated.

The present study has laid satisfactorily basis for selecting mustard as a candidate 'pull' crop and coriander or cleome as candidate for 'push' crops. Since cabbage / kale are grown in a wide range of ecological zones, it would be useful to verify the adaptation of these companion crops to the different crop production ecological zones. Testing of different varieties of these crops could help select for specific ecological adaptation. Also, the optimum planting dates for the companion crops, so as to impart maximum impact on DBM reduction needs to be worked out in the benchmark sites.

An effort should also be made to quantify the economic and ecological benefits of the 'push-pull' strategy for DBM. This should include monitoring the cabbage head for pesticide-based control in the cabbage monocrop compared to intercropped cabbage. The number of sprays reduced due to companion cropping would help estimating the ecological benefits of the approach.

5.2 Recommendations and suggestions for future work

Future further research on the following aspects is recommended:

1. Further selection of suitable varieties of mustard, coriander and cleome for major ecological zones where cabbage / kale are affected by DBM.
2. Optimization of planting dates and planting pattern of the companion crops to maximize their benefits.
3. Quantification of economic and ecological benefits of the 'pull-push' approach
4. Assessment of potential risks that would result from the planting of mustard plants as DBM trap crops.
5. Evaluation of indirect benefit of coriander/ cleome as nectar/ pollen source for beneficial arthropods.

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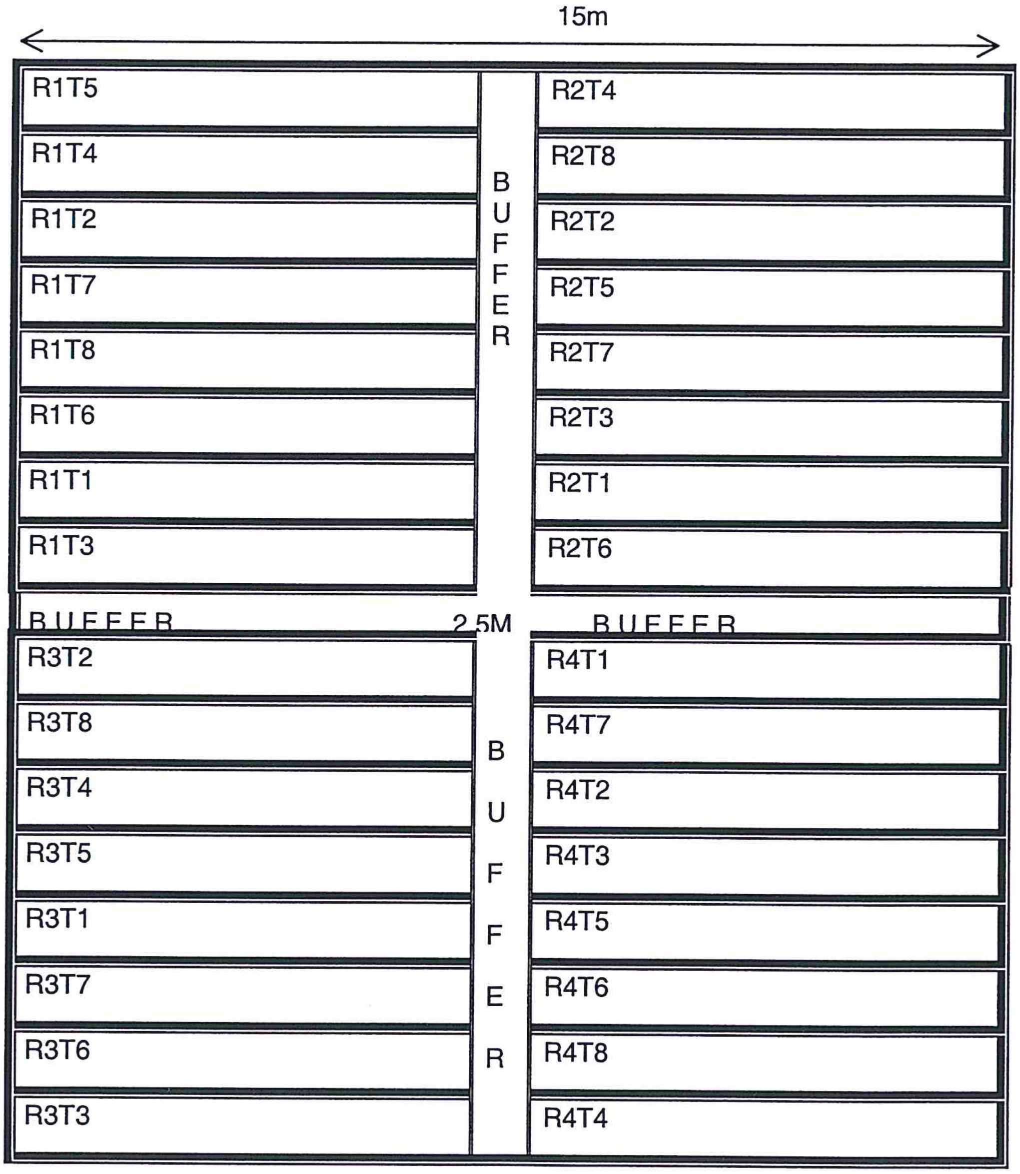
APPENDICES

Appendix 1: Field trial design outline (17 x 65 m) with 2.5 m between replicates and 1.5 m between plots.



Key:

R1- Replicate 1
R2- Replicate 2
R3- Replicate 3
R4- Replicate 4
T1- Cleome- cabbage intercrop
T2- Coriander- cabbage intercrop
T3- Onion –cabbage intercrop
T4- Mustard-cabbage intercrop
T5- Rape-cabbage intercrop
T6- Kale-cabbage intercrop
T7- Dipel sprayed monocrop cabbage
T8- Cabbage unprotected monocrop