Diamondback Moth, *Plutella xylostella* (L.), (Lepidoptera: Plutellidae), and Other Insects of Canola, *Brassica napus* L., in Gauteng Province, South Africa

Submitted in fulfillment of the requirements for the
Degree of Master of Science of
Rhodes University

By

M. S. Mosiane

March 2001

TABLE OF CONTENTS

Acknowledgements

I thank Matthew Ngaoto, Deidre Charleston, David Motiang, Joel Mooka, Tharina Bird, Wimpie Roux, Petrus Dikobe, Hanlie Schmidt, Frans Ramollo, and Beauty Tema (Insect Ecology- Plant Protection Research Institute) for their technical assistance. Dr. Kirsten Kruger (PPRI) for her encouragement and criticism; Drs. M. Mansell & G. Prinsloo, M. Stiller and R. Stals (PPRI, for identification of insects pests and parasitoids); Mardé Booyse (Agrimetrics) for the statistical analysis of data. I gratefully acknowledge Dr. David Arcoll and Human Kotze (Department of Agriculture -Elsenburg) for the invaluable information they provided, and the staff of Carnia at Bapsfontein for allocating a plot for this study.

I wish to express my deep sense of gratitude and appreciation to my mentor, Dr. Rami Kfir, for his advice and guidance during my studies. A special note of thanks to my supervisor Dr. Martin Villet, for his support and guidance. My sincerest thanks to Leonore Louw (Professional Development Project-ARC Headoffice), for providing financial assistance which enabled me to complete my studies.

I would like to say "thank you" to friends, colleagues and staff of PPRI who helped me in one way or another.

This study would not have been attainable without the support, sacrifice, patience, understanding and encouragement of my dearest wife, Veronica, and our children, Didintle and Pitso.

Lastly I would like to say "thank you" to God Almighty who made everything possible.

Abstract

Canola, *Brassics napus* L. is a relatively new crop in South Africa. Insect pests have not yet been a major problem, but the notorious brassica specialist, diamondback moth (DBM), *Plutella xylostella* (L.) (Plutellidae) is establishing itself as a serious pest of this crop. DBM is the most important insect pest of plants from the family Brassicaceae throughout the world. It has developed resistance to all chemical pesticides used against it in the field and to toxins of the bacterium *Bacillus thuringiensis*. The pest status of DBM in South Africa is lower than in other countries with similar climates. However, due to indiscriminate use of pesticides, local populations of DBM are showing signs of resistance.

An initial survey has indicated that in addition to DBM, canola is also attacked by aphids, *Myzus persicae* (Sulzer), *Brevicoryne brassicae* (L.), *Lipaphis erysimi* (Kaltenbach), (Aphiade), thrips, *Thrips tabaci* (Lindeman) and other pests mostly brassica specialists.

The study was initiated to determine the composition of the community of insects found on canola, the seasonal phenology of DBM populations in canola, and the composition, relative abundance and seasonality of its parasitoids.

Monitoring of the insects was carried out at weekly intervals for three years at Rietondale and Bapsfontein in Gauteng province of South Africa.

Berlese funnels have been found to be useful in extracting insects from plants, and were used to indicate the presence of DBM larvae and other insects found on canola.

Adults of DBM were monitored with synthetic pheromone traps; larval and pupal populations were monitored by scouting canola plants. Samples of larvae, pupae and parasitoid cocoons were brought into the laboratory. Parasitoids that emerged were identified and their incidence recorded.

Monolepta cf. bifasciata (Chrysomelidae) and *Listroderes costrirostris* (Schoener) (Curculionidae) were the most abundant of the coleopteran pests. (DBM) and *Heliothis armigera* (H.) (Noctuidae) were most abundant lepidopteran pests of canola.

There was a high proportion of first and second instar larvae as indicated by the results of the Berlese funnels as compared to visual scouting in Bapsfontein.

From May to August the infestation level of DBM was high, reaching the maximum of 0.25 larvae per plant in June 1996, then declined and remained low for the rest of the season in Rietondale.

From September to December for all three years of the study, the population levels of DBM were high, reaching a maximum of 9.6 larvae per plant in September 1997, and remained low from January to August in Bapsfontein.

The number of adult moths per trap per week ranged from 0 to 91 in Rietondale, peaking in January 1996 and September 1997. There was no correlation between infestation levels and the pheromone trap catches.

In contrast to Rietondale, there was a high correlation between pheromone trap catches and subsequent larval infestations at Bapsfontein.

Although DBM infestation levels were generally low, parasitism levels often reached 100% caused by a complex of parasitoids. During the period of study, the following hymenopteran parasitoids were recorded: *Cotesia plutellae* (Kurdjumov) and *Apanteles eriophyes* (Nixon), Braconidae), both larval parasitoids, *Diadegma mollipla* (Holmgren) (Ichneumonidae), and *Oomyzus sokolowskii* (Kurdjumov) (Eulophidae), larval-pupal parasitoids, *Diadromus collaris* (Gravenhorst) (Ichneumonidae) pupal parasitoid, and the hyperparasitoids *Mesochorus* sp. (Ichneumonidae) and *Pteromalus* sp. (Pteromalidae). *Cotesia plutellae* was the most abundant parasitoid occurring throughout the year.

Declaration

I declare that this work is an original version of my studies and has never been submitted anywhere else.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

Introduction and Literature Review

1.1 The Crop

The oilseed rape Canola, *Brassica napus* L. (Brassicaceae), is rapidly becoming one of the most important sources of oil and protein in the world (Lamb 1989). The crop is one of the few edible oil sources that can be successfully produced in the extreme of the temperate regions, because of its ability to survive and grow at relatively low temperatures (Downey 1983, Kneen 1992). It can also be cultivated at high elevations and as a winter crop in the subtropics (Downey 1983).

The expanded use of the crop, and resultant increase in its production, occurred after a successfully breeding program to lower the euricic acid in the seed (Lamb 1989). The term canola refers to *Brassica* oil seeds that produce oils with more than 2% euricic acid and meals with more than 18 moles of total glucosinolates per gram of seed biomass (Lamb 1989, Ramachandran *et al.* 1998).).

Brassica napus L. is a composite of two species, *Brassica campestris* L. and *Brassica oleracea* L. (Downey 1983), does not occur in wild populations and was probably domesticated in southern Europe (Lamb 1989). Canola is rape, transformed through selective breeding to produce what is presently considered to be the healthiest of edible oils (Kneen 1992).

Canola oil is used as salad and cooking oil, and for margarine (Colton & Sykes 1992). In addition to these uses, the oil is also used as fuel additives, detergents and lubricants (Murphy 1996). After crushing extraction, the residual cake meal is used in livestock and poultry diets as a high protein meal (Colton & Sykes 1992, Evans & Scarisbrick 1994, Jouanin *et al.* 2000).

The crop Canola was introduced in South Africa in 1994 and its area of production is steadily increasing (Arcoll personal communication). Commercial production is at an early stage with about 5000ha planted in the first year and 15000ha in 1995 (Kfir 1997), 17 000 in 1996, 18 000 in 1997, 23 000 in 1998, and 25 000 in 1999 (Human Kotze personal communication). The area under canola production is expected to rise rapidly in the next few years to satisfy the local demand (Arcoll personal communication, Kfir 1997).

1.2 The Pests

Several insect pests that attack canola also attack other cruciferous vegetables such as cabbage, cauliflower and radish (Lamb 1989). *Plutella xylostella* (L.) Diamondback moth (DBM) (Lepidoptera: Plutellidae), is a major insect pest of plants from the family Brassicaceae (Talekar & Shelton 1993). DBM is known to have been present in South Africa for more than 80 years (Gunn 1917). Ullyett (1947) did a thorough study on the mortality factors of the pest around Pretoria in the early 1930s. Dennill & Pretorius (1995), and Kfir (1996, 1997, 1998) carried out further studies on the status of DBM and its parasitoids in South Africa.

The moth is active throughout the year, although its rate of development slows down in winter (Annecke & Moran 1982). There does not appear to be any period of dormancy or diapause, so the activity may be resumed at any period of favourable temperatures regardless of the time of its occurrence (Robertson 1939). DBM is believed to be the most universally distributed of all Lepidoptera (Hardy 1938, Alam 1992). Due to its capacity for adaptability, DBM can establish itself in almost every climatic zone of the world (Robertson 1939).

As the land under canola increases, insect problems associated with the crop may also increase (Wheatley & Finch 1984, Evans & Scarisbrick 1994, Ramachandran *et al.* 1998). In South Africa, indiscriminate use of pesticides against DBM, even though its status is lower than in other countries with similar climates (Kfir 1997), has led to local populations showing signs of pesticide resistance (Sereda *et al.* 1997).

DBM larvae appear to feed exclusively on Brassicaceae crops (Talekar & Shelton 1993), but seldom cause serious damage to any except on cabbage, cauliflower, and rape (Marsh 1917). The larvae usually remain on the under-surface of the leaf throughout their feeding period (Annecke & Moran 1982). They remove all tissues with the exception of the veins and upper epidermis, giving rise to the characteristic transparent patches which later form holes in the leaf as the latter grows and the dead tissue tears (Harcourt 1957, Annecke & Moran 1982). On the canola crop, the larvae also feed on the stems, flowers and seed pods, causing poor pod filling and reduced yield (Justus & Mitchell 1996).

There are no data available about pests of canola in South Africa, except that they are Brassica specialists, and therefore the discussion will be based on what is known from other countries.

The most serious insect pests of oilseed Brassica crops, especially in Europe and North America, are of the order Coleoptera: *Phylotreta cruciferae* (Goeze) (Chrysomelidae) and *Meligethes sp.* (Nitidulidae) (Bracken & Bucher 1986, Nilsson 1987, Lamb 1989). The bertha armyworm, *Mamestra configurata* Walker (Lepidoptera: Noctuidae), is a sporadic pest of canola in western Canada (Bracken 1987). According to Wyman (1992), the other pests of importance are cabbage maggot, *Delia radicum* (L.) (Diptera: Anthomyiidae), the cabbage aphid, *Brevicoryne brassicae* (L.) (Homoptera: Aphididae), thrips, *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae), and lepidopterous larvae such as the imported cabbage worm (ICW) *Artogiea rape* (L.) (Lepidoptera: Pieridae), and the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae).

The larvae of the bertha armyworm feed initially on the leaves of the canola plant, and during the last two instars, attack the maturing pods (Bracken 1987). In Sweden, Nilsson (1987) discovered that the larvae and adults of a pollen beetle, *Meligethes* sp. feed on pollen in the buds and flowers. Injury to small buds and severe injury to larger buds cause them to abort, leaving podless stalks (Nilsson 1987). According to Lamb (1984), *P. cruciferae* damage causes differences in plant growth, development and height, evenness of maturity and total seed yield. Thrips causes wilting and browning of the leaves, blasting of buds and serious damage to the flower parts (Burgess & Weegar 1988). Aphids, *B. brassicae* and *Lipaphis erysimi* (Kaltenbach) (Homoptera: Aphididae) reduce plant height and delay plant development (Bunting & Raymer 1994), and also transmit several viruses such as cauliflower mosaic virus and cabbage ring necrosis virus (Bonnemaison 1965).

Although little is known about the relative damage potentials of these pests in canola, it is likely that such differences as exist are influenced by geography and climate (Broatch & Vernon 1997). Because the relative abundance of these pests also varies in space and time during and between growing seasons, the potential development of management practices for these pests in canola is more complicated than if only single species were involved (Broatch & Vernon 1997).

1.3 Control

The management of DBM with single-component strategies has failed because the pest has the ability to develop resistance to chemical pesticides (Sereda *et al.* 1997). Therefore, emphasis should be placed on developing multiple strategies that are compatible, and on educating farmers about the need for multiple approaches (Shelton *et al.* 1997). These approaches include the following strategies.

1.3.1 Chemical control

Ever since the introduction of the insecticides in the 1950s, chemical insecticide has been the mainstay of insect pest control (Dent 1991). In South East Asia, the lack of suitable and effective natural enemies, especially parasitoids, and the continued availability of insecticides, forced farmers to use insecticides to control DBM (Lim 1986).

DBM larvae feeds on the marketable portions of the crop, therefore, synthetic insecticides will remain essential for the management of this pest (Hill & Foster 2000). Although there is an abundance of natural enemies in South Africa, insecticides still provide the mainstay of DBM management as in many countries of the world, because the role of parasitoids is either ignored or misunderstood.

DBM has a history of eventually becoming resistant to every chemical insecticide used against them in the field including the bacterial pesticide *Bacillus thuringiensis* (Talekar & Shelton 1993, Tabashnik *et al.* 1990). The abuse of chemicals by spraying excessively and frequently has led to this resistance (Chua & Ooi 1986). The first DBM insecticide resistance was reported in 1953 in Java, Indonesia (Ankersmit 1953). According to Tabashnik *et al.* (1990) DBM was the first insect pest to develop resistance to the bacterium *Bacillus thuringiensis*. The other chemicals that DBM developed resistance to are organophosphates, pyrethroids and carbamates (Cheng 1986). The farmers used mixtures of chemicals, increased the dosage and sprayed more often to overcome resistance, which led to excessive residue on the products and to environmental degradation (Talekar *et al.* 1990).

1.3.2 Cultural Control

1.3.2.1 Sprinkler irrigation

Heavy rainfall causes high DBM mortality. As a result DBM is only a serious pest during the dry season (Talekar *et al.* 1986). This factor could be exploited by using overhead irrigation of the crop. As the larvae are exposed on the leaf surface, the drops of an overhead sprinkler drown and wash the pest from the plant, thus reducing damage (Lim 1992). It appears that leaving the sprinkler on from dusk through the early evening hours disrupts the mating and oviposition activities of adult DBM (Nakahara *et al.* 1986)

1.3.2.2 Trap crops/ Inter-cropping

Trap cropping is the use of an attractive crop planted on a small scale on a commercial field to lure pests away from the main crop, thereby minimizing or eliminating the need for control activities in the main crop (Hokkanen 1991). The trap crop has to be planted earlier than the commercial crop, and must be available throughout the growing period of the latter in order to facilitate oviposition by resident and immigrating moths (Srinivasan & Moorthy 1992). This may lead to the elimination of chemical insecticides because DBM larvae will be retained in the trap crop, and become parasitised (Talekar & Shelton 1993). Indian mustard, *Brassica juncea* (L.), can be successfully utilized as a trap crop (Srinivasan & Moorthy 1991, Srinivasan & Moorthy 1992, Talekar & Shelton 1993, Pawar & Lawande 1995, Charleston & Kfir 2000). Mitchell *et al.* (1997) has indicated that collard greens, *Brassica oleracea* var. *acephala* L., has potential as a trap crop. *Iberis umbellata* L., (Brassicaceae) can also be successfully utilised as a trap crop (Bigger & Chaney 1998).

Inter-cropping or mixed-cropping could also serve to decrease the density of target pest whilst not affecting the natural enemies (Madriaga & Gabriel 1996, Bucci & Gould 1997, Bigger & Chaney 1998, Verkerk *et al.* 1998). The plants may act as barriers to insect pest movement (Talekar & Shelton 1993), or produce chemical cues that may confuse the pest (Sheehan 1986).

1.3.2.3 Crop rotation

Although not a standard practice in the intensive crucifer-producing areas, crop rotation can play an important role in the management of DBM (Talekar & Shelton 1993). This practice will eliminate the continuous build-up of DBM, and resistance development due to the continuous application of chemical insecticides (Lim 1986). Canola can be successfully rotated with winter cereals and legumes (Colton & Sykes 1992). Yields from cereal crops are usually higher if canola is introduced into the rotation, because of better disease and weed control due to the different growth habit of canola (Colton & Sykes 1992).

1.3.3 Biological control

The failure to effectively solve the pest problems, and the human and environmental risks associated with chemical pesticides, has led to growing dissatisfaction worldwide with the use of these synthetic chemicals (Williamson 1998). The main aim of biological control is to maximize the contribution of natural enemies to keep the incidence of pests to a lower level than would be achieved without the presence of the controlling organism (Waage & Cherry 1992, Oudejans 1994).

Numerous natural enemies attack all stages of DBM (Talekar & Shelton 1993). Therefore, DBM is an excellent example of a serious pest that can be held in repression by parasites (Marsh 1917). Ullyett (1947) identified eleven parasitoids and the fungus *Entomophthora sphaerosperma* Fres, as natural enemies of DBM and Kfir (1997) has identified 21 parasitoids and hyperparasitoids of this pest in South Africa. The DBM parasitoid complex plays an important role in keeping the pest populations low (Mustata 1992). Natural enemies should be conserved, introduced where they do not occur, and augmented and inoculated through mass rearing (Dent 1991, Waage 1992).

1.3.4 Botanical pesticides

The extracts from the tree *Azadirachta indica,* A. Juss (Meliaceae), commonly known as the Neem tree, are widely used for the control of many insect pests, including DBM, that have become resistant to synthetic pesticides (Howatt 1994, Verkerk *et al.* 1998, Goudegnon *et al.* 2000). Neem extracts are less harmful to predator and parasitoid insects than conventional pesticides (Howatt 1994, Verkerk & Wright 1993, Verkerk *et al.* 1998, Goudegnon *et al.* 2000).

Although used as a medicine in pharmacology, an extract from dried powder from the leaves of *Andrographis paniculata* (Acanthaceae), can suppress the feeding of DBM larvae (Hermawan *et al.* 1997). Extracts from the fruits of chinaberry, *Melia azedarach* L., (Meliaceae), not only deterred oviposition by DBM, but also repelled these adults when applied to rapeseed (canola) seedlings (Chen *et al.* 1996).

Botanical pesticides are sometimes only used as substitutes for conventional pesticides without considering their potential of complementing and conserving natural enemies (Waage 1996). These pesticides are designed to affect only one specific pest or, in some cases, a few target organisms, in contrast to broad-spectrum, conventional pesticides that may affect organisms as different as birds, insects, and mammals (Verkerk & Wright 1993, Howatt 1994). Botanical pesticides often are effective in very small quantities and often decompose quickly, thereby resulting in lower exposures and largely avoiding the pollution problems caused by conventional pesticides (Verkerk & Wright 1993, Howatt 1994, Verkerk *et al.* 1998, Goudegon *et al.* 2000). When used as a component of Integrated Pest Management (IPM) programs, botanical pesticides can greatly decrease the use of conventional pesticides, while crop yields remain high.

1.3.5 Transgenic plants

Transgenic plants offer a new potent mechanism for managing insect pest populations, and also provide economic and environmental benefits (Roush 1994). *Bacillus thuringiensis* (Bt), an environmentally harmless insecticide (Tabashnik *et al.* 1997a), can be used in combination with *Cotesia plutellae* (Hymenoptera: Braconidae) a larval parasitoid, for the control of DBM (Chilcutt & Tabashnik 1999, Schuler *et al.* 1999). The combination of the parasitoid and *Bt* in the control of DBM not only reduced the application of synthetic pesticides, but also increased the marketable yield in the Philippines and Indonesia respectively (Rejesus *et al.* 1996, Sastrosiswojo & Grey 1996). The combination of these biological control agents is complementary, but their compatibility can be adversely affected if Bt has a negative impact on *C. plutellae* (Chilcutt & Tabashnik 1997, 1999, Altieri 1999). The larvae of the parasitoid developing in hosts infected by *Bt,* might be killed, or by decreasing the longevity of the parasitoid leading to decreased number of matings or number of eggs laid by the female parasitoid (Chilcutt & Tabashnik 1999).

Because parasitoids play an important role in suppressing DBM populations, their introduction and conservation will be a primary requirement to any sustainable IPM program (Talekar & Shelton 1993).

1.3.6 Integrated Pest Management

The ever-increasing demand for good quality vegetables has placed an enormous pressure on the farmers to reduce the risk of crop losses due to pests, therefore farmers are applying insecticides to control DBM and other pests of vegetables. The upsurge of DBM as a serious pest of crucifers could be due to (1) its rapid development of insecticide resistance, (2) the elimination of its natural enemies, and (3) the lessening of competition for food and habitat with other pests which are more easily controlled by insecticides Chen and Su (1986).

DBM has a significant number of natural enemies (Cruz & Segarra 1992), which could be used as alternatives to chemical control, because they are environmentally compatible (Rosen & Debach 1992). Generally, both chemical pesticides and parasitoids cannot singly control DBM completely (Tabashnik 1994). The best option is to utilize an integrated approach combining all the new technologies such as trap crops, host-plant resistance, development of new pathogens, and mating disruptions in an integrated manner, rather than relying on a single component that offers temporary benefits (Magallona 1986).

DBM is a key pest of brassica crops throughout the world. It is difficult to control because of its genetic resistance to insecticides. In addition to DBM, *M. persicae, B. brassicae, Hellula undalis* (F.) (Pyralidae), are other pests of canola. The management practices for these pests in canola are more complex than if only a single pest was involved, because their abundance varies in space and time during and between growing seasons. Because of the economic potential of canola in South Africa, and the need for information on which to base strategies to minimize pest damage and enhance yield, this study was initiated.

1.4 Aims of the Research Project

The aims of this study were to determine:

1. The composition of the insect community of canola.
2. The seasonal phenology of DBM populations in canola.
3. The composition, relative abundance and seasonal phenology of parasitoids attacking DBM, and their seasonality.

CHAPTER 2

The Insect Community of Canola

Introduction

Canola is a relatively new crop in South Africa and insect pests have not yet been a major problem in production of this oilseed crop. Repeated planting and expansion of canola production area will invariably lead to the establishment of a canola pest complex (Lane 1983, Wheatley & Finch 1984, Lamb 1989) which may require a program of pest management practices (Dent 1991). A large number of insect species, both beneficial and pest, are attracted to canola (Winfield 1992). The insects living in this crop represents a community that interacts with other agricultural and nonagricultural habitats (Lamb 1989). Although the same range of insects is potentially common to all brassicas (Bonnemaison 1965,Wheatley & Finch 1984, Lamb 1989, Evans & Scarisbrick 1994), the incidence of individual species differs according to how well their biology synchronizes with the cultural practices of each crop (Wheatley & Finch 1984). Canola originated in the Mediterranean region (Lamb 1989), therefore, the insects most harmful to the crop have originated from Europe or Asia (Bonnemaison 1965). The adoption of a new crop often brings new problems, most of which are pest related (Lane 1983). Insects can form a barrier to the adoption and production of a new crop if there is a lack of information on their status (Lane 1984).

Little is known about the insect fauna and damage potential of insects in canola in South Africa. The purpose of this study was to examine the insect community of canola and to determine their status as pests, natural enemies, pollinators and occasional visitors.

2.1 Materials and Methods

2.1.1 Experimental sites

The experimental sites were located at Bapsfontein, Carnia-seed experimental farm (25° 09'S, 28° 41'E, altitude 1600m), and at Rietondale, ARC-Plant Protection Research Institute (PPRI) research station (25° 44'S, 28° 13' E altitude 1333m).

Bapsfontein is a farming area with very little residential development, and Rietondale a residential area with agricultural development only on the research station.

Both sites are located in the summer rainfall region of South Africa in Gauteng province. Canola was planted in overlapping crops to ensure continuous sampling from 1996 to 1998. No insecticides were used in this study to allow infestation of the plants to occur.

2.1.2 Berlese funnels

Berlese funnels have been found to be useful in extracting insects from plants, and can be calibrated so that they may be used for estimating population densities (Boland & Room 1983). Each funnel was made of galvanised sheet metal with asbestos lid holding 4 x 75w light bulbs. The 50cm diameter wire mesh platform was located 13.5cm below the bottom of the light bulbs, to support the canola plant. A jar containing 75% alcohol was attached to the base of the funnel to trap insects that escape from the heat generated by the light bulbs.

Ten canola plants were randomly in the field selected and perforated nylon sleeves placed over each one of them. The 90cm in diameter and 185cm in length sleeves were tied at the base of each plant. After 7 days the sleeves were pulled over the plant and tied at the top to trap all the insects that were on the plant. The plant was cut at the base, placed in a cooler bag and brought to the laboratory.

In the laboratory, the nylon sleeves with the plant were placed in the freezer for 15 minutes to knock out the insects. The sleeves were then removed from the freezer, untied and the contents of each emptied singly into Berlese funnels. The asbestos lid was replaced and the lights on the lids were switched on and left for 48 hours. The light bulbs generated a temperature of 65° C at the wire mesh after 1 hour when the funnels were empty and ambient temperature was 24° C (Boland & Room 1983). While trying to escape the heat, the larvae fell into the alcohol jar at the base of the funnel. After 48 hours the lights were switched off and the alcohol jars removed. The insects collected from the alcohol, mounted and send for identification at the Biosytematics division of Plant Protection Research Institute.

2.2 Results and Discussions

A wide spectrum of insects was collected from the canola in Rietondale and Bapsfontein areas throughout the growing season. Most of the collected insects were identified as pests, (Brassicaceae specialists). Insects collected from different phenological stages of the plant were pooled together.

Table 2.1 Insect community of Canola collected in Bapsfontein and Rietondale during 1996-1998.

Order	**Family**	**Species**	**Status**
Coleoptera	**Anthicidae:**	*Formicus rubricollis* (Laferte) *Notoxus* sp.	Predators
	Carabidae: Harpalini Cicindelinae	*Harpalus* sp. *Lophyra* sp.	Pest Predator
	Chrysomelidae:(Leaf beetles) Galerucinae	*Monolepta cf. bifasciata*	Pest
	Coccinellidae: Scymninae Chilocorinae	*Hyperaspis* sp. *Exochomus* sp. or *Chilocorus* sp.	Predators
	Curculionidae: (Seedweevils) Rhythirrinini Ceutorhynchini Somatodini	*Listroderes costrirostris* (Schoener) *Ceutorhynchus* sp. *Hipporrhinus furvus* (Fåhraeus)	Pests
	Elateridae	Undetermined	Pest
	Melyridae: Malachinae	*Colotes albilateralis* (*Erichson*)	Predator
	Scarabaeidae: (Leaf chaffers) Rutelinae Melolonthinae	*Adoretus* sp. *Autoseria* sp.	Pests
	Staphylinidae	Undetermined	Predator
	Tenebrionidae: Lagrinae Opatrini Molurini	*Lagria* sp. *Gonocephalum* sp. *Somaticus* sp.	Pests

Diptera	**Agromyzidae**	Undetermined	Pest
	Chloropidae	*Anastricus* sp.	Pest
	Drosophilidae	Undetermined	Saprophyte
	Empididae (Dance flies)	Undetermined	Predators
	Lonchaeidae	Undetermined	Visitor
	Tephritidae (Fruit flies)	Undetermined	Pest
Hemiptera	**Aphidae**	*Brevicoryne brassicae* L. *Lipaphis erysimi* (Kaltenbach) *Macrosiphum euphorbiae* (Thomas) *Myzus persicae* (Sulzer)	Pests
Heteroptera	**Lygaeidae**	*Cletus* sp. *Paromius gracilis* (Rumbar) *Georcoris cognatus* (Fieber) *Dieuches umbrifer* (Stål)	Pests
	Pentatomidae	*Agonoscelis puberula* (Stål) *Carbula* sp. *Bagrada hilaris* (Burmeister) *Nezara viridula* (L.)	Pests
Hymenoptera	**Apidea**	*Apis mellifera* (L.)	Pollinator
	Braconidae	*Cotesia plutellae* (Kurdjumov) *Apanteles eriophyes* (Nixon)	Parasitoids (*Plutella xylostella*)
	Chalcididae	*Hockeria* sp	Parasitoid (*P. xylostella*)
	Eulophidae	*Euplectrus* sp. *Meruana* sp. *Oomyzus sokolowskii* (Kurdjumov)	Parasitoids (*P. xylostella*)
	Eupelmidae	*Eupelmus* sp.	Parasitoid

	Ichneumonidae	*Diadegma mollipla* (Holmgren) *Diadromus collaris* (Gravenhorst)	Parasitoids (*P. xylostella*)
	Pteromalidae	*Panstenon collaris* (Boucek) *Pteromalus* sp. *Pachyneuron* sp.	Parasitoids
Lepidoptera	**Noctuidae**	*Agrotis segetum* (Dennis & Schiffermuller *Heliothis armigera* (Hübner) *Trichoplusia orichalcea* (F.)	Pests
	Plutellidae	*Plutella xylostella* (L.)	Pest
	Pyralidae	*Hellula undalis* (F.)	Pest
Thysanoptera	**Phlaeopthripidae**	*Haplothrips gowdeyi* (Franklin) *H. nigriconis* (Bagnall)	Pest
	Thripidae	*Thrips tabaci* (Lindeman)	Pests

2.2.1 Coleoptera

The coleopterans, especially of the families Curculionidae, Chrysomelidae and Scarabaeidae are the most serious insect pests of cultivated crops and can cause total crop losses (Bonnemaison 1965, Britton 1973, Skaife 1979, Wheatley & Finch 1984, Scholtz & Holm 1985, Lamb 1989, Bunting *et al.* 1995). The Curculionidae (weevils or snout beetles) family are phytophagous insects and feed on all possible plant parts (Skaife 1979, Scholtz & Holm 1985). The adult and larval stages prefer to feed mainly on the young leaves, flowers, pollen and seed or fruit (Skaife 1979, Scholtz & Holm 1985). The larvae develop inside root tissue, leaves and seeds (Scholtz and Holm 1985). The larvae of *Ceutorhynchus* sp. develop and feed inside the seedpod (Bunting *et al.* 1995). Adults feed on the stems and green seedpods, thus reducing seed viability and quality (Williams & Free 1979, Bunting *et al.* 1995).

Monolepta bifasciata (Hornsted) adult, a chrysomelid genus of the Galerucinae feed on the leaves of the host plant whilst the larvae live and feed on the roots (Scholtz & Holm 1985).

The Rutelinae and Melolonthinea subfamilies of the Scarabaeidae, known as leaf chaffers or whitegrub (Scholtz & Holm 1985), are also serious pests of crop plants. The larvae of *Adoretus* sp. and *Autoseria* sp. feed on roots of crop plants, where they become serious pests. Adults are rarely seen during the day, but emerge from their ground burrows at sunset (Scholtz & Holm 1985).

The Tenebrionidae family also constitutes some of the minor pests of cultivated crops (Skaife 1979, Scholtz & Holm 1985). The larvae of *Gonocephalum* sp. and *Lagria* sp. are known to be pests of cultivated crops (Scholtz & Holm 1985), but the plant parts that they attack and their damage potential is not known. *Somaticus* sp. (toktokkies) feed on the roots of cultivated crops (Scholtz & Holm 1985).

Most coleopterans are pests, but some play an important role as predators of crop pests (Skaife 1979, Scholtz & Holm 1985). Coccinellids and anthicids are small beetles that keep the population of small insects and mites in check. The adult and larval stages of ladybirds, *Hyperaspis* sp. and *Chilocorus* sp. are mostly carnivorous and preys on aphids and coccids (Scholtz & Holm 1985).

Almost all carabids are predators except for *Harpalus* sp., which is phytophagous (Oberprieler 1985). Ciccinellids (tiger beetles) are insatiable predators and also active hunters (Scholtz & Holm 1985). The larvae of *Lophyra* sp. are also predators but burrow in the soil to lie in wait hidden for their prey (Oberprieler 1985). Coccinellids occurred throughout the season.

3.2.2 Diptera

Although most of the species in this order were undetermined, background information is provided. Some species of the Agromyzidae, Chloropidae and Tephritidae are of economic importance because they are pests of cultivated crops (Scholtz & Holm 1985). Agromyzidae larvae are phytophagous leaf and stem miners, and can also induce gall formation (Skaife 1979, Scholtz & Holm 1985). The tephritids feed on flowers, fruits, seed and stems causing serious economic losses (Scholtz & Holm 1985). They have a wide host range that includes apples, apricots, avocados, coffee, grapevines and guavas (Scholtz & Holm 1985). Chloropidae, like Tephritidae and Agromyzidae, can also cause serious injury to the crop leading to economic losses. The *Anastrichus* sp. has been recorded in grain sorghum on which the larvae attacks new shoots, causing the plant to become bushy with many shoots and few ears if any (Scholtz & Holm 1985). On canola the larvae also attack new shoots. The Empididae or dance flies are predators of others insects, especially Diptera (Skaife 1979, Scholtz & Holm 1985), therefore, they play an important role in keeping the populations of these pests low.

2.2.3 Hemiptera

Brevicoryne brassicae, Lipaphis erysimi, and *Myzus persicae* occur more commonly on crucifers (Annecke & Moran 1982) and were the most abundant species from the Aphidae found on canola. Aphids are phloem feeders on a wide range of host plants (Scholtz & Holm 1985, Bunting & Raymer 1994, Cole 1997). Dense clusters feeding on shoots, flower heads and developing seed heads of canola, can seriously reduce pod set, pod fill and seed quality (Lamb 1989, Colton & Sykes 1992, Berlandier 1999). Aphids develop very fast and can produce live offspring without mating (Scholtz & Holm 1985), however their life cycles vary according to the different subfamilies (Annecke & Moran 1982, Scholtz & Holm 1985). Aphid clusters on buds, shoot, flowers and pods are a sign of heavy infestation, which causes stunting of the plant, flower abortion, and reduced pod set leading to reduced yields (Lamb 1989, Bunting & Raymer 1994, Berlandier 1999). Aphids also transmit plant viruses (Annecke & Moran 1982, Scholtz & Holm 1985). Although aphids were present in canola throughout the year, the most abundant species were *B. brassicae. L. erysimi* was abundant in summer and during flowering. *M. persicae* and *M. euphorbiae* occurred throughout the growing season but in lesser numbers as compared to the other two. Glucosinolates may serve as host selection cues for Brassicaceae specialist *B. brassicae* (Cole 1997).

2.2.4 Hymenoptera

This order is comprised of parasitic and predatory wasps that play an important role in the control of insect pests, and bees, which are important for pollination (Skaife 1979, Daly *et al.* 1981, Scholtz & Holm 1985). It is the most economically beneficial insect order (Scholtz & Holm 1985). *Apis mellifera* (L.), the honeybee, is known as a social insect, and is extremely important to man for pollination and honey production (Daly *et al.* 1981, Scholtz & Holm 1985).

Meruana sp. and *Euplectrus* sp. of the family Eulophidae, are parasitoids of Diptera and Lepidoptera belonging to the leaf mining families (Skaife 1979, Daly *et al.* 1981, Scholtz & Holm 1985). Species of Coleoptera, Hemiptera, Orthoptera and Hymenoptera have also been recorded as hosts of Eulophidae (Scholtz & Holm 1985).

Hockeria sp. of the family Chalcididae is a known pupal parasitoid of DBM that also parasitizes pupae of saturniid moths and some dipteran species (Skaife 1979, Daly *et al.* 1981, Scholtz & Holm 1985, Van Driesche & Bellows 1996). The Genus *Eupelmus* attacks immature stages of Lepidoptera, and also attacks Curculionid beetles, soft scale insects, and cecidomyiid flies (Scholtz & Holm 1985).

Pteromalids are primary or secondary parasitoids with a wide host range of insects. *Pachyneuron* sp. are parasitoids of syrphid flies, but also hyper-parasitic in aphids and psyllids (Riek 1973, Daly *et al.* 1981, Scholtz & Holm 1985). *Panstenon collaris* Boucek and *Pteromalus* sp. parasitise coleopteran families of Curculionidae, Bruchidae, Bostrychidae and Anobiidae (Skaife 1979, Scholtz & Holm 1985), and DBM has also been recorded as a host (Kfir 1997).

2.2.5 Heteroptera

Although this order is dominated by plant-feeders, many species of various families attack crop pests, and are considered to be of great economic importance (DeBach & Rosen 1991). Lygaeidae or seed bugs feed preferentially on seeds, but may occasionally be predaceous (Daly *et al.* 1981, Scholtz & Holm 1985). *Georcoris* feed on red scale but may survive on seed (Scholtz & Holm 1985). *Dieuches umbrifer* (Stål) feed on seeds (Daly *et al.* 1981, Scholtz & Holm 1985) which may result in serious economic losses.

Pentatomidae are commonly referred to as shield or stinkbugs and include a number of pest species that are of economic importance (Skaife 1979, Daly *et al.* 1981, Annecke & Moran 1982, Scholtz & Holm 1985). Injury is most common on newly emerged plants through the 4th true-leaf stage, but it also may occur on mid-whorl-stage plants. Stinkbugs pierce the side of the stalk with their proboscis. The proboscis injected into the leaf during feeding creates pinholes on leaves. Dead, brown tissue and a yellow halo often surround holes.

Bagrada hilaris (Burmeister) is a troublesome bug that prefers crucifers (Annecke & Moran 1982, Scholtz & Holm 1985, Colton & Sykes 1992). The bug is usually active early in the growing season when the plants are young. It kills the seedling by sucking the sap from leaves and shoots (Annecke & Moran 1982). *Nezara viridula* (L.), a pentatomid has a wide host range, and attacks canola from flowering to podding (Woodward *et al.* 1973). The adults and nymphs suck sap from the leaves, flowers, developing and ripening seedpods (Colton & Sykes 1992). *Agonoscelis purbella* (Stål) and *Carbula* sp. are also troublesome minor pests of cultivated crops (Scholtz & Holm 1985), and were rare compared to *B. hilaris* and *N. viridula.*

2.2.6 Lepidoptera

The Lepidoptera are one of the most familiar and largest insect orders (Common 1973, Skaife 1979, Henning 1985). Insects from this order are pests of many cultivated crops and can cause serious economic losses. The Noctuidae are mostly nocturnal and the largest family of moths (Henning 1985). *Agrotis segetum* (common cutworm), *Heliothis armigera* (American bollworm), and *Trichoplusia orichalcea* (cabbage looper), have a wide host range (Annecke & Moran 1982, Henning 1985) and can cause serious economic losses if left unchecked. The larvae of *A. segetum* climb on the seedlings and young plants and feed on the leaves, or cut stems near the ground level, thus killing the plant, usually at night (Annecke & Moran 1982, Colton & Sykes 1992).

T. orichalcea and *H. armigera* prefer to feed on tender leaves, flowers and seedpods (Annecke & Moran 1982, Henning 1985), causing heavy damage to seedpods, severely reducing yield. Heavy aphid infestation and dry weather appear to favour *H. armigera* infestation because the egg laying moths are attracted to the honeydew as an alternative or additional food source to flower nectar (Colton & Sykes 1992). The larvae of *H. armigera* were more abundant in spring and during flowering. This pest is establishing itself as one of the major insect pests of canola. DBM is one of the destructive pests of cruciferous crops, and will be discussed in detail in Chapter 3.

Hellula undalis (F.), cabbage web worm, a pyralid, is a minor pest of crucifers (Annecke & Moran 1982), but can cause serious damage on young plants. The larvae spin a silken web on the underside of the leaves and feed on the sheltered area (Annecke & Moran 1982, Henning 1985), and occur early in the growing season.

2.2.7 Thysanoptera

Thrips tabaci (Lindeman), a member of the cosmopolitan Thripidae, occurs wherever plants grow, and has been recorded in the desert and arctic regions (Reed 1973). *Thrips tabaci* is responsible for transmission of 12 virus diseases (Scholtz & Holm 1985). Thrips scrape the leaves and buds and feed on the juices that ooze out (Skaife 1979, Scholtz & Holm 1985). Damaged leaves turn brown, become distorted or may curl up and develop a silver colour. Phlaeothripids are also widespread and have numerous habitats, and are knowparasitise *T. tabaci* (Scholtz & Holm 1985).

CHAPTER 3

Seasonal Phenology of *Plutella xylostella* (L.) Populations in Canola

Introduction

DBM is the most serious pest of cruciferous crops throughout the world (Chisholm *et al.* 1979, Mustata 1992, Verkerk & Wright 1996, Justus & Mitchell 1996, Idris & Grafius 1997). In South Africa, commercial cruciferous vegetables are grown all year round which provides an increased supply of food source for DBM. The consumption of cruciferous vegetables is increasing, more so in the disadvantaged communities of this country (Kfir 1997). According to Annecke & Moran (1982), DBM is an important pest of cruciferous crops in South Africa, but its pest status is lower than in other countries, which has similar climatic conditions (Kfir 1996). The spread of the crop into areas traditionally growing cruciferous vegetables will result in increased pesticide usage to control DBM (Evans & Scarisbrick 1994).

DBM larvae feed on the leaves of the canola plant during the vegetative stage of the crop, on growing tips during bolting stage, and on the flowers and pods during flowering, and pod developmental stages (Ramachandran *et al.* 1998).

DBM has been known to cause serious economic damage on cabbages locally, reaching up to 100% crop losses (Dennill & Pretorious 1995). Cool weather reduces the moth flight activity (Annecke & Moran 1982), therefore, DBM may be a serious pest during warmer months.

The objective of the study was to determine the seasonal phenology of DBM populations in canola.

3.1 Materials and Methods

3.1.1 Experimental sites

The experimental sites were located in Bapsfontein and Rietondale areas.

Plant sampling results for Rietondale 1997 are not included in the discussions because of crop failure. The results of Berlese samples from Rietondale are also not included in the discussions because of low infestation levels and sparse distribution of instars. The focus therefore, of the discussion of results of DBM infestations determined by using Berlese funnels, will be based on Bapsfontein results only.

Analysis of variance (ANOVA) was used to analyse data on the seasonal abundance of DBM on both experimental sites, and to correlate the infestation levels and the trap catches.

3.1.2 Plant sampling

Four weeks after planting and once the canola seedlings were established, larval and pupal populations of DBM were monitored in these plots, throughout the year to provide information for population modelling. At weekly intervals, 30 plants were randomly selected and scouted, to determine the infestation levels and seasonal phenology of DBM. The total numbers and stages of development (instars) of DBM larvae and the numbers of pupae on the plants was recorded. The presence of other insects was also recorded.

3.1.3 Berlese funnels

It is difficult to sample small DBM larvae because of their small size and tendency to be concealed in the heart leaves (Butts & McEwen 1981, Baker *et al.* 1982). Berlese funnels have been found to be useful in extracting insects from plants, and can be calibrated so that they may be used for estimating population densities of DBM (Boland & Room 1983).

The procedure is similar to the one described in the previous chapter, but in this instance our interest is on the DBM larvae only.

3.1.4 Adult monitoring

Three delta shaped synthetic sex pheromone traps (registered trade name Biotrap) (Kfir 1997), were deployed in and around the plots to monitor adult DBM populations. In the traps, sticky floors coated with a layer of polybutene adhesive were used (Kfir 1997). Rubber septa impregnated with DBM female pheromone dispenser (supplied by AgriSense-BCS Limited, UK) were placed in the middle of the sticky floor inside the metal trap. At weekly intervals the traps were examined, male moth catches recorded, and the sticky floors replaced.

3.2 Results and Discussions

3.2.1 Plant sampling

In Rietondale infestation levels peaked during May to August in 1996, reaching the maximum of 0.25 larvae per plant (Fig 3.1), declined and remained low for rest of the season. In Bapsfontein, the population levels of DBM larvae per plant were high from September to December, reaching the maximum of 9.6 larvae per plant, and low from January to August throughout the three years of the study (Fig.3.2). The infestation levels were generally low in winter and started to increase from early spring.

In general Bapsfontein had a higher infestation as compared to Rietondale. The high DBM populations in Bapsfontein could be attributed to cruciferous weeds, which play an important role in maintaining DBM populations (Muhamad *et al.* 1994, Begum *et al.* 1996).

The two localities are significantly different regarding seasonal abundance of the pest. For Rietondale the peaks are from May to August in 1996 and 1998, while Bapsfontein's peaks are from September to December for the 3 years. The interaction term locality. season is highly significant (ANOVA; $p<0.001$).

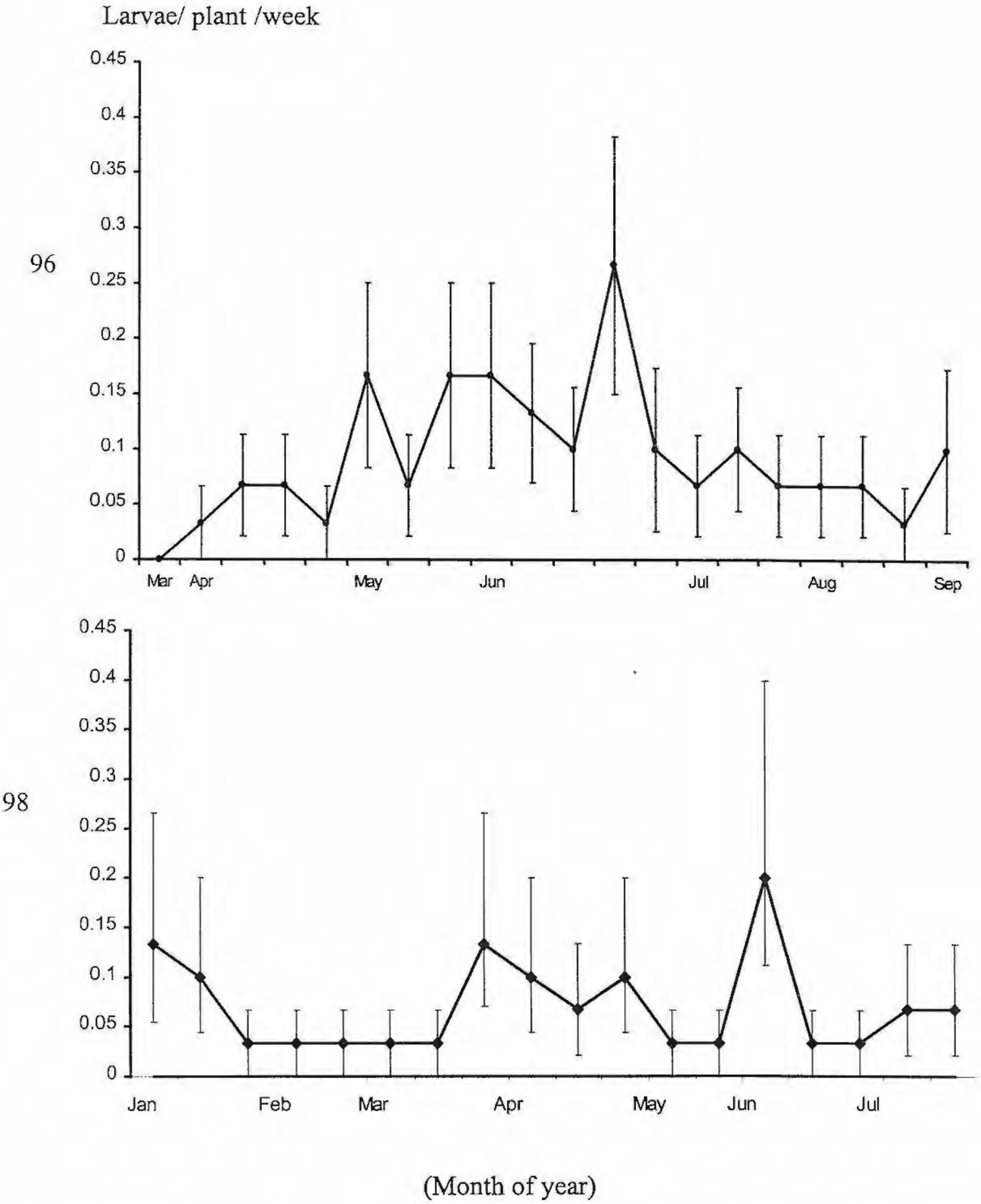

Fig. 3.1 Seasonal abundance of diamondback moth larvae in Rietondale during 1996 (above) and 1998 (below). Bars represent standard error (SE) when larger than the symbol size. (Larval counts were obtained from scouting).

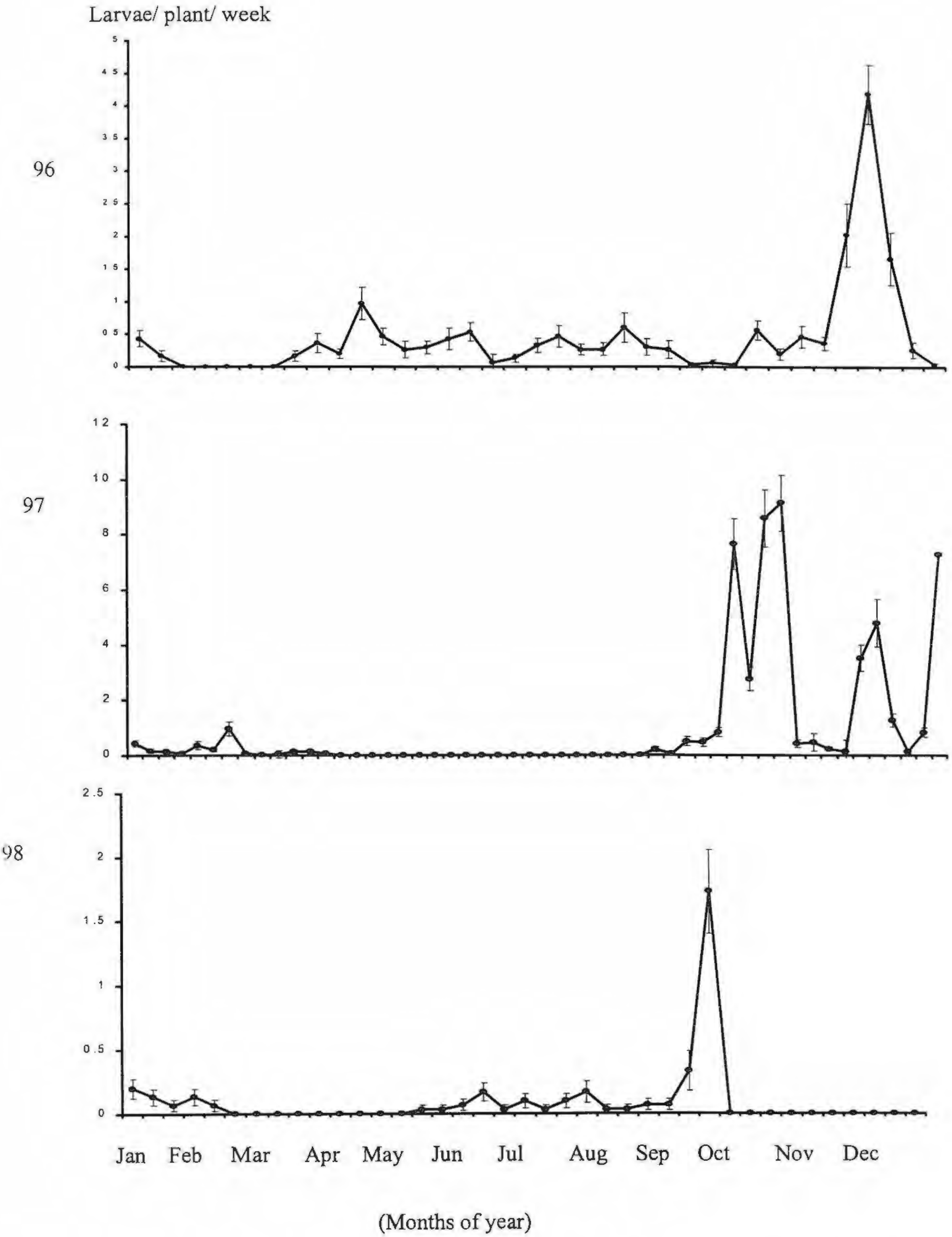

Fig. 3.2 Seasonal abundance of diamondback moth larvae in Bapsfontein during 1996-1998. Bars represents standard error (SE) when larger than the symbol size. (Larval counts were obtained from scouting).

3.2.2 Berlese funnels

Results from the Berlese funnels indicate that there were higher proportions of the first and second instar larvae (Table 3.1) as compared to the visual scouting (Table 3.2). The results are an average of 10 plants.

Table 3.1. DBM larval density and instar distribution in Bapsfontein during September -December 1997 results from Berlese funnels, (average of 10 plants). Numbers in brackets represent percentages of total.

Date	*1st Instar*	(%)	*2nd Instar*	(%)	*3rd Instar*	(%)	*4th Instar*	(%)
9/9/97	143	(64)	54	(24)	19	(9)	6	(3)
18/9/97	90	(61)	29	(20)	18	(12)	10	(7)
25/9/97	182	(48)	106	(28)	63	(17)	27	(7)
2/10/97	323	(34)	288	(31)	181	(19)	149	(16)
8/10/97	449	(35)	398	(31)	263	(20)	184	(14)
15/10/97	202	(40)	148	(29)	99	(20)	58	(11)
22/1097	104	(48)	44	(21)	38	(18)	28	(13)
29/10/97	4	(11)	3	(8)	7	(18)	24	(63)
5/11/97	5	(17)	8	(28)	6	(21)	10	(34)
12/11/97	0		0		0		3	(100)
19/11/97	0		0		0		0	
26/11/97	0		0		0		0	
2/12/97	4	(9)	9	(21)	7	(16)	24	(54)
10/12/97	7	(24)	6	(21)	7	(24)	9	(31)
18/12/97	0		4	(57)	0		3	(43)

There is a clear indication that a greater number of the smaller DBM larvae were missed whilst scouting because of their size and tendency to tunnel into leaves (Table 3.2). The age of the plant also influences the infestation levels and distribution of instars. The larvae prefer young succulent plants to mature plants. The younger the plants, the higher the number of larvae. Berlese funnels can be successfully utilized to estimate population levels of DBM in canola fields, but this destructive sampling method is good for research purposes and not practical for farmers.

Table 3.2. DBM larval density and instar distribution in Bapsfontein during September- December 1997, field scouting (average of 30 plants). Numbers in brackets represent percentages of total.

Date	1st *Instar* (%)	2nd*Instar* (%)	3rd *Instar* (%)	4th*Instar* (%)
20/8/97	2 (33)	1 (17)	2 (33)	1 (17)
28/8/97	1 (50)	0	0	1 (50)
4/9/97	1 (7)	2 (13)	8 (53)	4 (27)
12/9/97	2 (13)	2 (13)	7 (47)	4 (27)
18/9/97	11 (44)	10 (40)	1 (4)	3 (12)
25/9/97	69 (31)	75 (34)	45 (20)	33 (15)
2/10/97	12 (14)	47 (57)	19 (23)	5 (6)
8/10/97	53 (23)	95 (40)	39 (21)	39 (16)
15/10/97	88 (34)	82 (31)	50 (19)	43 (16)
22/10/97	1 (10)	6 (60)	1 (10)	2 (20)
29/10/97	13 (100)	0	0	0
5/11/97	0	0	0	0
12/11/97	2 (29)	4 (57)	1 (14)	0
19/11/97	7 (54)	5 (38)	1 (8)	0
26/11/97	40 (38)	49 (46)	14 (13)	3 (3)
2/12/97	29 (20)	56 (39)	35 (24)	24 (17)
10/12/97	22 (58)	13 (34)	3 (8)	0
18/12/97	0	2 (50)	1 (25)	1 (25)
22/12/97	5 (20)	12 48)	2 (8)	6 (24)
31/12/97	1 (20)	1 (20)	3 (60)	0

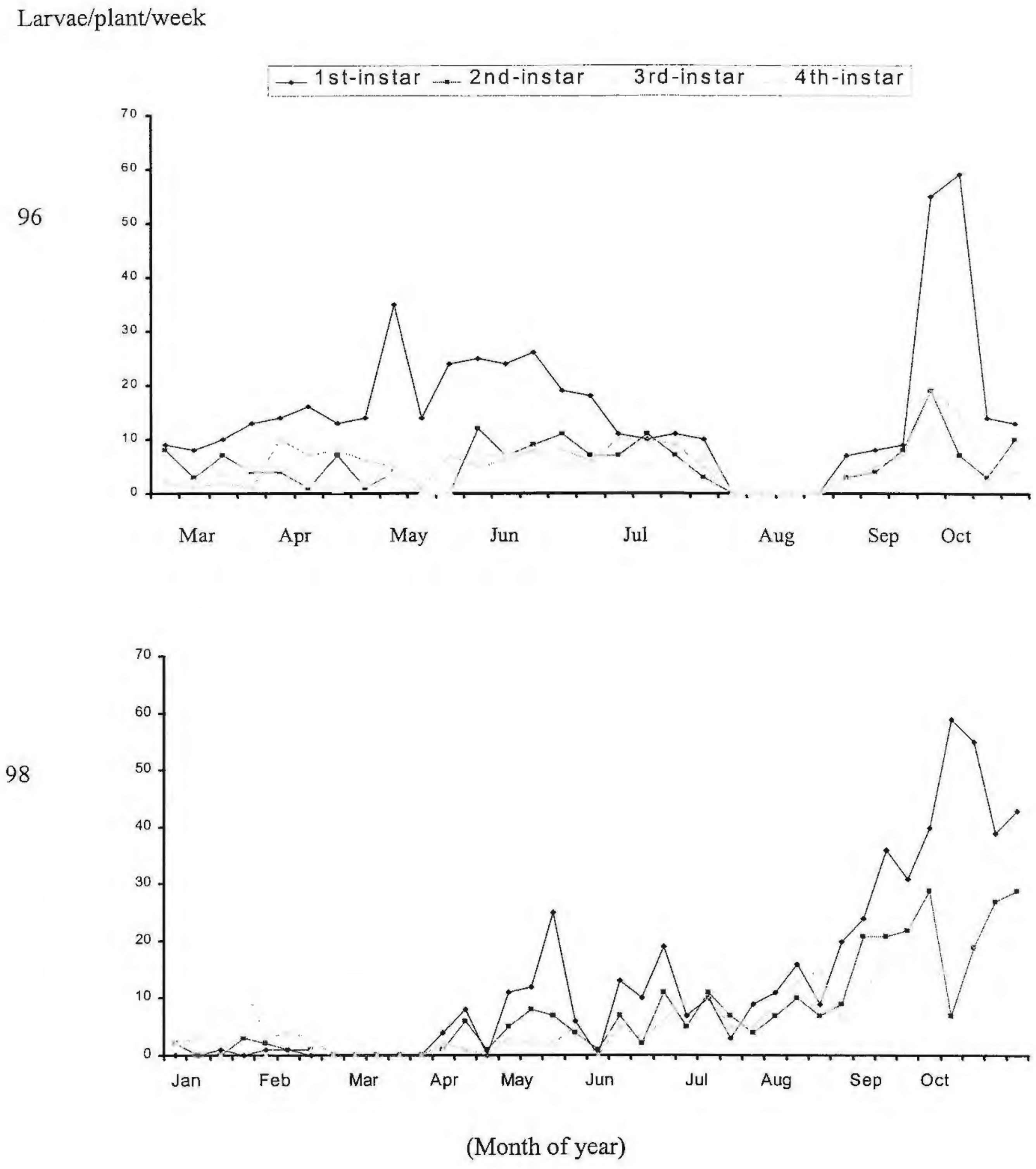

Fig. 3.3 Instar distribution of diamondback moth larvae on canola in Bapsfontein during 1996 (above) and 1998 (below). (Larval counts were obtained from Berlese funnels).

3.2.3 Adult monitoring

DBM adults are nocturnal fliers with peak activities occurring from dusk to dawn (Goodwin & Danthanarayana 1984, Nakahara *et al.* 1986). The results of the pheromone trap catches indicate that flights occurred all year round. The number of adult moths per trap per week ranged from 0 to 91 in Rietondale in 1996 (fig 3.4). During 1996 and 1998 the number of moths per trap was lower from February to August, and high from September to January. In 1997, trap catches were higher from May to August and lower from September to April, compared to the same periods in 1996 and 1998. There was no correlation between trap catches and crop infestation in Rietondale due to sparse values in infestation data. The correlation coefficient, r = 0.06, indicates no relationship between infestation levels and the trap catch variable.

In contrast to Rietondale, the infestation levels in Bapsfontein were higher from August to January and lower from February to July (fig 3.5), reaching 189 moths per trap per week in September 1997. This coincides with peaks of immature stages found in the crop during the same period (Fig 3.2). Maximum numbers of moths were observed during spring and early summer, when there was a gradual increase in the daily temperature (Kfir 1997). The correlation coefficient, r = 0.794 indicates a strong positive relationship between trap catches and infestation levels (Fig 3.2).

The pheromone traps were useful for determining the presence and relative abundance of DBM. Although these traps cannot predict the potential for crop damage, the trap counts provide a warning of a possible infestation. DBM can be a serious pest during spring and early summer as indicated by the Bapsfontein results. It is a prolific breeder and different life stages occur at the same time.

Chemical control of DBM can be difficult because of genetic resistance to insecticides. Insecticides do not control eggs and pupae, therefore, the population that is in the egg or pupal stage at the time of spraying will not be controlled (Liu *et al.* 1981).

DBM parasitoids occur naturally and can play a major role in reducing the next egglaying generation. All stages of DBM are attacked by a number of parasitoids and predators that play a dominant role in the biological control of this pest (Talekar & Shelton 1993).

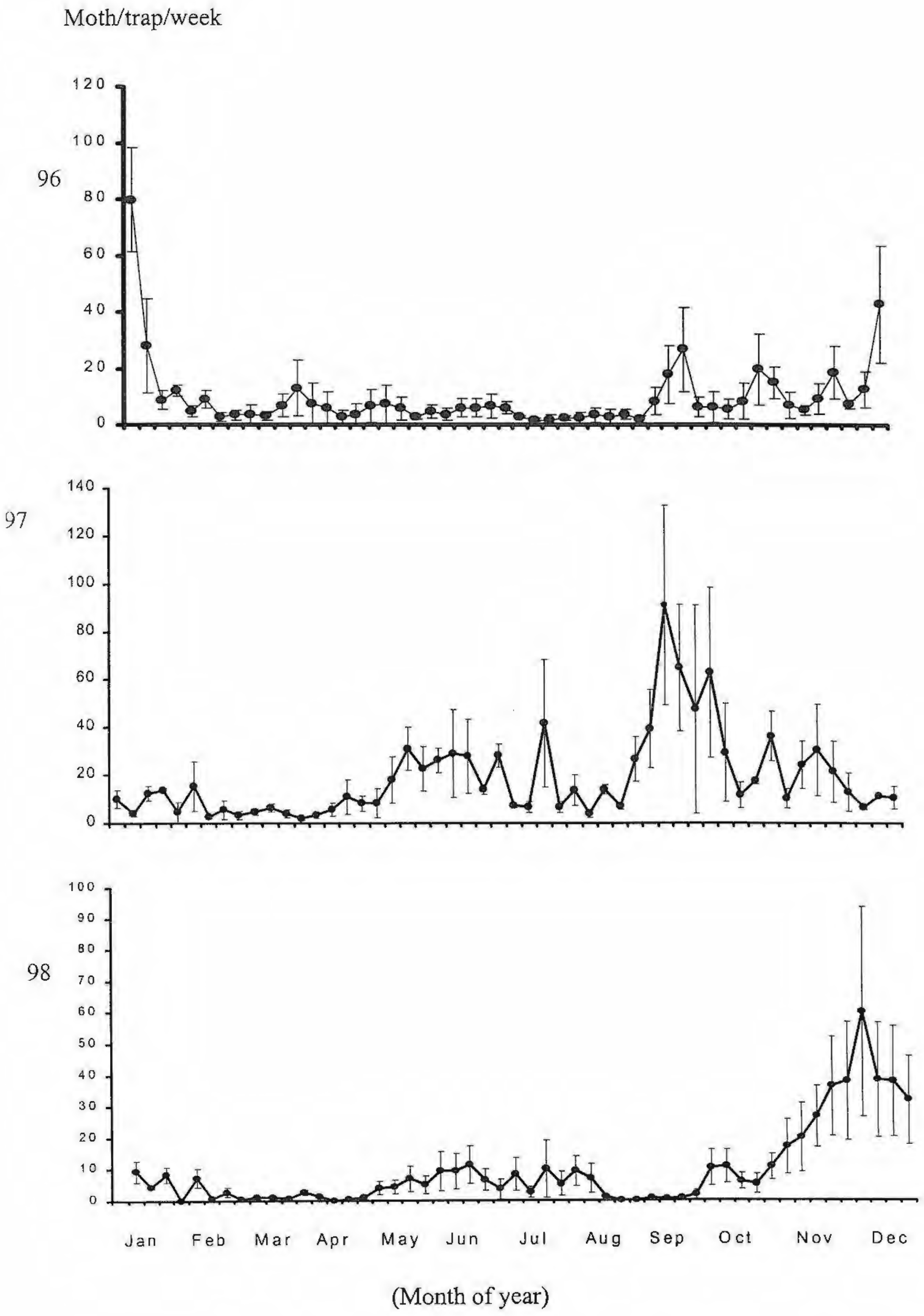

Fig. 3.4. Synthetic sex pheromone trap catchesof diamondback moth in Rietondale during 1996-1998. Bars represent standard error (SE) when larger than the symbol size.

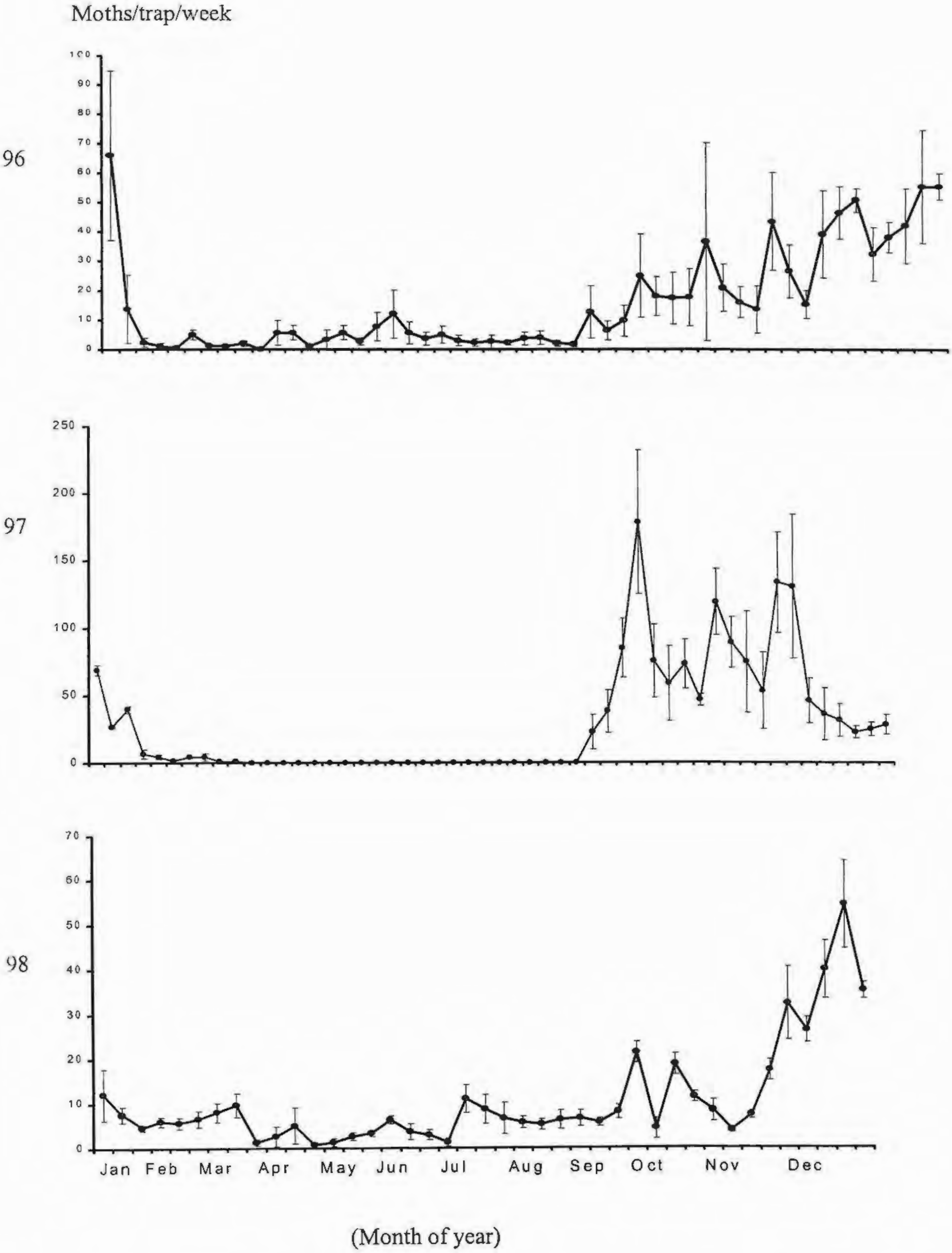

Fig. 3.5 Synthetic-sex pheromone trap catches of diamondback moth in Bapsfontein during 1996-1998. Bars represent standard error (SE) when larger than the symbol size.

CHAPTER 4

The Composition, Relative Abundance and Seasonal Phenology of Parasitoids Attacking *Plutella xylostella* (L.)

Introduction

Conventional pest control is related to taking actions to stop infestations of a pest, and in this instance an insect (Ooi 1992). Indiscriminate use of insecticides against DBM has negatively affected the parasitoids and predators that contributed to reducing DBM population to some extent (Talekar & Yang 1991, Sereda *et al.* 1997). Preceding the discovery of chemical insecticides, farmers relied on natural biological control and cultural practices including selecting varieties that were more tolerant to pest damage (Ooi 1992). The continuous availability of host plants throughout the year, the rapid succession of generations under favourable environmental conditions, and the intense use of insecticides, has led to the development of resistance of DBM to insecticides used against it in the field (Cheng1986, Sun *et al.* 1986).

South Africa has an abundance of DBM parasitoids and natural enemies (Ullyett 1947, Kfir 1997). Ullyett (1947) recorded a complex of 11 parasitoids, and a fungus, *E. sphaerosperma* as natural enemies of DBM in South Africa. In a study conducted by Dennill & Pretorius (1995) only 1 parasitoid was recorded, but in subsequent studies by Kfir (1996, 1997, 1998), 21 parasitoids and hyper-parasitoids were recorded.

Sereda *et al.* (1997) indicated that local DBM populations have indicated signs of resistance to chemical pesticides, therefore, biological control is the best option to consider (Azidah *et al.* 2000).

As an attempt in establishing a biological control program, the aim of the study was to determine the composition, relative abundance and seasonal phenology of parasitoids attacking DBM.

4.1 Materials and Methods

4.1.1 Plant sampling

Four weeks after planting and once the canola seedlings were established, the larvae, pupae and parasitoid cocoons were monitored every week in Bapsfontein and Rietondale from 1996-1998. At weekly intervals 30 canola plants were randomly selected and scouted, and the number of DBM larvae, pupae and parasitoid cocoons were recorded from each plant. Samples of DBM larvae, pupae and parasitoid cocoons were collected, transferred into glass vials (2.5 x 10 cm), placed into a cooler bag and brought to the laboratory.

In the laboratory, DBM larvae were placed singly in petri dishes and provided with a fresh portion of cabbage leaf. The lid of the petri dish was replaced and tightly sealed with rubber bands so that the larvae could not escape. The cabbage leaves were replaced every second day until DBM pupae or parasitoid cocoons formed.

The field collected pupae and parasitoid cocoons were also placed singly in glass vials with tightly fitting perforated lids until moths or parasitoids emerged. The parasitoids that emerged were identified, and their seasonal and relative abundance calculated. The larvae that escaped or died, and pupae and parasitoid cocoons that failed to emerge were excluded from the calculation of parasitism.

4.2 Results and Discussions

DBM parasitoids were active throughout the year. During three years of study the following five parasitoids and two hyperparasitoids were recorded. The same DBM parasitoid complex recorded in Bapsfontein was also found in Rietondale, although at lower numbers. The parasitoids from both experimental sites were pooled.

4.2.1 Larval parasitoids

Cotesia plutellae (Kurdjumov) (Hymenoptera:Braconidae) was the most abundant parasitoid occurring throughout the year.

Apanteles eriophyes (Nixon) (Hymenoptera:Braconidae) was also present throughout the year except during winter months.

4.2.2 Larval- pupal parasitoids

Oomyzus sokolowskii (Kurdjumov) (Hymenoptera: Eulophidae) parasitised DBM larvae and emerged from the pupae. *O. sokolowskii* also emerged from cocoons of *C. plutellae* but only if it parasitised DBM that was parasitised by *C. plutellae* (Kfir 1997), which was very rare.

Diadegma molipla (Holmgren) (Hymenoptera: Ichneumonidae) a solitary endoparsitoid was also very active except during winter months.

4.2.*3* Pupal-parasitoid

Diadromus collaris (Gravenhorst) (Ichneumonidae) occurred mostly in spring and autumn.

4.2.4 Hyperparasitoids

The solitary endoparasitoids *Pteromalus* sp. (Pteromalidae) and *Mesochorus* sp. (Ichneumonidae) were the most abundant hyperparasitoids. According to (Kfir 1997) *Mesochorus* sp. attacked larvae of *C. plutellae* and *A. eriophyes* inside the DBM larvae, and only started feeding when the primary parasitoid had completed their development and formed cocoons. *Pteromalus* sp. attacked cocoons of *C. plutellae, A. eriophyes* and *Diadegma* sp. The two hyperparasitoids emerged from the cocoons of their hosts. The actions of hyperparasitoids can limit the efficiency of primary parasitoids in controlling DBM populations (Mustata 1992, Kfir 1997).

Although the DBM infestation levels were low, parasitism often reached 100% in Bapsfontein (Fig. 4.1). Parasitism trends (Fig. 4.1) were different from those of infestation levels (Fig. 3.2), i.e. higher from January to August and lower from September to December. The parasitoids were more active and effective when the plant infestation levels were low. As the number of DBM larvae increased, there was a decrease in parasitism (Fig. 4.1). Most of the parasitoids of DBM were inactive during winter months except for *C. plutellae.* Due to lack of data on temperature limitations on the DBM parasitoids, it can be assumed that this may be caused by slow larval development. Parasitism occurred during winter albeit the decline in both the host and parasitoid complex.

According to Harcourt (1960) parasitoids populations in the field fluctuate in direct proportion with the density of the host and its reduction.

The retention and host-seeking efficacy of parasitoids is strongly influenced by the availability and accessibility to food sources in their immediate area of activity (Lewis *et al.* 1998). The honeydew excreted by certain hosts serves as food source for some parasitoids (Jervis & Kidd 1986), whilst others depend on non-host food such as floral nectar, pollen or honeydew (Jervis *et al.* 1993). Plant derived food and hosts may be located in different areas, therefore, depending on their hunger, parasitoids will be forced to change from host seeking to food searching (Lewis *et al.* 1998). Fecundity and longevity of *Diadegma insulare* (Cresson) (Hymenoptera:

Ichneumonidae) has been directly correlated to the diameter of flower corolla opening, indicating that the smaller parasitoids have a greater potential in accessing nectaries from a wide range of different flowers (Lewis *et al.* 1998). But according to Lewis *et al.* (1998), not all plant-derived food is suitable for parasitoids. Low parasitization levels can also be attributed to hosts escaping attack by phenological or spatial seclusion (Samways 1997).

There have been successful introductions of DBM parasitoids in some countries of the world, which led to the reduction in damage by DBM. Ooi (1992) reported that the introduction of DBM parasitoids, *Diadegma semiclausum* (Hymenoptera: Ichneumonidae) and *D. collaris,* in the Cameron Highlands, Malaysia, had an impressive impact in minimizing the pest population.

The introduction of *C. plutellae* and *O. sokolowskii* in the Caribbean islands has provided significant control of DBM (Alam 1992). *D. semiclausum* introduced in the central highlands of Taiwan in 1986, has provided adequate control of DBM, thus contributing to the reduction in chemical use by farmers (Talekar *et al.* 1992).

According to Yaseen (1978), the established *C. plutellae* and *D. collaris,* together with the endemic *O. sokolowskii* have diminished DBM damage by 80% in Zambia.

In establishing biological control programs, farmers should be involved from the implementation stage (Williamson 1998). Farmers understanding the ecological basis of the program will most likely cooperate in the establishment of the parasitoid and its ultimate conservation following establishment (Sastrosiswojo & Sastrodiharjo 1986, Talekar *et al.* 1990). Attempts at classical biological control programs have failed in the past in many countries because farmers did not clearly understand the efforts (Lim 1992). Farmers continued spraying thereby creating unfavorable conditions for the natural enemies (Lim 1992, Ooi 1992).

Less chemical insecticides than before are being used against DBM in Malaysia, Philippines, Australia, Indonesia, New Zealand and Taiwan where parasitoids have been established, because they can exert their full impact (Lim 1992, Talekar *et al.* 1992). By building biological control into pest management, natural enemies may soon become the suprising benefactors of a pesticide industry that had relegated them into obscurity (Waage 1992).

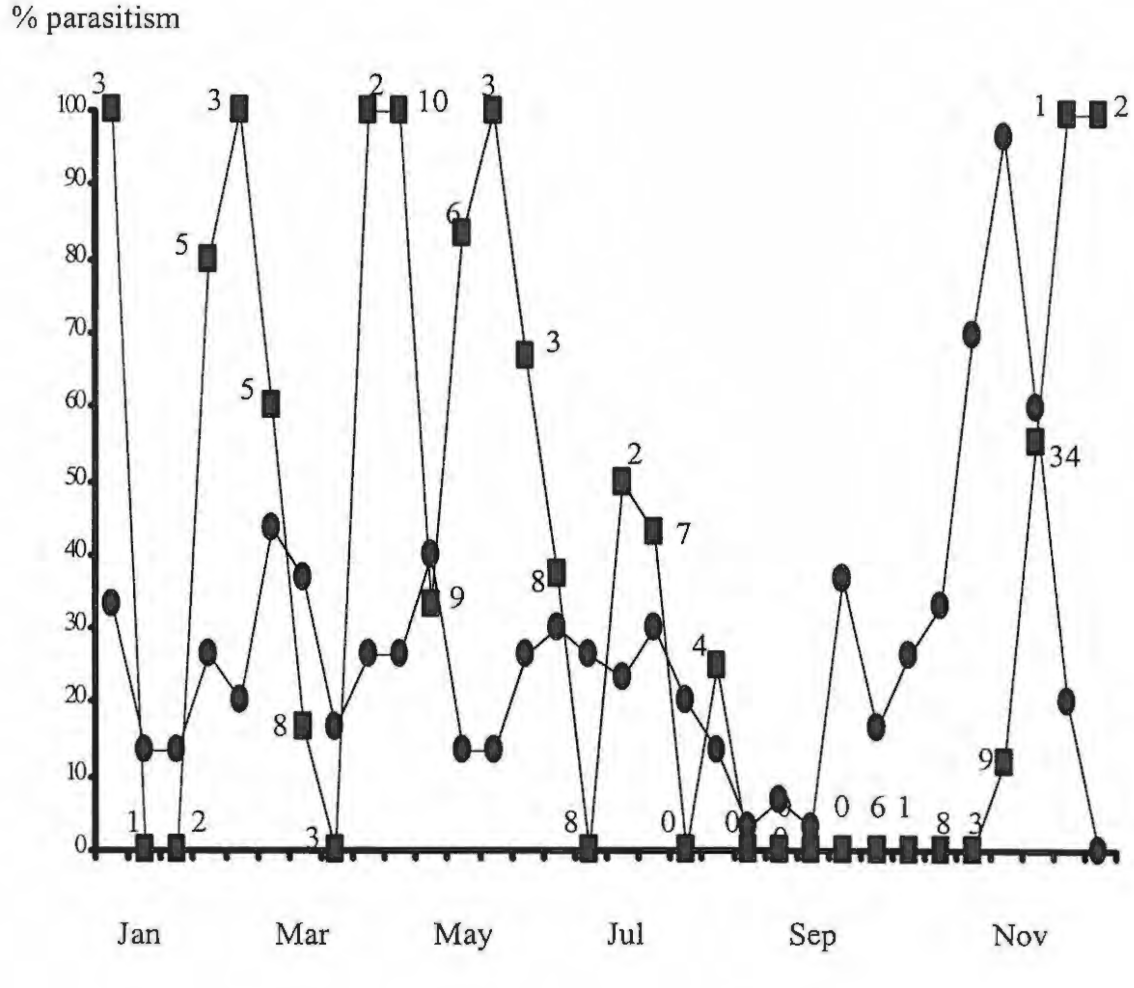

Fig. 4.1 Percentage parasitism of diamondback moth larvae and pupae (squares) and percentage plants infested (circles) in Bapsfontein during 1996.(Numbers represent sample size).

4.3 Discussions

DBM is establishing itself as a serious pest of canola in South Africa. It is difficult to control because of the genetic resistance to insecticides (Talekar & Shelton 1993, Tabashnik 1994). The larvae feed on leaves, stems, flowers and seedpods causing poor pod filling leading to reduced yield (1995).

Most insect pests of canola are also known pests of crucifer vegetables (Lamb 1989), but their status in this crop is unknown locally. The difference in the measure and importance per unit area between canola and cruciferous vegetable crops assures that the ecology of these pests and strategies adopted to control them will be substantially different (Lamb 1989).

The importance of an insect as a pest is not only distinguished by the vigour of its attack in a specific area, but also its dispersal and related loss within and between localities (Dent 1991).

The relationship between damage and seed production is difficult to determine because no threshold levels have been established, and the infestation levels cannot be directly correlated to subsequent yield (Dent 1991). Action thresholds based on the biology, damage to crop, and effects on yield (Evans & Scarisbrick 1994, Oudejans 1994), should be determined for several pests of canola in South Africa.

Insect pests cause different amounts of damage and add to yield loss of varying extents according to where and how they feed, and the quantity they consume (Dent 1991). Regular monitoring with synthetic sex pheromone traps and scouting, will identify potential problems enabling timely action, which will ensure an adequate plant stand and a successful crop.

DBM and other insects have been identified, and their status as key pests of canola determined, but the degree and damage potential of these insect pests in canola is unknown. The continuous planting of canola will result in more insect pests establishing themselves on the crop, and more severe attacks will be observed.

When a new crop is introduced in an area, experience in dealing with its pest problems is non-existent (Lane 1984) and the available information is from external sources. Therefore, management strategies discussed here are Australia, Canada and Europe.

4.3.1 Management of Insect Pests of Canola

Presently, insect pest management practices include monitoring pest populations, assessing the risk of damage to crops, and intervening with controls (biological, cultural and chemical control methods) when economic thresholds have been exceeded.

DBM, *B. brassicae, M. persicae, L. erysimi,* and other insects have been identified as key pests that are likely to cause serious economic damage to canola, therefore, devising suitable control techniques that would reduce their population is of utmost importance (Evans & Scarisbrick 1994). Pest management depends on decisions made by the farmer or grower on whether to apply control measures or not, based on the actual crop and pest situation in his/ her field. Understanding of the factors that influence the population dynamics of an insect species and the way in which the cropping systems differ from natural systems can provide an indication of strategies that should be engaged in the management of a pest (Dent 1991).

4.3.2 Monitoring

Monitoring techniques are integrated into a practical, regular program that forms the basis for decision-making (Dent 1991). The program reflects the biology and seasonality of the pests. Monitoring is one of the most important components of integrated pest management (Dent 1991, Evans & Scarisbrick 1994, Oudejans 1994). Sweep nets, sticky traps, and pheromone traps can be used to collect insects for both identification and population density information.

A more effective method of monitoring would be a system of counting and identifying the insects. Besides determining the distribution and abundance of crop pests, monitoring helps to detect when action threshold has been reached (Dent 1991, Evans & Scarisbrick 1994, Oudejans 1994). DBM adults were monitored with synthetic sex pheromone traps, and scouting the canola plant monitored the larval populations. Knowledge about the presence or absence of a pest is important in reducing the frequency of chemical pesticide application (Jones 1994).

4.3.3 Semiochemicals

Semiochemicals produced by insects can be successfully utilized as pest management tools (Dent 1991, Evans & Scarisbrick 1994, Oudejans 1994, Bentley *et al.* 1995, Pickett *et al.* 1997, Verkerk *et al.* 1998), as has been the case with sex pheromones for Lepidoptera (Jones 1994). These chemicals can be divided into two main groups, 1) pheromones which includes sex pheromones, alarm pheromones and aggregation pheromones, and 2) allelochemicals are divided into allomones, kairomones or synomones (Dent 1991, Oudejans 1994).

According to Teerling *et al.* (1993), western flower thrips alarm pheromone is a kairomone to its natural enemy, *Orius tristicolor* (Anthocoridae), and has been used to attract predators to crops. Synthetic pheromones could be used for attracting insect pests to insecticide treated areas of the crop (Teerling *et al.* 1993, Jones 1994), or attracting natural enemies to the crop (Dent 1991, Peng & Weiss 1992, Evans & Scarisbrick 1994, Oudejans 1994, Verkerk *et al.* 1998).

4.3.4 Transgenic crops

Bacillus thuringiensis (Bt.) is becoming an important tool in insect pest management (Tabashnik *et al.* 1997 b), due to its selective toxicity, rapid environmental degradation and vertebrate safety (Bauer 1995). Several subspecies of *Bt.* are effective against lepidopteran, dipteran and coleopteran insect pests (Stewart *et al.* 1996, Sharma *et al.* 2000). *Bt.* in the conventional way is not suitable, as it does not reach all parts of the plant where insects could be feeding (Evans & Scarisbrick 1994, Brousseau *et al.* 1999, Jackson 1999).

Transgenic plants express the toxin throughout the plant tissue; therefore, they may be suitable in reducing damage caused by pests (Evans & Scarisbrick 1994, Brousseau *et al.* 1999, Jackson 1999). However, pollinators such as honeybees are not affected by transgenic canola, because the transgene is not expressed in pollen and nectar (Jouanin *et al.* 1998).

4.3.5 Host plant resistance

Through plant breeding, selection and domestication, man has interfered with the defense mechanisms of plants (Teetes 1996). By understanding the interactions between insect pests and the crop, environmentally friendly and economically viable options to control insect pests can be devised. Reliance upon conventional pesticides has created serious problems such as insect resistance to pesticides, secondary pest outbreaks, and increased costs of production and environmental contamination (Smith 1997). The mechanism of resistance should be understood before the proportion of resistance in a plant can be determined (Smith 1997). Pest resistant cultivars could help in eliminating or limiting the use of environmentally disruptive synthetic chemicals (Gould 1988).

There are three types of genetic resistance namely: antibiosis, antixenosis and tolerance (Dent 1991, Teetes 1996, Al Ayedh 1997, Smith 1997). Antibiosis resistance affects the biology of the insect resulting in increased mortality or reduced longevity and reproduction of the insect (Dent 1991, Talekar & Shelton 1993, Teetes 1996, and Smith 1997). Antexenosis affects the behaviour of an insect and the plant is unsuitable for food and oviposition (Dent 1991, Teetes 1996, Al Ayedh 1997, Smith 1997*)*. Tolerance is the ability of the plant to withstand or recover from damage caused by insect pest abundance that could damage the susceptible host (Teetes 1996, Smith 1997). Insects habitually develop resistance to transgenic plants with one major gene resistance, because it (the plant) exerts a high selection pressure (Smith 1997). Therefore, horizontal resistance which is controlled by several polygenes and is highly stable (Smith 1997), is the best option when selecting for plant resistance.

Alternatively, a feeding deterrent could be inserted into the plant to present protection against all the crop's pests throughout the growing season (Evans & Scarisbrick 1994).

Glucosinolates are insect attractants and feeding stimulants for most of crucifer feeding insects (Evans & Scarisbrick 1994, Reed *et al.* 1989). The removal or reduction of these attractants from the canola plant through breeding, is another option that should be considered.

4.3.6 Inter-cropping

Increasing crop diversity by planting more than one plant species in the field suppresses pest outbreaks linked to monocultures (Endersby & Morgan 1991). Inter-cropping may increase the abundance of natural enemies because one of the intercropped plants may provide nectar or allelochemicals that may attract them (Sheehan 1986, Evans & Scarisbrick 1994, Verkerk *et al.* 1998), and reduce incidence of insects (Tingey & Lamont 1988, Dent 1991, Talekar & Shelton 1993). Understanding the mechanism involved in the reduction of pests in more diversified systems will help in choosing the correct combination of crops to plant. Insect pests use specific chemicals and plant cues to locate host plants (Prokopy & Owens 1978), however, in diversified crop field, the presence of other plants may mask these cues thereby disrupting the orientation of the pest in locating its host (Sheehan 1986).

4.3.7 Chemical control

Chemical pesticides are applied as a preventative treatment to protect crop plants against infestations by pests, or as a curative measure to destroy or limit population development of destructive organisms (Oudejans 1994). Generally, broad-spectrum pesticides are commonly used for insect pests of canola (Evans & Scarisbrick 1994), but they adversely affect beneficial insects. The best option would be to use a lure and kill method, because less pesticide is used to achieve the same level of control and deleterious effects on beneficial and non-target organisms are reduced (Jones 1994). The present chemical control means and method must be redesigned in order to delay the development of resistance, become suitable for an integrated approach and avoid harmful interactions with biological control agents and the environment (Oudejans 1994).

4.3.8 Integrated Pest Management

IPM employs all appropriate control strategies to reduce pest populations below economically damaging levels while minimizing negative impacts on the environment (Dent 1991, Oudejans 1994). Benefits typically include reduced production costs, an extension of the effective use period of pesticides, and protection of environment from pesticide contamination (Lim 1992). Regular monitoring is the key component of IPM and is the basis for improved decision-making regarding timing and selection of appropriate control strategies (Dent 1991). IPM components such as host plant resistance, biological control, monitoring, inter-cropping, and the use of selective chemical pesticides are the best options that can be employed in managing pests of canola.

CONCLUSION

Parasitoids play an important role in reducing DBM populations in South Africa. DBM parasitoids lagged during winter except for *C. plutellae*. In view of the dominant role of *C. plutellae* in parasitoid complex of DBM in South Africa, additional studies are required on this species for any consideration of control programs for this pest. The studies should consider the factors that are likely to continue to allow its success under variable field conditions experienced locally. Further studies and research need to be undertaken to identify the natural enemies of the other key pests of canola in this country. This will improve knowledge of their biology, ecology and phenology, assess their potential for control, improve knowledge of their population dynamics at various spatial scales and develop ways of conserving their populations and enhancing their effectiveness.

LITERATURE CITED

Alam, M. M. (1992). The diamondback moth and its natural enemies in Jamaica and other Caribbean islands, 233-43 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Al Ayedh, H. Y. (1997). ANTIXENOSIS: The Effect of Plant Resistance on Insect Behaviour. Insect Behaviour Review Article, 1-6 pp. www.colostate.edu/Depts/Entomology/en507/papers_1997/alayedh.html

Altieri, M. A. (1999). The Environmental Risks of Transgenic Crops: An Agroecological Assessment. *Biosafety Reviews* 5, (Issue 1& 2) 1-9 pp.

Ankersmit, G. W. (1953). DDT- Resistance in *Plutella maculipennis* (Curt.) (Lepidoptera) in Java. *Bulletin of Entomological Research* 44, 421-425.

Annecke, D. P., Moran, V. C. (1982). Insects and Mites of Cultivated Plants in South Africa, Butterworths, Durban, South Africa.

Azidah, A. A., Fitton, M. G., Quicke, D. L. (2000). Identification of the *Diadegma* species (Hymenoptera: Ichneumonidae, Campopleginae) attacking the Diamondback moth *Plutella xylostella. Bulletin of Entomological Research* 90, 375-389.

Baker, P. B., Shelton, A. M., Andaloro, J. T. (1982) Monitoring of Diamondback Moth (Lepidoptera: Yponomeutidae) in Cabbage With Pheromones. *Journal of Economic Entomology* 75, 1025-1028.

Bauer, L. S. (1995). Resistance: A Threat to the Insecticidal Crystal Proteins of *Bacillus thuringiensis. Florida Entomologist* 78, (3) 414-443.

Begum, S., Tsukuda, R., Fujisaki, K., Nakasuji, F. (1996). The Effects of Wild Cruciferous Host Plants on Morphology, Reproductive, Performance and Flight Activity in the Diamondback Moth, *Plutella xylostella* (Lepidoptera: Yponomeutidae). *Research on Population Ecology* 32, (2) 257-263.

Bentley, J. W., Castano-Zapata, J., Andrawts, K. L. (1995). World Integrated Pathogen and Pest Management, and Sustainable Agriculture in Developing World. *Advances in Plant Pathology* 11, 249-276.

Berlandier, F. (1999). Managing Aphids in Canola. Farmnote 45/99.

Bigger, D. S., Chaney, W. A. (1998). Effects of *Iberis umbellata* (Brassicaceae) on Insect Pests of Cabbage and on Potential Biological Control Agents. *Environmental Entomology* 27, (1) 161-167.

Boland, N. P., Room, P. M. (1983). Estimating Population Density of a *Cyrtobagous* sp. (Coleoptera: Curculionidae) 0n the Floating Weed *Salvinia* Using Berlese Funnels. *Journal of Australian Entomological Society* 22, 353-354.

Bonnemaison, L. (1965). Insect Pests of Crucifers and their Control. *Annual Review Entomology* 10, 233-56.

Bracken, G. K. (1987). Relation Between Pod Damage Caused by Larvae of Bertha Armyworm, *Mamestra configurata* Walker (Lepidoptera: Noctuidae), and Yield Loss, Shelling, and Seed Quality in Canola. *Canadian Entomologist* 119, 365-369.

Bracken, G. K., Bucher, G. E. (1986). Yield Loss in Canola Caused by Adult and Larval Flea Beetles, *Phylotreta cruciferae* (Coleoptera: Chrysomelidae). *Canadian Entomologist* 118, 319-324.

Britton, E. B. (1973). Coleoptera 495-621 pp. In: The Insects of Australia, A Textbook for Students and Research Workers, Commonwealth Scientific and Industrial Research Organization, Australia.

Broatch, J. S., Vernon, R. S. (1997). Comparison of Water Pan Traps and Sticky Traps for Monitoring *Delia* sp. (Diptera: Anthomyiidae) in Canola. *Canadian Entomologist* 129, 979-984.

Brousseau, R., Masson, L., Hegedus, D. (1999). Insecticidal Transgenic Plants: Are they Irresistible. *AgBiotech* 1, 17 pp. CAB International.

Bucci, R., Gould, F. (1997). Impact of Intraplot Mixtures of toxic and nontoxic plants on the population Dynamics of Diamondback Moth (Lepidoptera: Plutellidae) and its Natural Enemies. *Journal of Economic Entomology* 90, (2) 241-251.

Bunting, G. D., Raymer, P. L. (1994). Pest Status of Aphids and Other Insects in Winter Canola in Georgia. *Journal of Economic Entomology* 87, (4) 1097- 1104.

Bunting, G. D., McCaffrey, J. P., Raymer, P. L., Romero, J. (1995). Quality and germination of rapeseed and canola seed damaged by adult cabbage seedpod weevil, *Ceutorhynchus assimilis* (Paykull) (Coleoptera: Curculionidae). *Canadian Journal of Plant Science* 75, 539-541.

Burgess, L., Weegar, H. H. (1988). Thrips (Thysanoptera) in Canola Crops in Saskatchewan. *Canadian Entomologist* 120, 815-819.

Butts, R. A., McEwen, F. L. (1981). Seasonal Populations of Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae), In Relation to Day-Degree Accumulation. *Canadian Entomologist* 113, 127-131.

Charleston, D. S., Kfir, R. (2000). The Possibility of using Indian mustard, *Brassica juncea,* as a Trap Crop for Diamondback Moth, *Plutella xylostella*, in South Africa. *Crop Protection* 19, 455-460.

Chen, C., Chang, S., Chen, L., Hou, R. F. (1996). Deterrent Effect of Chinaberry Extract on Oviposition of DBM *P. xylostella* L., (Lep. Yponomeutidea). *Journal of Applied Entomology* 120, (3) 165-169.

Chen, C. N., Su, W. Y. (1986). Ecology and Control Thresholds of Diamondback Moth on Crucifers in Taiwan 415-421 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Cheng, E. Y. (1986). The Resistance, Cross-Resistance and Chemical Control of Diamondback Moth in Taiwan, 329-345 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Chiang, H. C. (1980). Biological Control as a strategy in Integrated Pest Management. *Plant Protection Bulletin* 22, 215-221.

Chilcutt, C. F., Tabashnik, B. E. (1997). Host-mediated competition Between the Pathogen *Bacillus thurigiensis* and the parasitoid *Cotesia plutellae* of the Diamondback Moth (Lepidoptera: Plutellidae*). Environmental Entomology* 26, (1) 39-45.

Chilcutt, C. F., Tabashnik, B. E. (1999). Effects of *Bacillus thuringiensis* on Adult *Cotesia plutellae* (Hymenoptera: Braconidae), a Parasitoid of the Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Biocontrol Science and Technology* 9, 435-440.
Chisholm, M. D., Underhill, E. W., Steck, W. F. (1979). Field trapping of the Diamondback Moth, *Plutella xylostella,* Using Synthetic Sex Attractants. *Environmental Entomology* 8, 516-518.

Chua, T. H., Ooi, P. A. C. (1986). Evaluation of Three Parasites in the Biological Control of Diamondback Moth in the Cameron Highlands, Malaysia, 173-184 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Cole, R. A. (1997). The Relative Importance of Glucosinolates and amino acids to the development of two aphid pests *Brevicoryne brassicae* and *Myzus persicae* on wild and cultivated brassica species. *Entomologia Experimentalis et Applicata* 85, 121-133.

Colton, R. T., Sykes, J. D. (1992). Canola, Agfact P5.2.1, 4 fourth edition, NSW Agriculture.

Common, I. F. B. (1973). Lepidoptera, 765-866 pp. In: The Insects of Australia, A Textbook for Students and Research Workers, Commonwealth Scientific and Industrial Research Organization, Australia.

Cruz, C., Segarra, A. (1992). Potential for Biological Control of Crop Pests in the Caribbean. *Florida Entomologist* 75, (4) 409-13.

Daly, H. V., Doyen, J. T., Ehrlich, P. R. (1981). Introduction to Insect Biology and Diversity. International Student Edition. McGraw-Hill International Book Company.

DeBach, P., Rosen, D., 2nd ed. (1991). Biological Control by Natural Enemies. Cambridge University Press.

Dennill, G. B., Pretorius, W. L. (1995). The status of Diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae), and its parasitoids on Cabbage in South Africa. *African Entomology* 3, (1) 65-71.

Dent, D. (1991). Insect Pest Management. CAB International, Wallingford.

Downey, R. K. (1983). The Origin and Description of the Brassica Oilseed Crops 1-20 pp. In: Kramer, J. K. G., Sauer, F. D., Pidgen, W. J. (eds.). High and Low Euric Acid Rapeseed Oils Production, Usage, Chemistry, and Toxicological Evaluation, New York: Academic.

Endersby, N. M., Morgan, W. C. (1991). Alternatives to Synthetic Chemical Insecticides for Use in Crucifer Crops. *Biological Agriculture and Horticulture* 8, 33-52.

Evans, K. A., Scarisbrick, D. H. (1994). Integrated insect pest management in Oilseed Rape crops in Europe. *Crop Protection* 13, (6) 403-412.

Goodwin, S., Dantharayana, W. (1984). Flight activity of *Plutella xylostella* L. (Lepidoptera: Yponomeutidae). *Journal of Australian Entomological Society* 23, 235-240.

Goudegnon, A. E., Kirk, A. A., Schiffers, B., Bordat, D. (2000). Comparative Effects of Deltamethrin and Neem kernel solution treatments on Diamondback moth and *Cotesia plutellae* (Hymenoptera: Braconidae) parasitoid populations in Cotonou peri-urban area in Benin. *Journal of Applied Entomology* 124, 141-144.

Gould, F. (1988). Evolutionary Biology and Genetically Engineered Crops. *BioScience* 38, (1) 26-33.

Gunn, D., (1917). The small Cabbage Moth. *Bulletin of the Department of Agriculture,* Union of South Africa 8, 1-10.

Harcourt, D. G. (1957). Biology of the Diamondback Moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in Eastern Ontario II. Life History, Behaviour, And Host Relationships. *Canadian Entomologist* 89, 554-564.

Harcourt, D. G. (1960). Biology of diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in Eastern Ontario III. Natural Enemies. *Canadian Entomologist* 92, 419-428.

Hardy, J. E. (1938). *Plutella maculipennis* Curt., its Natural Enemies and Biological Control in England. *Bulletin of Entomological Research* 29, 343-372.

Henning, S. F. (1985). Lepidoptera, 341-392 pp. In: Scholtz, C. H., Holm, E. (eds.). Insects of Southern Africa, Butterworths Publishers, Durban.

Hermawan, W., Nakajima, S., Tsukuda, R., Fujisaki, K., Nakasuji, F. (1997). Isolation of an Antifeedant Compound from *Andrographis paniculata* (Acanthaceae) against the Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Applied Entomology and Zoology* 32, (4) 551-559.

Hill, T. A., Foster, R. E. (2000). Effect of Insecticides on the Diamondback Moth (Lepidoptera: Plutellidae) and Its Parasitoid *Diadegma insulare* (Hymenoptera: Ichneumonidae). *Journal of Economic Entomology* 93, (3) 763-768.

Hokkanen, H. M. T. (1991) Trap Cropping in Pest Management. *Annual Review Entomology* 36, 119-38

Howatt, K. (1994). *Azadirachta indica*: One Tree's Arsenal against Pests. http://www.colostate.edu/Depts/Entomology courses/en570/papers_1994/howatt.html.

Idris, A. B., Grafius, E. (1995). Wildflowers as Nectar Sources for *Diadegma insulare* (Hymenoptera: Ichneumonidae), a Parasitoid of Diamondback Moth (Lepidoptera: Yponomeutinidae). *Environmental Entomology* 24, 1726-1735.

Idris, A. B., Grafius, E. (1997). Nectar-Collecting Behavior of *Diadegma insulare* (Hymenoptera: Ichneumonidae), a Parasitoid of Diamondback Moth (Lepidoptera: Plutellidae). *Environmental Ecology* 26, (1) 115-120.

Jackson, T. A. (1999). Factors in the Success and Failure of Microbial Control Agents for Soil Dwelling pests. *Integrated Pest Management Reviews* 4, 281-285.

Jervis, M. A., Kidd, N. A. C. (1986). Host-feeding strategies in Hymenopteran Parasitoids. *Biology Review* 61, 395-434.

Jervis, M. A., Kidd, N. A. C., Fitton, M. G., Huddleston, T., Dawah, H. A. (1993). Flower visiting by Hymenopteran parasitoids. *Journal of Natural History* 27, 67-105.

Jones, O. T. (1994). Semiochemicals: The Current Use of Pheromones and Other Semiochemicals in the Integrated Management of Insect Pests. *Pesticide Outlook* 26-31, August Issue.

Jouanin, L., Girard, C., Bonade-Bottino, M., Metayer, M., Nizou, A. L. P., Lerin, J., Delegue, M. H. P., le-Metay, M. (1998). Impact of Transgenic Oilseed rape Expressing Proteinase Inhibitors on Coleopteran pests and Honeybees. *Cahiers-Agricultures* 7, (6) 531-536.

Justus, K. A., Mitchell, B. K. (1996). Oviposition Site Selection by the Diamondback Moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). *Journal of Insect Behavior* 9, (6) 887-898.

Kfir, R. K. (1996). Diamondback Moth natural enemies in South Africa. *Plant Protection News* 43, 20-21.

Kfir, R. K. (1997) The Diamondback Moth with Special Reference to its Parasitoids in South Africa 54-60 pp. In: Sivapragasam, A., Loke, W. H., Hussan, A. K., Lim, G. S. (eds.). The Management of Diamondback Moth and Other Crucifer Pests Proceedings of the Third International Workshop, Kuala Lumpur, Malaysia.

Kfir, R. K. (1998). Origin of the Diamondback moth (Lepidoptera: Plutellidae). *Annals of the Entomological Society of America* 91, (2) 164-167.

Kneen, B. (1992). The Rape of Canola. Toronto: N. C. Press.

Lamb, R. J. (1984). Effects of Flea Beetles, *Phyllotreta* sp. (Chrysomelidae: Coleoptera), on the Survival, Growth, Seed Yield and Quality of Canola, Rape and Yellow Mustard. *Canadian Entomologist*, 116: 269-80.

Lamb, R. J. (1989). Entomology of Oilseed Brassica Crops. *Annual Review of Entomology* 34, 211-229.

Lane, A. B. (1983). Benefits and Hazards of New Crops: Oilseed Rape in the U.K. *Agriculture, Ecosystems and Environment* 10, 299-309.

Lane, A. B. (1984). An Inquiry into the Response of Growers to Attacks by Insect Pests: In Oilseed Rape (*Brassica Napus* L.), a Relatively New Crop in the United Kingdom. *Protection Ecology* 7, 73-78.

Lewis, W. J., Stapel, J. O., Cortesero Anne Marie, Takasu, K. (1998). Understanding How Parasitoids Balance Food and Host Needs: Importance to Biological Control. *Biological Control* 11, 175-183.

Lim, G. S. (1986). Biological Control of Diamondback Moth, 159-171 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Lim, G. S. (1992). Integrated Pest Management of Diamondback Moth: Practical Realities, 565-576 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Liu, M. Y., Tzeng Y. J., Sun, C. N. (1981). Diamondback moth Resistance to Several Synthetic Pyrethroids. *Journal of Economic Entomology* 74, 393-396.

Madriaga, C. S., Gabriel, B. P. (1996). Abundance of Diamondback Moth and its Natural Enemies in Different Cabbage-Based Cropping Systems. *Philippine Journal of Crop Science* 20, (1) 1-21 pp.

Magallona, E. D. (1986). Developments in Diamondback Moth Management in the Philippines, 423-435 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Marsh, H. O. (1917). Life History of *Plutella maculipennis* (Diamondback Moth). *Journal of Agricultural Research* 10, 1-10.

Mitchell, E. R., Hu, G. Y., Okine, J. S. (1997). Diamondback moth infestation and parasitism by *Diadegma insulare* in collards and adjacent cabbage fields. *Florida Entomologist* 80, (1) 54-61.

Muhamad, O., Tsukuda, R., Oki, Y., Fujisaki, K.,Nakasuji, F. (1994) Influences of Wild Crucifers on Life History Traits and Flight Ability of the Diamondback Moth, *Plutella xylostella* (Lepidoptera: Yponomeutidae). *Research on Population Ecology* 36, (1) 53-62.

Mustata, G. (1992). Role of Parasitoid Complex in Limiting the Population of Diamondback Moth in Moldavia, Romania, 203-211 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Nakahara, L. M., McHugh, J. J. J., Otsuka, C. K., Funasaki, G. Y., Lai, P.Y. (1986) Integrated Control of Diamondback Moth and other Insect Pests Using an Overhead

Sprinkler System, an Insecticide, and Biological Control Agents on Watercress in Hawaii, 403-413 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Nilsson, C. (1987). Yield Losses in Summer Rape Caused by Pollen Beetles (*Meligethes* sp.). *Swedish Journal of Agricultural Research* 17, 105-111.

Oberprieler, R. G. (1985). Caraboidea 192-198 pp. In: Scholtz, C. H., Holm, E. (eds.). Insects of Southern Africa, Butterworths, Durban.

Ooi, P. A. C. (1992). Role of Parasitoids in Managing Diamondback Moth in the Cameron Highlands, Malaysia, 255-262 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Oudejans, J. H. (1994). Agro-Pesticides, Properties and Functions in Integrated Crop Protection. United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Bangkok, Thailand.

Pawar, D. B., Lawande, K. E. (1995). Effects of Mustard as a Trap Crop for Diamondback Moth on Cabbage. *Journal of Maharashtra Agricultural University* 20, (2) 185-186.

Peng, C., Weiss, M. J. (1992). Evidence of an Aggregation Pheromone in the Flea Beetle, *Phyllotreta cruciferae* (Goeze) (Coleoptera: Chrysomelidae). *Journal of Chemical Ecology* 18, (6), 875-884.

Pickett, J. A., Wadhams, L. J., Woodcock, C. M. (1997). Developing Sustainable Pest Control from Chemical Ecology. *Agriculture, Ecosystems & Environment* 64, 149-156.

Prokopy, R. J., Owens, E. D. (1978). Visual Generalist and Visual Specialist Phytophagous Insects: Host Selection Behavior and Application Management. *Entomologia Experimentalis et Applicata* 24, 409-420.

Ramachandran, S., Buntin, G. D., All, J. N., Raymer, P. L. (1998). Diamondback Moth (Lepidoptera: Plutellidae) Resistance of *Brassica napus* and *B. oleracea* Lines with Differing Leaf Characteristics. *Journal of Economic Entomology* 91, (4) 987-992.

Reed, E. M. (1973). Thysanoptera 458-464 pp. In: The Insects of Australia, A Textbook for Students and Research Workers, Commonwealth Scientific and Industrial Research Organization, Australia.

Reed, K. A., Pivnick, Underhill, E. W. (1989). Identification of Chemical Oviposition Stimulants for the Diamondback moth, *Plutella xylostella*, Present in three species of Brassicaceae. *Entomologia Experimentalis et Applicata* 53, 277-286.

Rejesus, B. M., Inocencio, E. L., Fajardo, G. P., Cardona, E.V., Eusebio, J. E. (1996). Parasitoid -based Management of Diamondback Moth *Plutella xylostella* (L.) on crucifers in the Philippines. *Philippine Journal of Crop Science* 20, (1) 1-4 pp.

Riek, E. F. (1973). Hymenoptera 867-959 pp. In: The Insects of Australia, A Textbook for Students and Research Workers, Commonwealth Scientific and Industrial Research Organization, Australia.

Robertson, P. L. (1939). Diamondback Moth Investigation in New Zealand. *New Zealand Journal of Science and Technology 20, 330-64.*

Rosen, D., DeBach, P. (1992). Foreign Exploration: The Key to Classical Biological Control. *Florida Entomologist* 75, (4) 409-15.

Roush, R. T. (1994). Managing Pests and Their Resistance to *Bacillus thuringiensis:* Can Transgenic Crops Be Better Than Sprays? *Biocontrol Science and Technology* 4, 501-516.

Samways, M. J. (1997). Classical Biological Control and Biodiversity Conservation: What risks are we prepared to accept? *Biodiversity and Conservation* 6, 1309-1316.

Sastrosiswojo, S., Grey, G. (1996). Biological Control of the Diamondback Moth under Indonesia's National IPM program. Biological Pest Control in Systems of Integrated Pest Management. Proceedings of an International Symposium on," The Use of Biological Control Agents under Integrated Pest Management". Taipei, Taiwan: FFTC ASPAC, 172-177 pp.

Sastrosiswojo, S., Sastrodihardjo, S. (1986). Status of Biological Control of Diamondback Moth by introduction of parasitoid *Diadegma eurocephaga* in Indonesia, 185-194 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Scholtz, C. H., Holm, E. (1985). Insects of Southern Africa, Butterworths, Durban.

Schuler, T. H., Potting, R. P. J., Denholm, I., Poppy, G. M. (1999). Parasitoid Behaviour and Bt Plants. *Nature* 4, 825-826, London.

Sereda, B., Basson, N. C. J., Marais, P. (1997). Bioassay of insecticide resistance in *P. xylostella* in South Africa. *African Plant Protection* 3, (2) 67-72.

Sharma, H. C., Sharma, K. K., Seethrama, N., Ortiz, R. (2000). Prospects for Using Transgenic resistance to Insects in Crop Improvement. *Electronic Journal of Biotechnology* 3, (2) 22 pp.

Sheehan, W. (1986). Responses by Specialist and Generalist Natural Enemies to Agroecosystem Diversification: A Selective Review. *Environmental Entomology* 15, 456-461.

Shelton, A. H., Perez, C. J., Tang, J. D., Vandenberg, J. D. (1997). Prospects for Novel approaches Towards Management of the Diamondback moth 17-20 pp. In: Sivipragasam, A., Loke, W. H., Hussan, A. K., Lim, G. S. (eds.). The Management of Diamond Moth and Other Crucifer Pests: Proceedings of the Third International Workshop, Kuala Lumpur, Malaysia, Malaysian Agricultural Research and Development Institute, and Malaysian Plant Protection Society.

Skaife, S. H. (1979). African Insect Life, Struik, Cape Town.

Smith, C. (1997). Host Plant Resistance to Insects. http://kali.usask.ca/bio364/essay97. htm

Srinivasan, K., Moorthy, P. N. K. (1991). Indian Mustard as a Trap crop for Management of major Lepidopterous Pests on Cabbage. *Tropical Pest Management* 37, (1) 26-32.

Srinivasan, K., Moorthy, P. N. K. (1992). Development and Adoption of Integrated Pest Management for Major Pests of Cabbage using Indian Mustard as a Trap Crop, 511-520 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Stewart, C. N. Jr., Adang, M. J., All, J. N., Raymer, P. L., Ramachandran, S., Parrot, W. A., Ramachandran, S. (1996). Insect Control and Dosage Effects in Transgenic Canola containing a synthetic *Bacillus thurigiensis* cryIAc gene. *Plant Physiology* 112, (1) 115-120.

Sun, C. N., Wu, T. K., Chen, J. S., Lee, W. T. (1986). Insecticide Resistance in Diamondback Moth, 359-371 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Tabashnik, B. E. (1994). Evolution of Resistance to *Bacillus thuringiensis. Annual Review of Entomology* 39, 47-79.

Tabashnik, B. E., Cushing, N. L., Finson, N., Johnson, M. W. (1990). Field Development of Resistance to *Bacillus thuringiensis* in Diamondback Moth (Lepidoptera: Plutellidae). *Journal of Economic Entomology* 83, 1671-1676.

Tabashnik, B. E., Liu, Y. B., Malvar, T., Masson, D. G. H. L., Ballester, V., Granero, F. Ménsua, J. L., Ferré, J. (1997 a). Global variation in the genetic and biochemical basis of diamondback moth resistance to *Bacillus thuringiensis.* Proceedings of the National Academy of Sciences 94, 12780-12785.

Tabashnik, B. E., Liu, Y. B., Finson, N., Masson, L., Heckel, D. G. (1997 b). One gene in Diamondback Moth Confers Resistance to four *Bacillus thuringiensis* toxins. Proceedings of the National Academy of Sciences 94, 1640-1644.

Talekar, N. S. (1996). Biological Control of Diamondback Moth in Taiwan. A review. *Plant Protection Bulletin-Taipei* 38, (3) 167-189.

Talekar, N. S., Lee, S. T., Huang, S. W. (1986). Intercropping and Modification of Irrigation method for the control of Diamondback moth, 145-155 pp. In: Talekar, N. S., Griggs, T.D., (eds.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the First International Workshop. Shanhau, Taiwan, Asian Vegetable Research and Development Centre.

Talekar, N.S., Shelton, A. M. (1993). Biology, Ecology, and Management of Diamondback Moth. *Annual Review Entomology* 38, 275-301.

Talekar, N. S., Yang, J. C. (1991). Characteristics of Parasitism of Diamondback moth by Two Larval Parasites. *Entomophaga* 36, 95-104.

Talekar, N. S., Yang, J. C., Liu, M. Y., Ong, P. C. (1990). Use of Parasitoids to Control Diamondback Moth, *Plutella xylostella* (L.) 106-114 pp. In: Mochida, O., Kiritani, K. (eds.) The Use of Natural Enemies to Control Agricultural Pests: Food and Fertilizer Technology Centre for Asian and Pacific Region, Taipei, Taiwan.

Talekar, N. S., Yang, J. C., Lee, S. T. (1992). Introduction of *Diadegma semiclausum* to control Diamondback Moth in Taiwan, 263-270 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Teerling, C. R., Gillespie, D. R., Borden, J. H. (1993). Utilization of Western flower Thrips Alarm Pheromone as a Prey-Finding Kairomone by Predators. *Canadian Entomologist* 125, 431-437.

Teetes, G. L. (1996). Plant Resistance to Insects: A Fundamental Component of IPM. http://ipmworld.umn.edu/chapters/teetes.htm

Tingey, W. M., Lamont, W. J. Jr. (1988) Insect Abundance in the Field of Beans altered by Intercropping. *Bulletin of Entomological Research* 78, 527-535.

Ullyett, G. C. (1947). Mortality factors in Populations of *Plutella maculipennis* Curtis (Tinedae: Lepidoptera), and their Relation to the Problem of Control. Entomology Memoirs, Department of Agriculture and Forestry, Union of South Africa 2, 77-202.

Van Driesche, R. G., T. S. Bellows. (1996) Biological Control, Chapman & Hall ITP, New York.

Verkerk, R. H. J., Wright, D. J. (1993). Biological Activity of Neem Seed Kernel Extracts and Synthetic Azadirachtin against Larvae of *Plutella xylostella* L. *Pesticide Science* 37, 83-91.

Verkerk, R. H. J., Wright, D. J. (1996). Multitrophic Interactions and Management of Diamondback Moth: a review. *Bulletin of Entomological Research* 86, 205-216.

Verkerk, R. H. J., Leather, S. R., Wright, D. J. (1998). The Potential for Manipulating Crop-Pest-Natural Enemy Interactions for Improved Insect pest Management. *Bulletin of Entomological Research* 88, 493-501.

Waage, J. K. (1992). Biological Control in the year 2000, 329-340 pp. In: Aziz, A., Kadir, S. A., Barlow, H. S. (eds). Pest Management and the Environment in 2000, CAB International, Wallingford.

Waage, J. (1996). " Yes, But Does It Work in the Field? " The Challenge of Technology Transfer in Biological Control. *Entomophaga* 41, (3/4) 315-332

Waage, J. K., Cherry, A. (1992). Quantifying the Impact of Parasitoids on Diamondback Moth, 245-253 pp. In: Talekar, N. S. (ed). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Wheatley, G. A., Finch, S. (1984). Effects of Oilseed Rape on the Status of Insect Pests of Vegetable Brassicas. British Crop Protection Conference- Pests and Diseases: National Research Station, Wellesbourne, Warwick, England, 807-814 pp.

Williams, I. H., Free, J. B. (1979). Compensation of oil-seed rape (Brassica napus L.) plants after damage to their buds and pods. *Journal of Agricultural Science* 92, 53-59.

Williamson, S. (1998). Understanding Natural Enemies: A Review of Training and Information in the Practical Use of Biological Control. *Biocontrol News and Information* 19, (4) 117-126.

Winfield, A. L. (1992). Management of Oilseed rape Pests in Europe. *Agricultural Zoology Reviews* 5, 51-95.

Woodward, T. E., Evans, J. W., Eastop, V. F. (1973). Hemiptera, 387-457 pp. In: The Insects of Australia, A Textbook for Students and Research Workers, Commonwealth Scientific and Industrial Research Organization, Australia.

Wyman, J. A. (1992). Management Approaches for Cruciferous Insect Pests in Central North America, 503-509 pp. In: Talekar, N. S. (ed.). Management of Diamondback Moth and Other Crucifer Pests: Proceedings of the Second International Workshop, Tainan, Taiwan, Asian Vegetable Research and Development Centre.

Yaseen, M. (1978). The Establishment of two parasites of Diamondback moth *Plutella xylostella* (Lepidoptera: Plutellidae) in Trinidad, W. I. *Entomophaga* 23, 111-114.