Seasonal phenology of the diamondback moth, *Plutella xylostella* (L.), (Lepidoptera: Plutellidae), and its parasitoids on canola, *Brassica napus* (L.), in Gauteng province, South Africa

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Canola, *Brassica napus* L. (Brassicaceae), is a relatively new crop in South Africa. Several insect pests, including diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), that attack cruciferous vegetables, also attack canola. The aims of this study were to determine the seasonal phenology of *P. xylostella* populations on canola, and the composition, relative abundance and seasonal phenology of parasitoids attacking *P. xylostella* on this crop. Diamondback moth adults were monitored with synthetic sex-pheromone traps. Larval and pupal populations of *P. xylostella* were monitored weekly for three years at Bapsfontein and Rietondale in Gauteng province. Samples of diamondback moth larvae, pupae and parasitoid cocoons were collected and transported to the laboratory. Parasitoids that emerged were identified and their incidence recorded. Berlese funnel catches were used as an indicator of the accuracy of the visual counts. The infestation level of *P. xylostella* larvae was high from May to August at Rietondale, while at Bapsfontein it was high from September to December. There was a high correlation ($r = 0.79$, $P < 0.001$) between pheromone trap catches and subsequent larval infestations at Bapsfontein. The pheromone traps indicated that diamondback moth adults were present throughout the year. Berlese funnel catches indicated that a large number of larvae, especially first instars, were overlooked during visual plant scouting. Parasitism rates were often very high, reaching 90–100 %. The following parasitoids were recorded from field-collected *P. xylostella*: the larval parasitoids *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae) and *Apanteles halfordi* Ullyett (Hymenoptera: Braconidae), the larval/pupal parasitoids *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae) and *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae), the pupal parasitoid *Diadromus collaris* (Gravenhorst) (Hymenoptera: Ichneumonidae), and the hyperparasitoids *Mesochorus* sp. (Hymenoptera: Ichneumonidae) and *Pteromalus* sp. (Hymenoptera: Pteromalidae). *Cotesia plutellae* was the most abundant parasitoid throughout the study.

Key words: *Plutella xylostella, Cotesia plutellae, Brassica napus,* canola, parasitoid, South Africa.

INTRODUCTION

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 can be successfully produced in marginal areas of temperate regions because of its ability to survive and grow at relatively low or high temperatures (Downey 1983; Kneen 1992).

Canola was introduced in South Africa in 1994 when 5000 ha was planted in the first year. In 1999 25 000 ha was planted (Arcoll, personal communication) indicating its acceptance as a crop in South Africa.

Since canola is a relatively new crop in South Africa, the insect pests of this crop have not been recorded in the country. Amid the many insect pests that attack canola, the globally distributed crucifer specialist, diamondback moth (*Plutella xylostella* (L.) (Lepidoptera: Plutellidae)), has established itself as a major pest (Hardy 1938; Alam 1992). The larvae of *P. xylostella* feed on canola leaves, on growing tips during the bolting stage, and on flowers and pods during the setting stages, causing poor pod filling and reducing yield (Lamb 1989; Justus & Mitchell 1996; Ramachandran *et al.* 1998).

Plutella xylostella was first recorded in South Africa more than 80 years ago (Gunn 1917). Ullyett (1947) studied the mortality factors of the pest around Pretoria, Gauteng province, Dennill & Pretorius (1995) and Kfir (1996, 1997, 1998) studied the status of *P. xylostella* and its parasitoids in the Brits area, North West Province, Waladde *et al.*

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(2001) and Smith & Villet (in press) studied the parasitoids associated with *P. xylostella* in the Eastern Cape Province, while Sereda *et al.* (1997) surveyed for resistance of this pest to insecticides.

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 (Robertson 1939). Owing to its adaptability, *P. xylostella* can establish itself in almost every climatic zone of the world.

Plutella xylostella may cause significant yield losses, leading to application of insecticides against the pest, which may result in the acceleration of resistance development (Kfir 1997). *P. xylostella* was the first insect pest to develop resistance to toxins of the bacterium *Bacillus thuringiensis* Berliner (Tabashnik *et al.* 1990) and eventually became resistant to every chemical insecticide used against it in the field (Talekar & Shelton 1993). In South-East Asia, to control the pest, farmers used mixtures of insecticides, increased dosages and sprayed more often to overcome insecticide resistance. This abuse of insecticides led to environmental degradation and excessive residue on the crop products (Talekar *et al.* 1990).

The pest status of *P. xylostella* in South Africa is lower than in other countries with similar climates (Kfir 1997), but because of indiscriminate pesticide use, local *P. xylostella* populations are showing significant signs of resistance to insecticides (Sereda *et al.* 1997).

In South Africa, as is the case in many other countries, chemical insecticides still provide the mainstay of *P. xylostella* control. Because of the economic potential of canola in South Africa, the threat of *P. xylostella* resistance to insecticides, insecticide residues on the products and in the environment, and need for information on which to base control and resistance management strategies, alternative, environmentally friendly *P. xylostella* management strategies are needed.

The aims of this study were to determine the seasonal phenology of *P. xylostella* populations on canola, and the composition, relative abundance and seasonal phenology of parasitoids attacking *P. xylostella* on this crop.

MATERIAL AND METHODS

The experimental sites were at Bapsfontein (Monsanto experimental farm, 25°09′S 28°41′E, altitude 1600 m) and at Rietondale (ARC-PPRI experimental farm, 25°44′S 28°13′E, 1333 m). Both sites are located in the summer rainfall region of South Africa in Gauteng province. Canola was planted twice a year in 1000 m^2 plots to ensure continuous sampling throughout the three-year study period (1996–1998). No insecticides were applied on the study plots. At Rietondale insect infestation was low during 1997 and plant sampling data is not presented.

Plant sampling

At weekly intervals, 30 plants were randomly selected, scouted and the numbers of *P. xylostella* larvae, pupae and parasitoid cocoons recorded for each plant. Samples of *P. xylostella* larvae, pupae and parasitoid cocoons were collected in Petri dishes, sealed, placed in a cooler box and transported to the laboratory. Larvae were placed singly in sealed Petri dishes and provided with a fresh portion of cabbage leaf. The leaves were replaced every second day until *P. xylostella* pupae or parasitoid cocoons formed. Field-collected pupae and parasitoid cocoons were also placed singly in sealed glass vials until moths or parasitoids emerged. The parasitoids that emerged were identified, and their seasonal and relative abundance recorded. The larvae that escaped or died of unknown causes, and pupae that failed to emerge, were excluded from the calculation of parasitism. Voucher specimens of parasitoids have been deposited in the National Collection of Insects, Biosystematics Division, ARC-Plant Protection Research Institute, Pretoria.

Berlese funnel sampling

Berlese funnels are useful for extracting insects from plants, and can be calibrated so that they may be used for estimating population densities (Boland & Room 1983). Each funnel (45 cm height × 55 cm in diameter) was made of galvanized sheet metal with an asbestos lid holding 4 × 75 w light bulbs. To support the canola plant, a 50-cm diameter wire mesh platform was located 13.5 cm below the bottom of the light bulbs. A jar (12.6 cm height × 5.5 cm width) containing 75 % ethanol solution was attached to the base of the funnel to trap insects escaping from the heat generated by the light bulbs.

At weekly intervals, ten canola plants were selected randomly in the field. Each plant was covered with a perforated nylon sleeve, 90 cm in

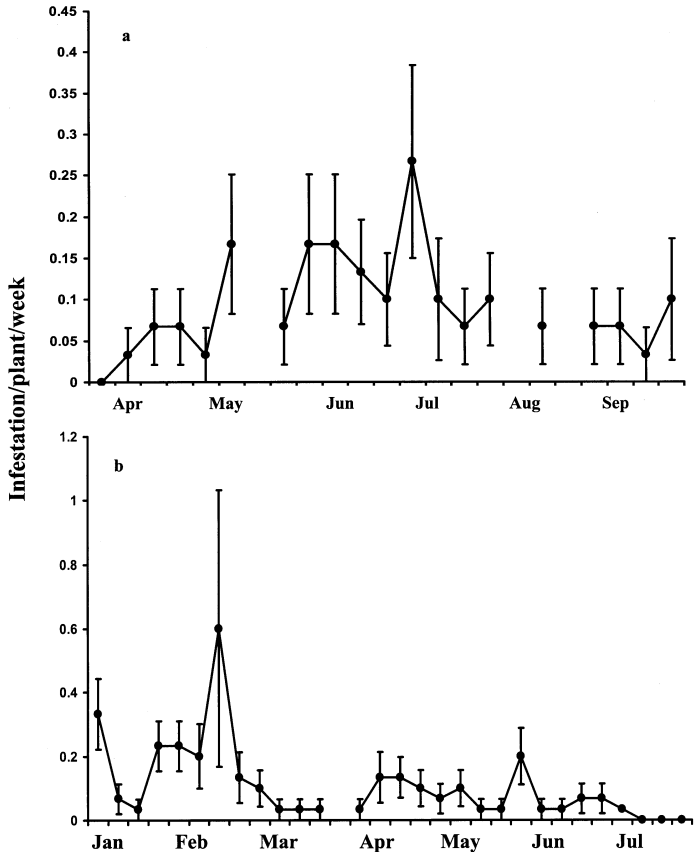

Fig. 1. Seasonal abundance of *Plutella xylostella* larvae and pupae at Rietondale, South Africa, during 1996 (**a**) and 1998 (**b**). Bars = one standard error of the mean.

diameter and 185 cm in length, which was folded downwards and tied at the base of each plant. After seven days the sleeves were pulled over the plants and tied at the top to trap all insects that were on the plants. The plants were cut at the base, placed in a cooler bag and brought to the laboratory.

In the laboratory, the plants contained in the sleeves were placed in the freezer for 15 minutes. The plants were then removed from the freezer, the sleeves untied and the contents of each sleeve emptied into Berlese funnels. The lights on the lids were switched on for 48 hours. The insects fell into ethanol in the jar at the base of the funnel. After 48 hours the lights were switched off and the jars removed. The insects collected from the ethanol were counted and identified.

Adult monitoring

Three delta-shaped synthetic sex-pheromone traps (26 cm length × 9.5 cm width × 13 cm height) were deployed in and around the plots to monitor *P. xylostella* male moth populations for the duration of the study. In the traps, sticky floors coated with a layer of polybutene adhesive were used to trap the insects (Kfir 1997). Rubber septa impregnated with *P. xylostella* female pheromone (supplied by AgriSense-BCS Limited, U.K.) were placed in the middle of the sticky floor inside the metal trap. At weekly intervals the traps were examined, the number of male moth catches recorded and the sticky floors replaced. The pheromone dispensers were replaced at six-week intervals.

Data analysis

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

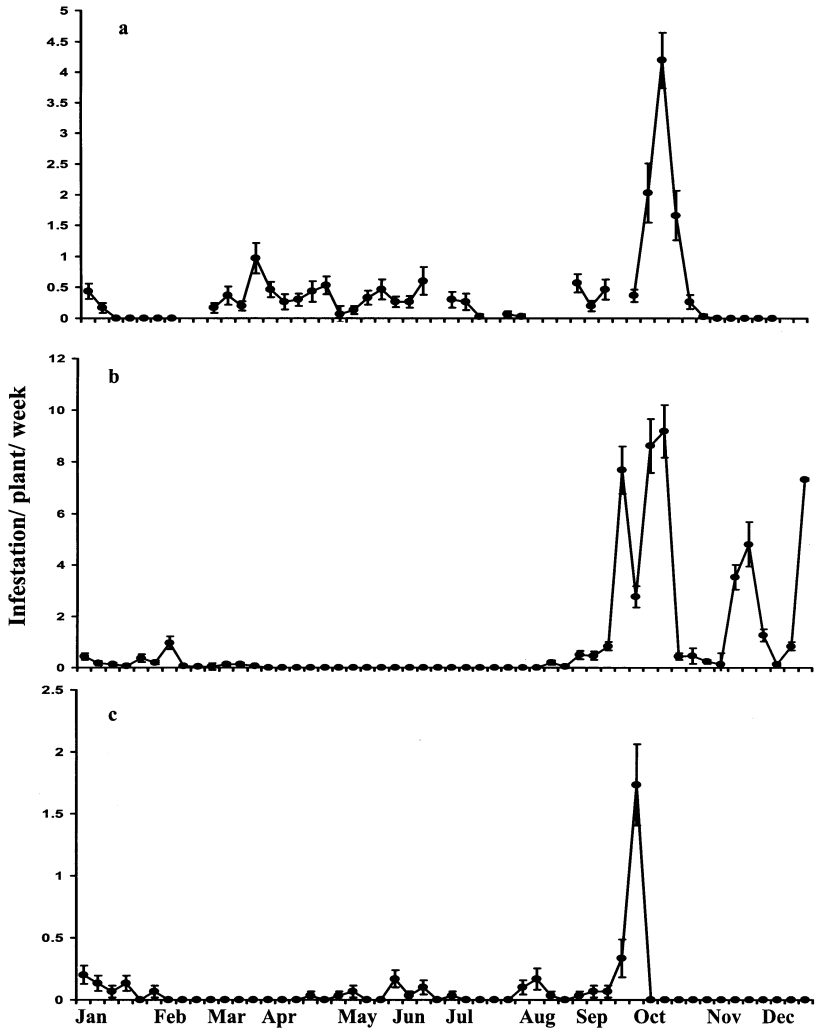

Fig. 2. Seasonal abundance of *Plutella xylostella* larvae at Bapsfontein, South Africa, during 1996 (**a**), 1997 (**b**) and 1998 (**c**). Bars = one standard error of the mean.

RESULTS AND DISCUSSION

Plant sampling

At Rietondale, infestation levels were low during 1996, fluctuating between 0 and 0.25 larvae per plant. During 1998, infestation peaked at 0.6 larvae per plant at the end of February and remained low for the rest of the season (Fig. 1). At Bapsfontein, the population levels were high in spring, peaking at 9.6 larvae per plant in October 1997, and low from January–August throughout the three years of the study (Fig. 2). The infestation levels were generally low in winter (May–August) and started to increase from early spring (September). The higher *P. xylostella* populations at Bapsfontein can be attributed to the fact that the experimental farm is situated in an agricultural area with an abundance of cultivated and wild crucifer plants, whereas Rietondale is in an urban area. Cruciferous weeds can play an important role in maintaining *P. xylostella* populations in a crop (Muhamad *et al.* 1994; Begum *et al.* 1996).

Berlese funnel sampling

Larval counts from Berlese funnels were higher than those from visual observations (Table 1). A greater number *P. xylostella* larvae were overlooked during visual scouting, particularly first

Table 1. *Plutella xylostella* larval density and instar distribution at Bapsfontein between September and December 1997 based on Berlese funnel sampling (no. larvae/10 plants) and field scouting (no. larvae/30 plants).

Date	1st instar		2nd instar		3rd instar		4th instar		Total	
	Berlese	Scouting	Berlese	Scouting	Berlese	Scouting	Berlese	Scouting	Berlese	Scouting
9/ix/97	143	2	54	2	19	7	6	4	222	15
18/ix/97	90	11	29	10	18	1	10	3	147	25
25/ix/97	182	69	106	75	63	45	27	33	378	222
2/x/97	323	12	288	47	181	19	149	5	941	83
8/x/97	449	53	398	95	263	39	184	39	1294	226
15/x/97	202	48	148	82	99	50	58	43	507	223
22/x/97	104	1	44	6	38	1	28	2	214	10
29/x/97	4	13	3	0	7	0	24	0	38	13
5/xi/97	5	0	8	0	6	0	10	0	29	0
12/xi/97	0	2	0	4	0	1	3	0	3	7
19/xi/97	0	7	0	5	0	1	0	0	0	13
26/xi/97	0	40	0	49	0	14	0	3	0	106
2/xii/97	4	29	9	56	7	35	24	24	44	144
10/xii/97	7	22	6	13	7	3	9	0	29	38
18/xii/97	0	0	4	2	0	1	3	1	7	4
Total	1513	309	1097	446	708	217	535	157	3853	1129
Total %	39.27	27.37	28.47	39.5	18.37	19.2	13.9	13.9		

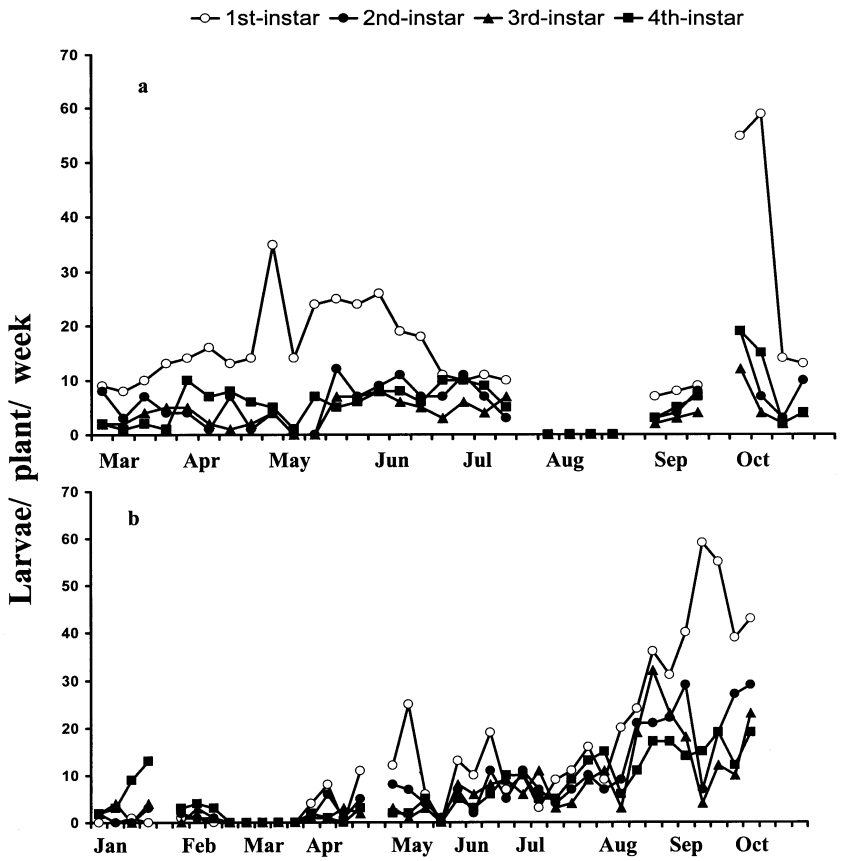

Fig. 3. Instar distribution of *Plutella xylostella* larvae on canola at Bapsfontein, South Africa, during 1996 (**a**) and 1998 (**b**), based on Berlese funnel sampling.

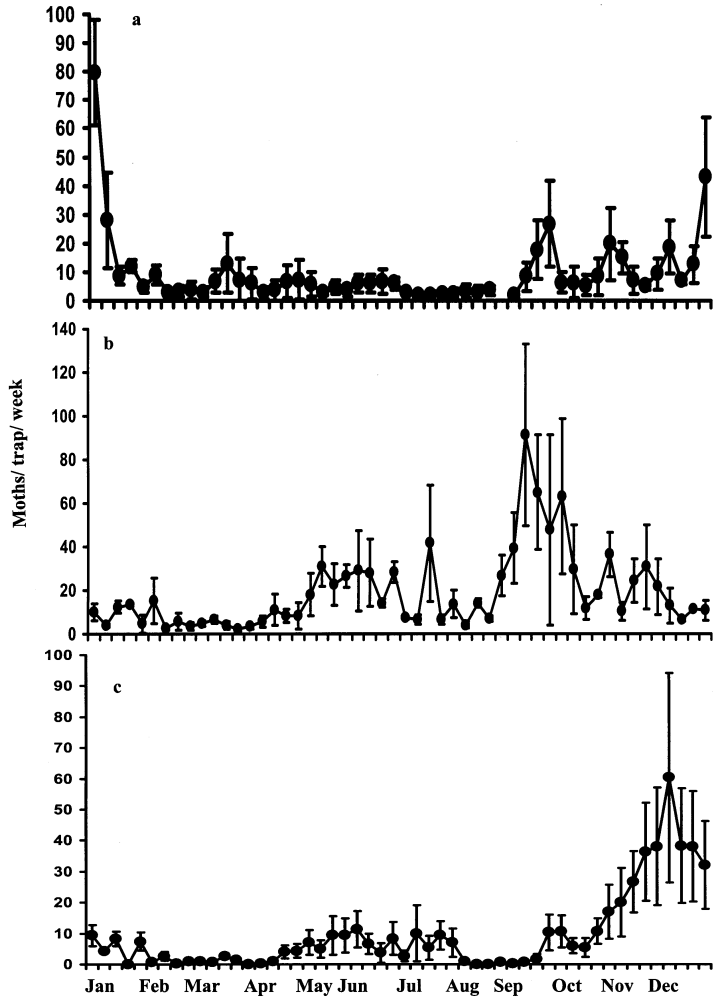

Fig. 4. Synthetic sex-pheromone trap catches of *Plutella xylostella* at Rietondale, South Africa, during 1996 (**a**), 1997 (**b**) and 1998 (**c**). Bars = one standard error of the mean.

instars because of their small size and tendency to tunnel into leaves (Butts & McEwen 1981; Baker *et al.* 1982). Generally, larval counts from Berlese funnels (Table 1, Fig. 3) were about 10 times higher than those obtained during visual scouting. The results of Berlese funnel sampling also indicate that all larval developmental stages were present through out the year (Fig. 3). This method seems to be good for estimating population levels of *P. xylostella* in canola fields but is not practical for farmers.

Adult monitoring

Plutella xylostella adults are nocturnal, with peak activities from dusk to dawn (Goodwin & Danthanarayana 1984; Nakahara *et al.* 1986). The results of pheromone trap catches indicated that *P. xylostella* adults were present throughout the year at both Rietondale and Bapsfontein (Figs 4, 5).

The catches at Rietondale were high from September–January, peaking at 91 moths per trap in October 1997, and low from February–August. There was no correlation between pheromone trap catches (Fig. 4) and crop infestations (Fig. 1) at Rietondale due to sparse infestation data (r = 0.06).

At Bapsfontein, the pheromone trap catches were high from August–January and low from February–July (Fig. 5), peaking at 189 moths per trap per week in September 1997, coinciding

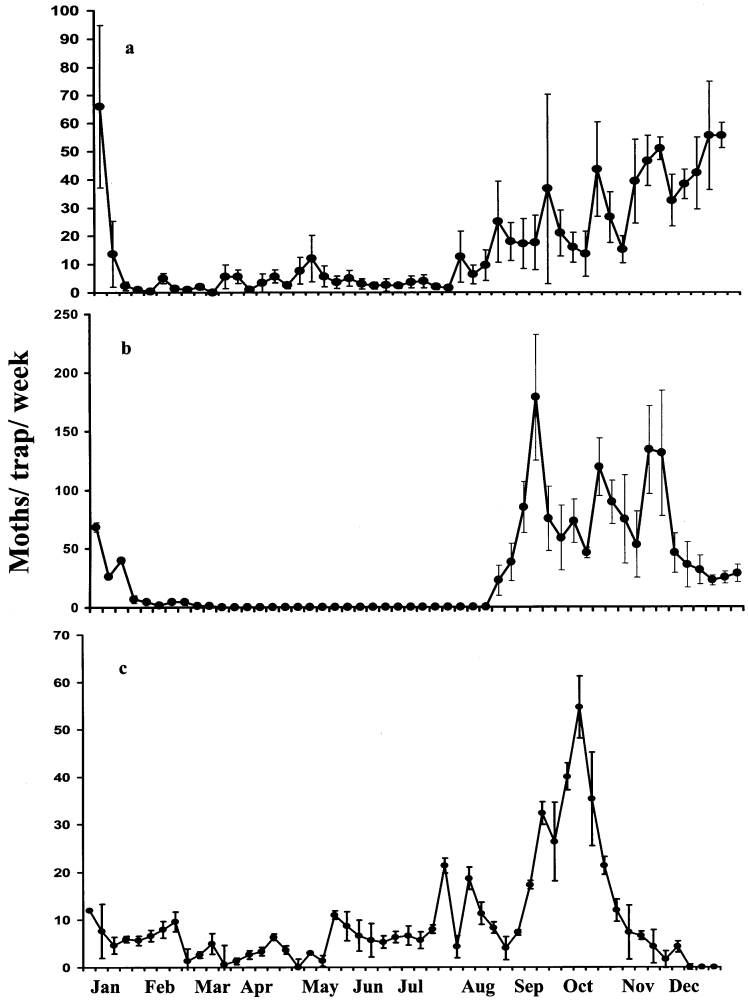

Fig. 5. Synthetic sex-pheromone trap catches of *Plutella xylostella* at Bapsfontein, South Africa, during 1996 (**a**), 1997 (**b**) and 1998 (**c**). Bars = one standard error of the mean.

with larval infestation in the crop (Figs 2, 3). Maximum numbers of moths were observed during spring and early summer, when there was a gradual increase in the daily temperature (Kfir 1997). There was a strong positive relationship (r = 0.794, $P < 0.001$) between trap catches (Fig. 5) and infestation levels (Figs 2, 3).

The pheromone trap catches were good indicators of the presence and relative abundance of *P. xylostella*. Although traps cannot always predict the potential for crop damage, trap counts can provide a warning of a possible infestation. *P. xylostella* can be a serious pest during spring and early summer as indicated by the Bapsfontein results. It is a prolific breeder with overlapping generations in the field, thus making it a difficult pest to manage (Ramachandran *et al.* 1999).

Parasitoids

The following parasitoids were recorded during the study:

Larval parasitoids. Cotesia plutellae (Kurdjumov) (Hymenoptera: Braconidae) was the most abundant parasitoid throughout the year and accounted for 55 % of total parasitism of *P. xylostella*. *Apanteles halfordi* Ullyett (Hymenoptera: Braconidae) was present mainly during the spring and summer months, but was responsible for only 2 % of total parasitism.

Larval/pupal parasitoids. Oomyzus sokolowskii

(Kurdjumov) (Hymenoptera: Eulophidae) was the second most abundant parasitoid, accounting for 17 % of total parasitism. *Oomyzus sokolowskii* also emerged from cocoons of *C. plutellae,* but only if it parasitized *P. xylostella* larvae that were already parasitized by *C. plutellae* (Kfir 1997), which was very rare. *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae), a solitary endoparasitoid that was absent only during winter, contributed 15 % to the total parasitism of *P. xylostella.*

Pupal parasitoid. Diadromus collaris (Gravenhorst) (Hymenoptera: Ichneumonidae) occurred mostly in autumn and spring and parasitized 3 % of *P. xylostella.*

Hyperparasitoids. The solitary endoparasitoids *Pteromalus* sp. (Hymenoptera: Pteromalidae) and *Mesochorus* sp. (Hymenoptera: Ichneumonidae) were the most abundant. Together they parasitized 8 % of *C. plutellae* and *A. halfordi.* According to Kfir (1997), *Mesochorus* sp. attacks larvae of *C. plutellae* and *A. halfordi* inside *P. xylostella* larvae parasitized by these two parasitoids and only starts feeding on the primary parasitoids when the primary parasitoids have completed their development and formed cocoons. *Pteromalus* sp. attacked cocoons of *C. plutellae, A. halfordi* and *D. mollipla.* The hyperparasitoids emerged from cocoons of the primary parasitoids. Hyperparasitoids can limit the efficiency of parasitoids in controlling *P. xylostella* populations (Mustata 1992).

Although *P. xylostella* infestation levels were low, parasitism often reached 100 % in January, March, April and May of 1996 at Bapsfontein mainly through the activities of *C. plutellae, D. mollipla* and *O. sokolowskii.* Parasitism trends were different from those of infestation levels (Fig. 2), *i.e.* higher from January–August and lower from September–December. The parasitoids were more active and effective when the plant infestation levels were low. Most of the parasitoids of *P. xylostella* were inactive during winter except for *C. plutellae.* In the absence of data on temperature limitations on *P. xylostella* parasitoids, it can be assumed that this may be caused by slow larval development and harsh conditions. At Bapsfontein, winters are very harsh and temperatures drop to well below freezing at nights.

Weather conditions can also play a role in determining the degree of infestation development. Rainfall can dislodge the larvae from the plants and can drown larvae in the water on the soil surface or on plants (Talekar *et al.* 1986).

Plutella xylostella is establishing itself as a major pest of canola in South Africa, and the production of canola is spreading into areas where wheat and brassica vegetables were traditionally grown. In some of thee areas, resistance to synthetic insecticides has been detected (Sereda *et al.* 1997). Thus it is essential to devise alternative, non-chemical strategies to manage *P. xylostella* on canola.

Indigenous parasitoids of *P. xylostella* in South Africa can play a major role in reducing the pest populations. *P. xylostella* is attacked by several parasitoids and, therefore, conservation and augmentation of parasitoids, through mass-rearing and releases, can play an important role in keeping the pest populations below economic damage levels.

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