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"Biological Control of Diamondback Moth in Cole Crops in South Africa"

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EXECUTIVE SUMMARY

A major feature of the initial proposal was to enroll a South African participant in this project, as a doctoral student at the Hebrew University of Jerusalem (HU). Towards this goal, Mr. Sicelo Robert Nofemela, has been admitted now as a PhD student at the HU. His three month work-visit to Israel last year had allowed Mr. Nofemela to start culturing *Diadegma* parasitoids to be introduced into South Africa in an attempt to improve biological control there.

The work carried out during this report period in both South Africa and Israel involves the characterization of diamondback moth (DBM) and its parasitoid populations in cole crops. This year too, *Diadegma semiclausum* was found to be the dominat parasitoid in Israel and therefore the promising wasp to be used in South Africa against DBM, an important pest of cole crops. Laboratory experiments in Israel this year assessed the performance of DBM on three host plants, cabbage (the cultivated plant) and mustard and radish (weedy plants that grow near field edges both in Israel and South Africa). These results would indicate the contribution of these weeds to DBM population build up in cabbage fields. Laboratory work in South Africa tested the climatic compatibility of several DBM parasitoid species.

These results (i) identify good biocontrol agents in Israel to be released in South Africa; (ii) provide solid baseline on the guild structure of DBM parasitoids prior to the release of new biocontrol agents in South Africa; (iii) test for the contribution of non-crop plants to DBM infestation in cabbage fields; and (iv) test the possibility the climatic incompatibility hampers parasitoid activity in South Africa. Next, we will import and field release *D. semiclausum* into South Africa, assess its impact on DBM populations, test for the wasp's climatic requirement, and explore the contribution of weeds to parasitoid activity in the field.

Section I

IA. Research Objectives:

The overall aim of this project is to use natural enemies from Israel to suppress diamondback moth populations in cole crops in South Africa.

Our working hypothesis states that parasitoids and predators effectively control the densities of the diamondback moth in Israel (and the Mediterranean area), the center of distribution and probably the area of origin of both the pest and its cruciferous host plants. By introducing effective natural enemies from Israel to South Africa, we shall be able to suppress diamondback infestations in cole crop systems.

The specific objectives are:

1. Compare the guild structure and population dynamics of diamondback moth parasitoids on cultivated and wild crucifer host plants in South Africa and Israel.
2. Compare the performance of important diamondback moth parasitoids on various cultivated crucifers in Israel and South Africa.
3. Introduce the most promising parasitoids from Israel into South Africa to control the diamondback moth in cole crops.
4. Evaluate the performance of field-released parasitoids.

The long-term goal of this project is to integrate the introduced natural enemies from Israel into an IPM program in cole crops in South Africa. The integrated program promises to reduce pesticide use while maintaining low levels of pest-induced losses. This, no doubt, will improve the well being of growers and consumers and establish sustainable cole crop production in South Africa.

IB. Research Accomplishments:

Field studies in Israel (Objective 1):

Material and Methods

An intensive survey for diamondback moth parasitoids consisted of weekly visits to five commercial cabbage and cauliflower fields. Surveyed fields were either organically grown (no insecticide applications) or received a minimal number of insecticide applications. Visits were made to the following sites, according to crop availability on a particular sampling date: Sde Elyahu, Netaim, Kfar Mordehai, Be'er Tuvia, and Hazav. On a given sampling date, about half of the fields were situated in the south coastal plain region and the other half in the Izra'el and Beit Shean valleys in the north of Israel.

On each visit, 30 randomly selected plants were examined in each field and the numbers of diamondback moth larvae, pupae and parasitoid cocoons were recorded. All the larvae, pupae and parasitoid cocoons found on the sampled plants were collected and held in the laboratory at 25 ± 1°C until adult moths or parasitoids emerged. In the laboratory, DBM larvae were provided with sections of fresh cabbage leaves until pupation. The number of emerging moths and parasitoids was recorded.

Three delta-shaped traps (0.26x0.095x0.13m, 'Biotrap') were posted in each of the sampled fields, 1m above ground. The traps were baited with one pheromone lure (AgriSense-BCS Limited, UK) impregnated with synthetic DBM sex pheromone and placed on a sticky floor. The traps were inspected on each visit to the field and the number of moths caught on the sticky floor of each trap was recorded. The lures were replaced every 5 weeks.

Results

Overall density of DBM was relatively low in all sampled field sites (Figures 1 & 2). In Kfar Mordechai, a maximum of about 5 males were captured in pheromone traps per night. Fewer moths were trapped in Netaim. Likewise, a maximum average infestation of about 6 larvae per plant was found on one sampling date. An increase in moth capture in spring (Feb-Apr 2004) was accompanied by increase in larval density on foliage. Infestation level, however, did not correspond with male capture rate. For example, more males were captured in March in Kfar Mordechai but larval density at that time was lower than that in Netaim.

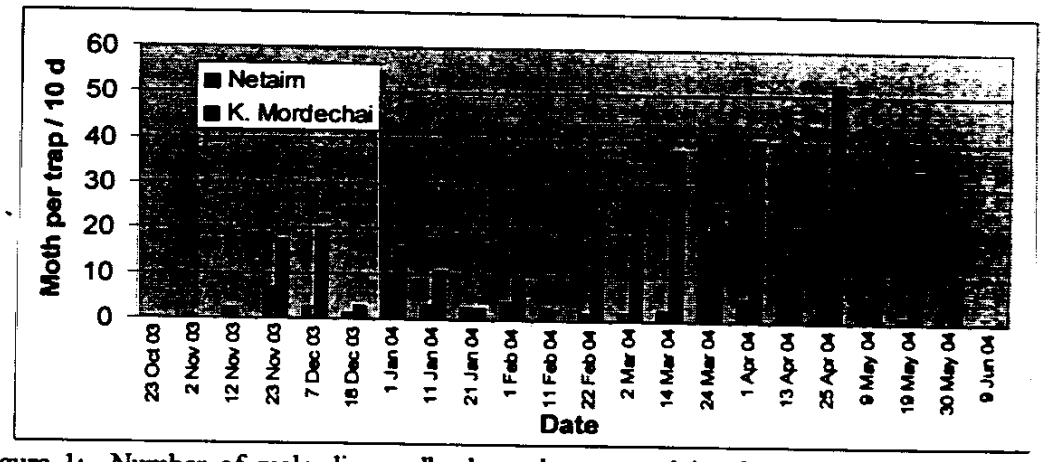

Figure 1: Number of male diamondback moths captured in pheromone traps in cabbage fields in 2004 growing season.

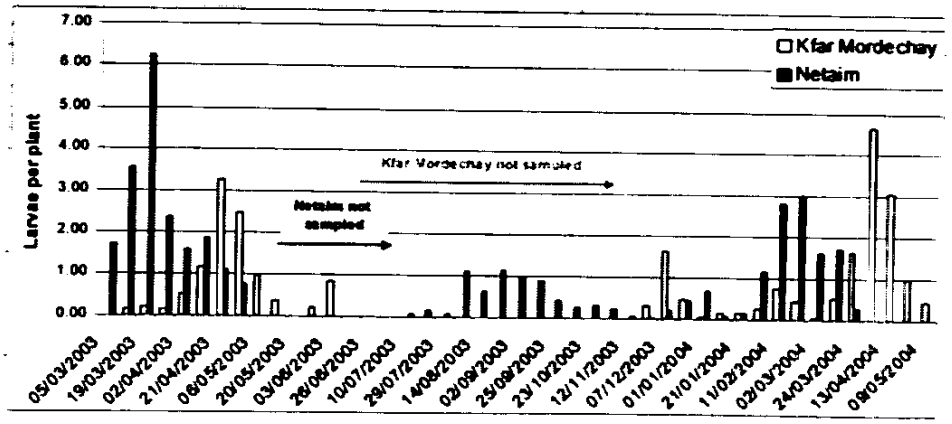

Figure 2: Density of DBM larvae and pupae on plants in four commercial cabbage and cauliflower fields in 2004.

Similar to last year, four primary parasitoids, namely *Diadegma semiclausum*, *Cotesia plutelae*, *Diadromus collaris*, and *Apanteles* sp., and two hyperparasitoid morphotypes were recovered in our survey. *D. semiclausum* was the predominant species, accounting for more than 85% of the parasitism. Yet some variation between fields was detected in species composition as well as parasitism rate (Figure 3).

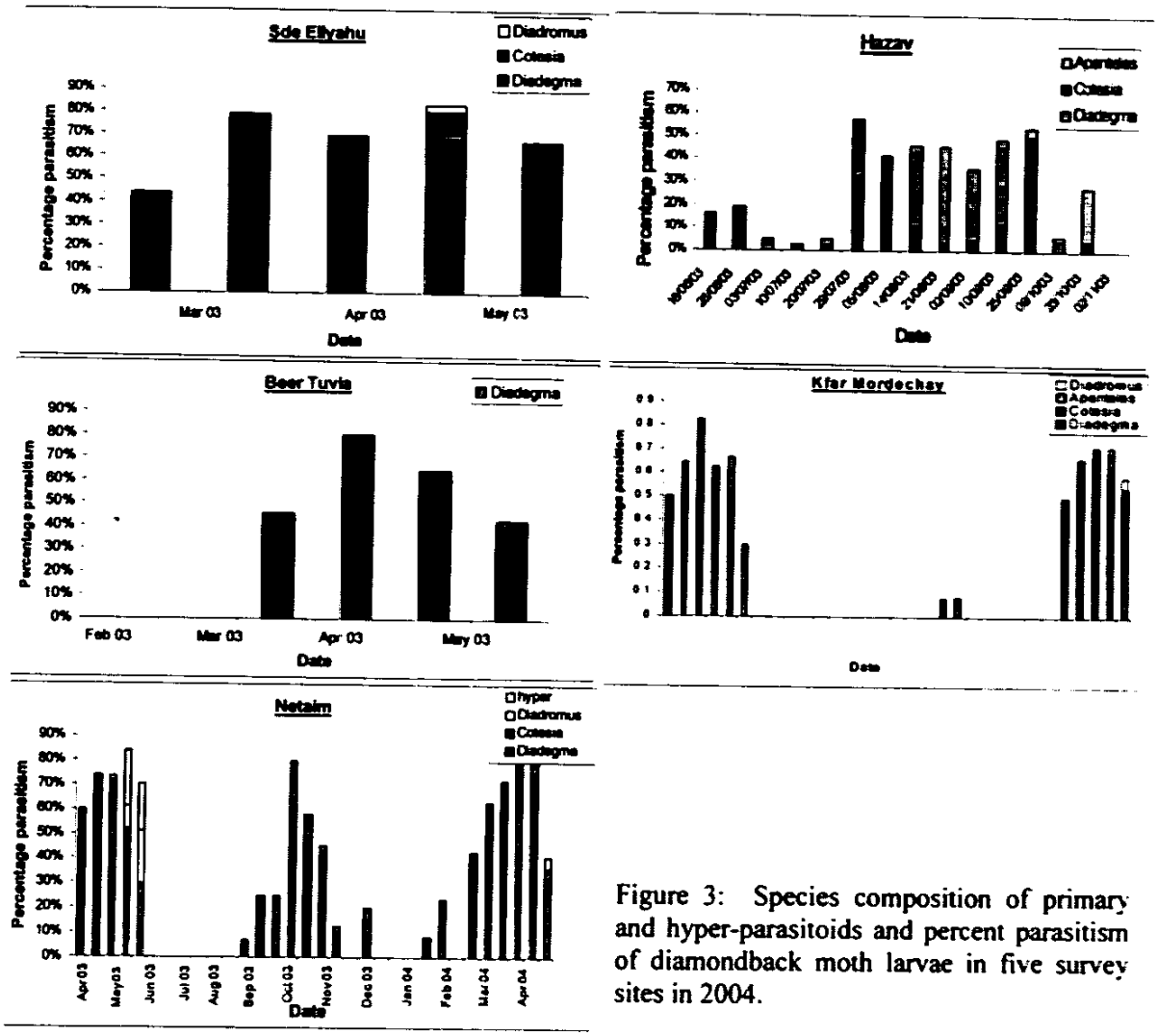

Figure 3: Species composition of primary and hyper-parasitoids and percent parasitism of diamondback moth larvae in five survey sites in 2004.

These species inflected an average parasitism rate of about 60% on the diamondback moth population. The consistent relatively high parasitism rates recorded throughout March, April and May suggest a high level of parasitoid movement and rapid colonization of continuously planted new fields.

Laboratory studies in Israel (Objective 2):

Materials and Methods

Wild radish and mustard plants are commonly found near cabbage fields in Israel, South Africa, and many other parts of the world. The wild plants may therefore serve as reservoirs for pest infestation in nearby cultivated fields. In contrast, these wild plants with possible diamondback moth populations may be beneficial if they arbor parasitoids that could move to attach pest populations in the field. In the first phase of the work under Objective 2, we report here on the comparison of the ability of diamondback moth larvae to survive and develop on three food plans, cabbage, radish and mustard. In the second phase of the work under this objective, we plan to compare the performance of *Diadegma semiclausum*, the dominant parasitoid in Israel, on host larvae fed on these three plant species.

To compare diamondback moth development on different plants, we individually placed moth eggs on either cabbage, mustard or radish leaf sections in Petri dishes lined with moist filter paper. The emerged larvae were followed to adulthood. Development time for each instar, survival time, pupal weight, and adult sex were determined for each larva. The experiment was replicated 24 times for a total of 72 larvae.

Results

Larval survival was significantly higher on cabbage than mustard leaves (ca 5% and 37% mortality, respectively; Figure 4). Survival on radish was intermediate with 20% mortality.

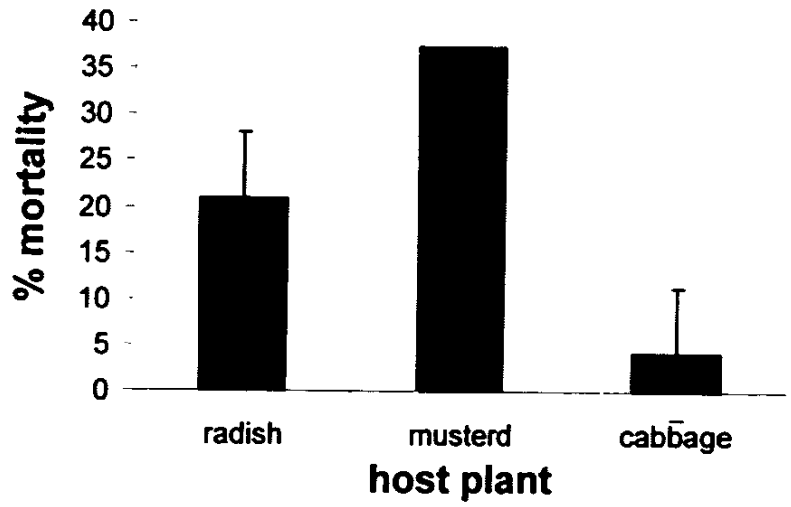

Figure 4: Mortality rate to adulthood of diamondback moth larvae fed radish, mustard or cabbage leaves.

Development time to adulthood did not differ significantly for larvae feeding on cabbage, radish and mustard leaves (Figure 5). Likewise, pupal weight did not differ significantly among the three food plants (Figure 6). The sex ratios (M:F) of eclosed moths were 1:1 on cabbage and mustard and 1:3 on radish.

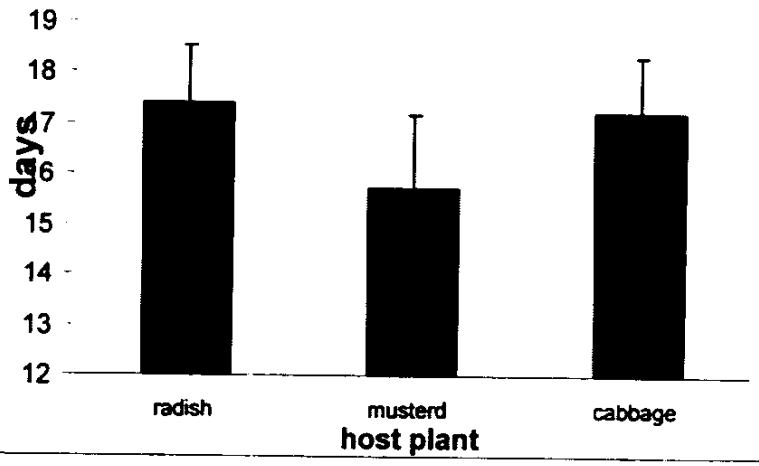

Figure 5: Developmental time to adulthood of diamondback moth on radish, mustard or cabbage leaves.

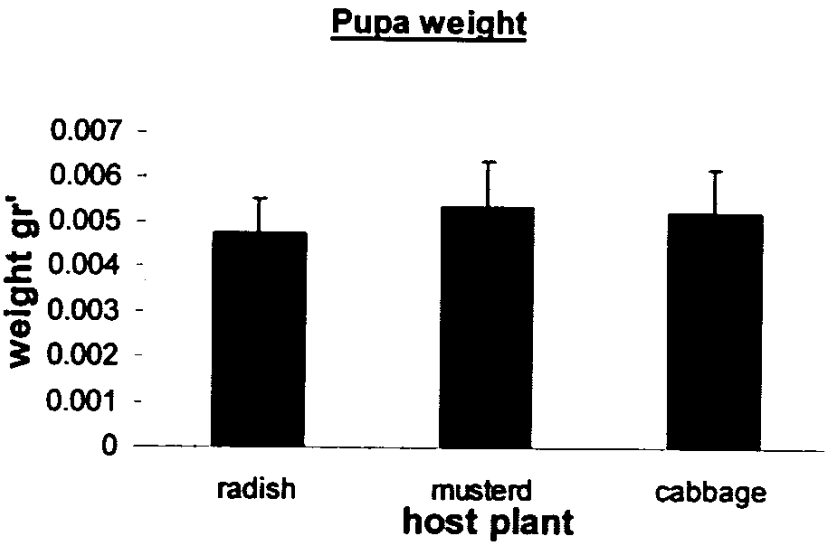

Figure 6: Pupal weight (gr) of diamondback moth fed on radish, mustard or cabbage leaves.

Field studies in South Africa (Objective 1):

Materials and methods

Two sites with different cropping systems were selected. Site 1 was located at Hartebeestpoort Agricultural Research Station near Brits (25°38'S, 27°47'E, altitude 1102m) in the North West Province, where cabbage seedlings were transplanted three consecutive times during the study period in a monocropping system in plots of about 47 X 20m (0.5m between plants and 1m row spacing). At Site 2, cabbage seedlings were also transplanted in three consecutive times but in mixed cropping system in an organic farm at Boschkop (25°47'73"S, 28°26'60"E), Gauteng Province, in plots of about 100 X 5m (0.5m between plants and 1m row spacing). In both sites, standard cultivation practices that include fertilising, weeding and irrigation were followed but without any pest control measures.

Flight patterns of P. xylostella *male moths*

In both sites, the flight activity of *P. xylostella* male moths was monitored with synthetic sex pheromone traps. Three delta-shaped traps (Biotrap®), (26 X 9.5 X 13cm), were deployed in each cabbage plot. The traps were mounted on steel posts erected around the cabbage plot at approximately 1m above the ground. Waxy paperboards were cut to fit the sliding bottom panels of the traps, thus covering the trap floors. The floors were then sprayed with a sticky polybutene adhesive. The lure, a small cylindrical-shaped rubber impregnated with a formulation of *P. xylostella* sex pheromone (supplied by Agrisense-BCS Limited, UK), was placed at the center of the sticky floor in each trap. The sticky floors were replaced at weekly intervals after counting the number of moths caught in each trap. The synthetic sex pheromones were replaced every five weeks.

Seasonal abundance of P. xylostella *larvae and pupae, and of its parasitoids*

Scouting for *P. xylostella* larvae and pupae commenced two weeks after transplanting the new cabbage seedlings in the field. At weekly intervals, 30 plants selected randomly were inspected and the number of *P. xylostella* larvae, pupae and parasitoid cocoons found in each plant recorded. In order to determine parasitism, samples of third and fourth instar larvae, pupae and parasitoid cocoons were collected. The samples were taken to the laboratory where they were maintained at 25 ± 1°C (mean ± s.d.), 65 ± 5% RH and 16: 8 (L: D) photoperiod. The larvae were provided with sections of fresh cabbage leaves and held singly in Petri dishes. The leaves were replaced every second day until the larvae pupated or parasitoid cocoons formed. Samples of parasitoid cocoons and *P. xylostella* pupae were confined individually in ventilated glass vials (2.5 X 10cm). Emerging parasitoids were identified and their incidence calculated. The number of moths that emerged from samples of larvae and pupae were also recorded. Larvae and pupae that died of unknown causes were excluded from calculations of parasitism.

Data analysis

To determine whether there is any relationship between the flight activity of *P. xylostella* and larval and pupal infestations on the crop, a correlation analysis was performed using Genstat 5 (Genstat for Windows 2000).

Results

Flight patterns of P. xylostella *male moths*

Pheromone trap catches indicated that *P. xylostella* moths were active throughout the year in both sites (Fig. 7). At Brits (Fig. 7A), trap catches were low in summer (January-February), autumn (March-May) and winter (June-August), fluctuating between zero and five moths per trap. At Brits a peak moth-flight activity was observed in spring (September-November) when up to 99 moths per trap was recorded in October. The moth activity declined again towards the end of spring (November) and fluctuated between five and 14 moths per trap in December. At Boschkop (Fig. 7B), however, moth activity followed a different pattern. Two flight peaks were observed, one in winter reaching 21 moths per trap in June and the other in spring (November) at 20 moths per trap. Moths activity was low during the rest of the year fluctuating between zero and five moths per trap.

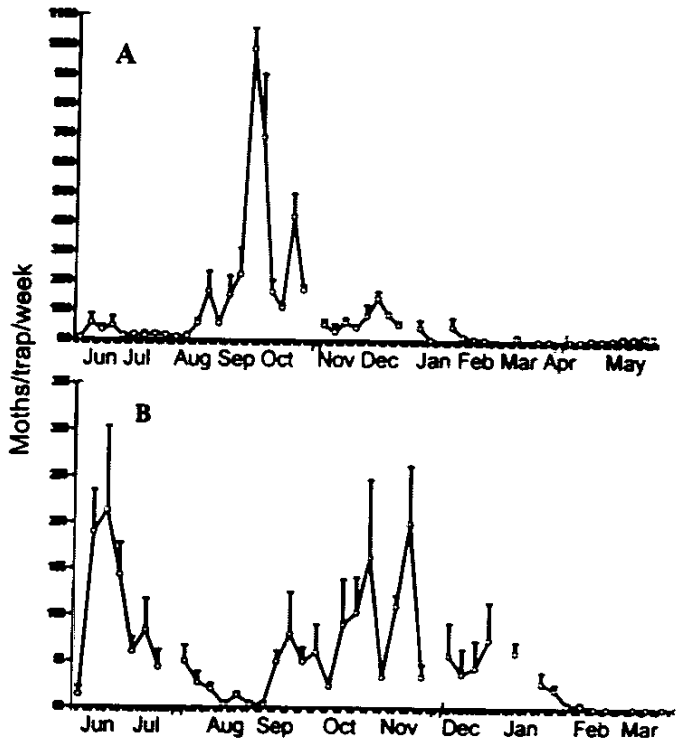

Fig. 7. Flight activity of *Plutella xylostella* male moths as shown by synthetic sex pheromone trap catches during June 2003-May 2004 at Brits (A), and at Boschkop (B) during June 2003-March 2004. Bars represent stadard errors. Diagonal lines on the x-axis represent transplanting on new cabbage seedlings.

Seasonal abundance of P. xylostella *larvae and pupae*

At Brits, the flight activity of male moths corresponded with larval infestations on the crops (Fig. 8A) and there was a positive correlation between the two variables ($r = 0.7882$, d.f. = 45, $P < 0.001$). At Boschkop, infestation (Fig. 8B) did not follow the moth flight pattern (Fig. 7B), but followed the same pattern as at Brits. There was no significant correlation ($r = 0.0498$ NS, d.f. = 37, $P = 0.7665$) between trap catches and infestation levels in Boschkop. In both Brits and Boschkop, infestations were generally low fluctuating between zero and one larva per plant in summer (January-February), autumn (March-May) and winter (June-August). Infestations increased towards the end of winter reaching peaks of 11 larvae per plant at Brits and 2.5 larvae per plant at Boschkop during the spring

(September-November) period. Even at low infestation levels, a relatively high number of plants were infested (Fig. 8), an indication of a regular distribution of the pest.

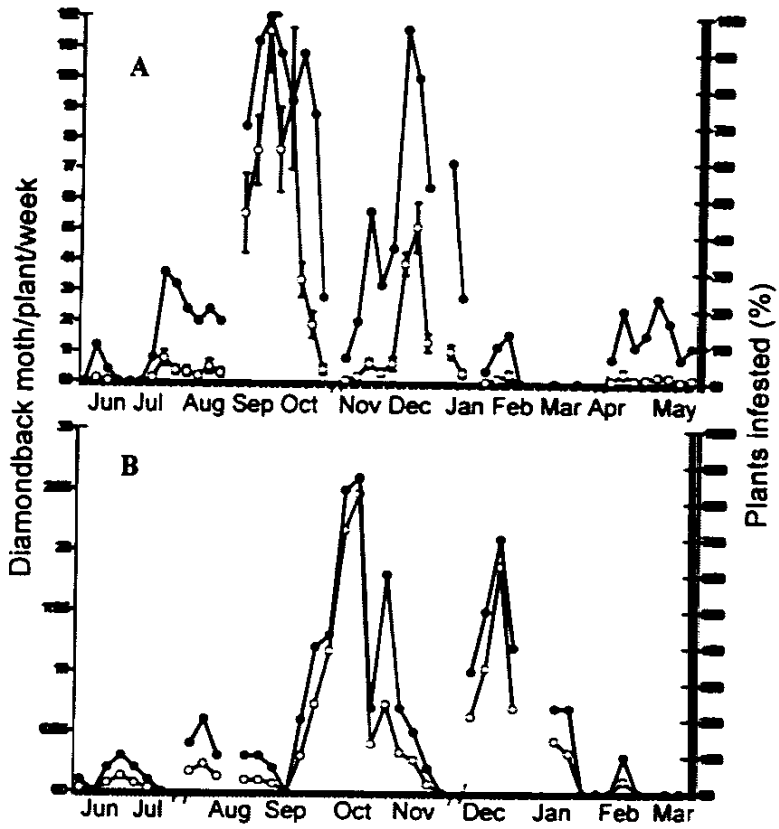

Fig. 8. Abundance of *Plutella xylostella* larvae and pupae on unsprayed cabbage plots during June 2003-May 2004 at Brits (A), and at Boschkop (B) during June 2003-March 2004. Open circles represent number of *P. xylostella* larvae and pupae per plant; solid circles represent proportion of plants infested. Bars represent stadard errors. Diagonal lines on the x-axis represent transplanting on new cabbage seedlings.

Diversity, seasonality and relative abundance of parasitoids

A total of eight species of hymenopteran parasitoids was reared from *P. xylostella* collected at the two sites (Fig. 9). Eight parasitoids were reared from Brits whereas seven were reared from Boschkop.

Larval parasitoids

Cotesia plutellae (Kurdjumov) (Braconidae), a solitary endoparasitoid, was active throughout the year and was the most abundant parasitoid in both sites (Figs. 9A and 9B). Another solitary larval endoparasitoid recorded was *Apanteles halfordi* (Ullyett) (Braconidae) [=*A. eriophyes* (Nixon). It was also active throughout the year in both sites, but its activity was very sporadic (Figs. 9A & 9B). *Apanteles halfordi* is endemic to South Africa and has been recorded only from *P. xylostella*.

Larval-pupal parasitoid

Oomyzus sokolowskii (Kurdjumov) (Eulophidae), a gregarious endoparasitoid, was active from October to January 2004 at Brits, and was the second most abundant parasitoid at that site (Fig. 9A). At Boschkop, it was a rare parasitoid, recorded only three times during November-December (Fig. 9B). Although it was mainly recorded from *P. xylostella* pupae, because it parasitizes larvae and emerges from pupae, in the calculations of percentage parasitism it was considered to be a larval parasitoid. On a few occasions, *O. sokolowskii* also emerged from *C. plutellae* cocoons, but its activity as a primary parasitoid far exceeded its hyperparasitic activity.

Pupal parasitoid

Diadromus collaris (Gravenhorst) (Ichneumonidae) was the only pupal parasitoid recorded during the study period, and its activity was very sporadic. It was recorded from October to December in Brits, whereas it was recorded on only one occasion in December in Boschkop (Fig. 9).

Hyperparasitoids

Hyperparasitoids were active from spring to autumn at Brits with hyperparasitism of *P. xylostella* ranging between 4-52% (Fig. 9A). At Boschkop, hyperparasitoids were active from August-January, fluctuating between 5 and 100% (Fig. 9B). The most abundant hyperparasitoid was *Eurytoma* sp. (Eurytomidae), followed by *Mesochorus* sp. (Ichneumonidae) and *Pteromalus* sp. (Pteromalidae). *Eurytoma* sp. and *Pteromalus* sp. attacked *Cotesia plutellae* cocoons and emerged from them. P*teromalus* sp. attacked also cocoons of *A. halfordi* and occasionally *D. collaris* inside *P. xylostella* pupae. *Mesochorus* sp. emerged from cocoons of field-collected *C. plutellae* and from cocoons that formed from field collected *P. xylostella* larvae. *Mesochorus* sp. attacked already parasitised *P. xylostella* larva, and then its offspring completed development once the primary parasitoid has formed a cocoon. It then pupated inside the cocoon of its host and emerged from it.

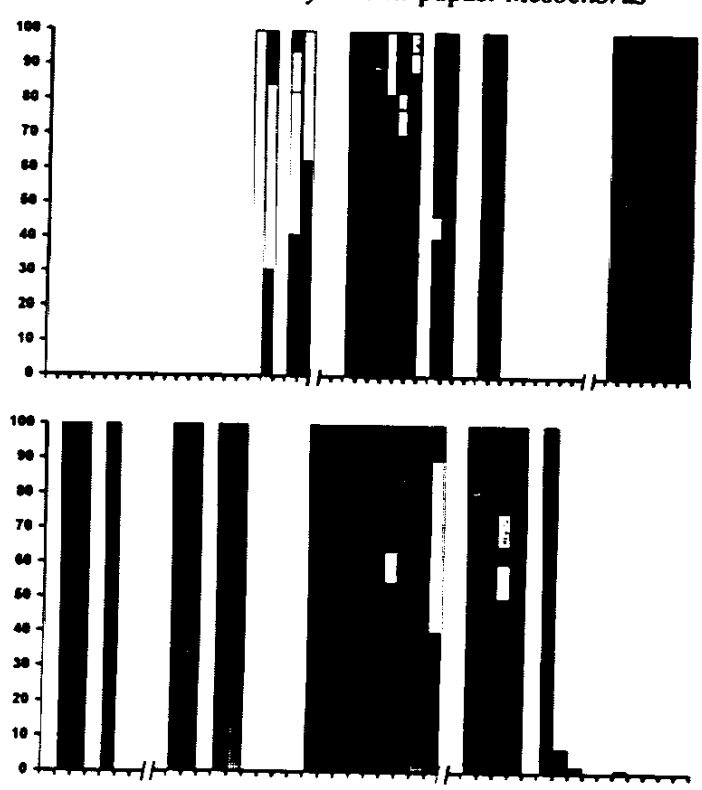

Fig. 9. Composition, relative abundance and seasonality of parasitoids associated with *Plutella xylostella* on unsprayed cabbage plots during June 2003-May 2004 at Brits (A), and at Boschkop (B) during June 2003-March 2004. Diagonal lines on the x-axis represent transplanting of the new cabbage seedlings.

Parasitism of *P. xylostella* larvae reached 100% on several occasions at Brits during spring and autumn but no parasitism was observed during winter (Fig 10A). Parasitism levels were lower at Boschkop but with some parasitism during winter (Fig 10B). Parasitism of *P. xylostella* pupae was low, accounting for only five and two and a half % at Brits and Boschkop and therefore was not plotted on the graphs.

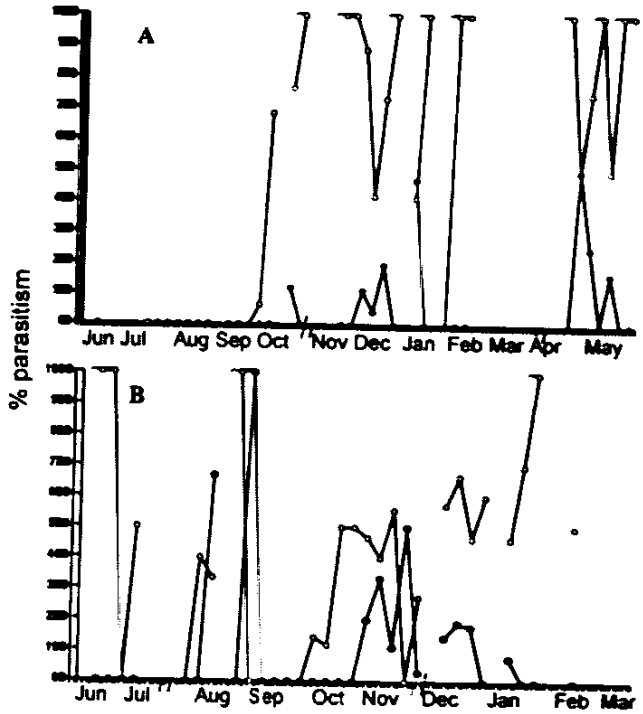

Fig. 10. Parasitism (open circles) and hyperparasitism (solid circles) of *Plutella xylostella* larvae on unsprayed cabbage plots during June 2003-May 2004 at Brits (A), and at Boschkop (B) during June 2003-March 2004. Diagonal lines on the x-axis represent transplanting of new cabbage seedlings.

Laboratory experiments in South Africa (Objective 2 & 3)

Material and Methods

This work was aimed at setting a baseline for the performance of *Cotesia plutellae* and *Diadegma mollipla*, the major parasitoids of diamondback moth in South Africa, under different temperature conditions. Similar tests would then be conducted for wasps imported from Israel to test their climatic competibility.

The studies were conducted in Labcon® LTGC 40 incubators set at constant temperatures of 21, 24, 27, 30 and 33 ± 0.5°C (mean ± s.d.). For *D. mollipla*, however, an additional lower test temperature of 18°C was included. In all the incubators, the photoperiod was maintained at 16L: 8D, and relative humidity was maintained between 50 and 60%. Thirty third instar larvae of *P. xylostella* were placed on a cabbage leaf in a glass jar (500ml), thereby forming an experimental unit, and 35 replicates were used. The jars were closed with gauze held tightly with rubber bands. A mated but naive one-day-old female parasitoid was introduced

into each jar and allowed to parasitize hosts for 24 hours. The parasitoids were provided with honey streaked thinly on the walls of the jars. After this period, the parasitoids were removed and the hosts were reared further on fresh cabbage leaves. The leaves were changed every second day until the larvae formed pupae or parasitoid cocoons formed. The number of *P. xylostella* larvae that died at each test temperature was recorded, and these were excluded from the calculations. Parasitoid cocoons were transferred into Petri dishes, and these were held in place with rubber bands The development of parasitoids was checked twice daily (at 08h00 and 16h00), from the third day after the start of the experiment, and the dates of pupation and adult parasitoid emergence were recorded. The time of pupal formation and parasitoid eclosion was determined as the midpoint between two consecutive observations between which the event occurred (Kfir *et al.* 1993; Roy *et al.* 2002). No differences were observed in the developmental time (egg-adult) between male and female *C. plutellae* at all the other test temperatures except for 24°C (Table 1). The duration of development (egg-adult) for male and female *D. mollipla* did not differ in all the temperatures tested (Table 2). Because the developmental time of male and female *C. plutellae* differed only at 24°C (Table 1), the data were combined for calculations. A minimum and maximum time to develop for each developmental stage (egg-pupa, pupa-adult) and generation time were determined and the analyses were based on the mean developmental time at each temperature.

Many studies have been conducted which empirically describe the relationship between the development of insects and temperature. This relationship is usually plotted as a developmental rate against a series of constant rearing temperatures. This relationship is curvilinear at extreme (low and high) temperatures but practically linear at intermediate temperatures (Campbell *et al.* 1974; Chiang 1985; Dent 1991; Jervis & Copland 1996; Roy *et al.* 2002). Due to the nonlinearity of the curve at extreme temperatures, the validity of using extrapolation of the linear portion of the curve to estimate the threshold for development (c) has been criticised by several workers, and several other methods have been developed (Lamb 1992; Bernal & González 1993; Raworth 1994; Lactin *et al.* 1995; Lamb 1998; Legg *et al.* 1998; Ikemoto & Takai 2000). Most of these new methods appear to be more accurate, and they provide measures of error in their estimates. However, their use requires large numbers of test temperatures that include low, optimum and high temperatures. Therefore, their use is not always practical. This is especially true when a study, such as this one, deals only with temperatures in the middle and upper ranges. Besides, the increased accuracy that may be obtained from these new formulae may not be as essential for practical applications as it is for theoretical ones (Lamb 1992). Furthermore, the method of estimating developmental threshold from extrapolation of the linear portion of the curve has been used successfully for insect pests in the field (Dent 1991; Lamb 1992). Therefore, this method was used to estimate the threshold for development for *C. plutellae* and *D. mollipla*.

The equation of the equilateral hyperbola, based on the assumption that the product of development time and temperature above a certain threshold is a constant (thermal constant), describes the effects of temperature on the duration of development in insects (Bodenheimer, 1958 in Moore & Kfir 1996). The hyperbola equation [$ThC = t\ (T\text{-}c)$] for *C. plutellae* and *D. mollipla* was calculated as follows: rates of development for the temperatures (T) used were obtained as the reciprocals of the developmental periods (t) shown in Tables 3 and 4; the linear regression ($y = a + bx$) of the developmental rate on temperature was then calculated

using the method of least squares; the parameters of the equilateral hyperbola (thermal constant = *ThC* and developmental threshold = *c*) were then obtained from the identities $ThC = 1/b$; $c = -a/b$ (Moore & Kfir 1996).

To determine whether there were any differences in parasitism of *P. xylostella*, duration of development and emergence of *C. plutellae* and *D. mollipla* at different temperatures, the data were subjected to Analyses of Variance followed by multiple comparison Fisher's Protected Least Significant Difference test. Before analysis, data were subjected to a Bartlett test for homogeneity and Watson test for normality. The data were analysed using the statistical program Genstat 5 (Genstat for Windows 2000).

Results

At each temperature tested, using 95% confidence intervals, the developmental time (egg-adult) for male and female *C. plutellae* was not significantly different (21°C: $t = 0.73$, d.f. = 277, $p = 0.463$; 27°C: $t = -0.03$, d.f. = 67, $p = 0.972$; 30°C: $t = -1.18$, d.f. = 95, $p = 0.239$; 33°C: test inconclusive due to a small (<5) sample size), except for 24°C ($t = -5.77$, d.f. = 275, $P < 0.001$). At all temperatures tested, using 95% confidence intervals, the duration of development (egg-adult) for male and female *D. mollipla* were not significantly different (18°C: $t = -0.98$, d.f. = 202, $p = 0.327$; 21°C: $t = -0.45$, d.f. = 101, $p = 0.654$; 24°C: -1.38, d.f. = 46, $p = 0.174$; 27°C: $t = 0.19$, d.f. = 55, $p = 0.854$; 30°C: $t = -0.2$, d.f. = 12, $p = 0.841$).

The developmental time for *C. plutellae* decreased significantly ($F = 3094.56$, d.f. = 4, 130, $P < 0.01$) with an increase in temperature (Table 3). The duration of development for *D. mollipla* was also significantly shorter ($F = 4809.45$, d.f. = 4, 127, $P < 0.01$) as the temperature increased (Table 4). *Cotesia plutellae* completed development at all test temperatures (Table 3) whereas *D. mollipla* completed development at temperatures up to 30°C (Table 4). As no development occurred above 30°C, it can be concluded that the upper threshold for development for *D. mollipla* is around 31°C. The linear regression was calculated as $Y = -0.037 + 0.0046X$ (s.e. for intercept = 0.006; s.e. for slope = 0.00025; $r^2 = 0.72$; $r = 0.85$; $p \leq 0.001$) for *C. plutellae*, and for *D. mollipla* it was calculated as $Y = -0.043 + 0.0042X$ (s.e. for intercept = 0.002; s.e. for slope = 0.00009; $r^2 = 0.94$; $r = 0.97$; $p \leq 0.001$). *Cotesia plutellae* required 217.39 degree-days (*ThC*) above 8.14°C (*c*) (Fig. 4.1A) to develop from egg to adult, whereas *D. mollipla* required 238.1 degree-days above 10.23°C (Fig. 4.1B).

At all temperatures tested, the duration of development (egg-adult) for *C. plutellae* was shorter than that of *D. mollipla* (Tables 4.3 and 4.4). Because both parasitoid species prefer to attack the same host stages (i.e. second and third instars), the shorter generation time for *C. plutellae* gives it a competitive advantage over *D. mollipla*. Parasitism levels of *P. xylostella* larvae were generally higher for *D. mollipla* than *C. plutellae* at all test temperatures (Tables 3 and 4). *Plutella xylostella* parasitism by *D. mollipla* was highest at 24°C, and there was a decline in the proportion of hosts parasitized both at higher and lower temperatures (Table 4). For *C. plutellae*, parasitism was highest at 21°C and decreased with increasing temperature (Table 3). Emergence of *D. mollipla* (Table 4) was rather low compared to *C. plutellae*

(Table 3), and for both parasitoid species the eclosion of adult parasitoids decreased with increasing temperature. An increase in temperature did not appear to affect the sex ratio (proportion of males) in the progeny (Tables 3 and 4).

Studies have shown that the survival of *P. xylostella* larvae is high at lower temperatures (<20°C) than at higher temperatures (>25°C) (Wakisaka 1992; Liu *et al.* 2002; Smith 2002). It is most probable therefore that the recorded parasitism rates of *P. xylostella* at higher temperatures may have been under estimated due to the lower survival of the hosts.

Table 1 Duration of development of male and female *Cotesia plutellae* at five constant temperatures. Values in the same column followed by an asterisk (*) are significantly different.

	Temperature (°C)				
	21	24	27	30	33
Male	20.63 ± 0.05	11.47 ± 0.08	10.71 ± 0.13	10.37 ± 0.07	9 ± 0.00
Female	20.58 ± 0.06	12.10 ± 0.07*	10.71 ± 0.15	10.50 ± 0.08	9 ± 0.00

Table 2 Duration of development of male and female *Diadegma mollipla* at five constant temperatures. Values in the same column followed by an asterisk (*) are significantly different.

	Temperature (°C)				
	18	21	24	27	30
Male	29.78 ± 0.14	24.37 ± 0.12	15.68 ± 0.07	13.11 ± 0.04	12.42 ± 0.15
Female	30.03 ± 0.21	24.56 ± 0.34	15.95 ± 0.18	13.1 ± 0.07	12.5 ± 0.5

Table 3. Effects of temperature on *Plutella xylostella* parasitism by *Cotesia plutellae*, and on its rates of development and emergence and sex ratio at five constant temperatures. Values in the same column followed by the same letter are not significantly different.

Temperature (°C)	(n)	Duration of development (days) (Mean ± S.E.) egg-pupa	pupa-adult	egg-adult	% Parasitism (Mean ± S.E.)	% Emergence (Mean ± S.E.)	Sex ratio (male: female)
21	(746)	13.93 ± 0.14a[1]	6.61 ± 0.15a[2]	20.54 ± 0.06a[3]	63.8 ± 3.32a[4]	67.9 ± 2.91a[5]	1.79: 1
24	(610)	8.04 ± 0.1b	3.94 ± 0.09b	11.98 ± 0.05b	65.9 ± 3.79a	71 ± 3.63a	1.47: 1
27	(240)	6.93 ± 0.13c	3.89 ± 0.09b	10.60 ± 0.11c	50.9 ± 5.64b	66.1 ± 5.35a	1.46: 1
30	(330)	6.7 ± 0.08cd	4.03 ± 0.11b	10.96 ± 0.1d	48.7 ± 4.41b	71.1 ± 5.05a	1.22: 1
33	(52)	6.51d	2.52c	9e	29 ± 3.36c	40.2 ± 8.73b	1.5: 1

LSD values ($P < 0.05$, Fisher's Protected LSD test): 1 = 0.3094; 2 = 0.3175; 3 = 0.2291; 4 = 11.92; 5 = 13.23.

Table 4. Effects of temperature on *Plutella xylostella* parasitism by *Diadegma mollipla*, and on its rates of development and emergence and sex ratio at five constant temperatures. Values in the same column followed by the same letter are not significantly different.

Temperature (°C)	(n)	Duration of development (days) (Mean ± S.E.) egg-pupa	pupa-adult	egg-adult	% Parasitism (Mean ± S.E.)	% Emergence (Mean ± S.E.)	Sex ratio (male: female)
18	(450)	11.81 ± 0.12a[1]	18.72 ± 0.17a[2]	30.53 ± 0.1a[3]	67.3 ± 4.21bc[4]	67.2 ± 4.19a[5]	2.4: 1
21	(363)	7.86 ± 0.12b	16.34 ± 0.12b	24.2 ± 0.15b	71.6 ± 5.1bc	37.1 ± 4.24b	10.44: 1
24	(370)	6.18 ± 0.07c	9.59 ± 0.08c	15.73 ± 0.05c	84.9 ± 3.92a	59.7 ± 3.58a	4: 1
27	(207)	4.54 ± 0.07d	9.13 ± 0.13d	13.64 ± 0.11d	79.8 ± 4.69ab	38.7 ± 5.89b	2: 1
30	(170)	4.64 ± 0.06d	8.1 ± 0.12e	12.74 ± 0.11e	65 ± 4.86c	16.9 ± 5.12c	6: 1
33		no development					

LSD values ($P < 0.05$, Fisher's Protected LSD test): 1 = 0.2619; 2 = 0.1293; 3 = 0.3112; 4 = 12.79; 5 = 13.10.

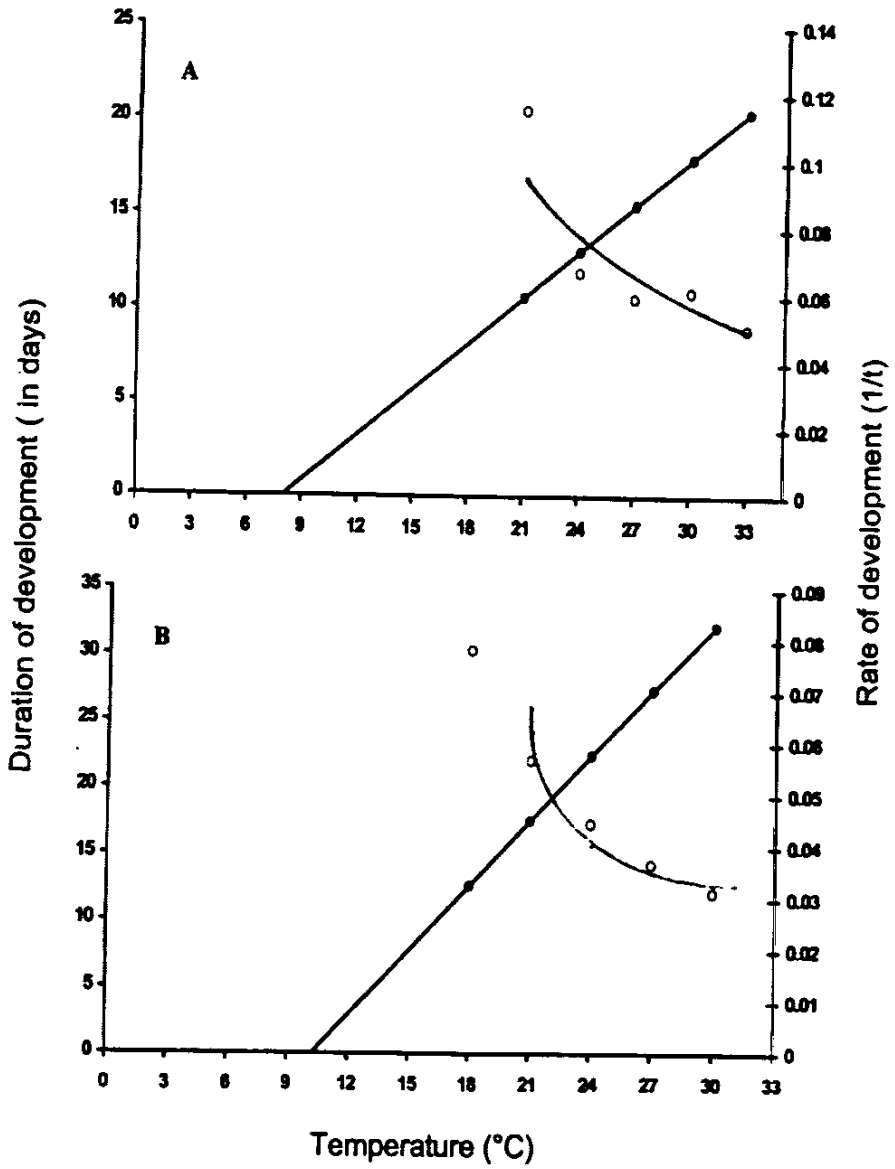

Fig. 4.1 Effect of temperature on the duration and rate of development of *Cotesia plutellae* (A) and *Diadegma mollipla* (B). Open circles represent duration of development; solid circles represent rate of development

I.C. Scientific Impact of Collaboration:

A major feature of the proposal was to enroll a South African participant to this project, as a doctoral student at the Hebrew University of Jerusalem (HU). After the last minute withdrawal of Mr. Satch Mosiane from the project in early 2002, we have identified a new suitable South African candidate, Mr. Sicelo Robert Nofemela. Mr. Nofemela is now officially enrolled as a Ph.D. student at the HU. He arrived in Israel in February 2004 and is taking the course-work toward his degree. He is also developping his dissertation reaserch plan. Mr. Nofemela is making good progress. We expect him to complete all course-work requirements and have his dissertation research-plan approved before he departs back to South Africa in July to commence his research there. Mr. Nofemela is also collecting *Diadegma* parasitoids in Israel and is planning to hand-carry ca 500 wasps to start a colony in quarantine in South Africa. We have already obtained the necessary import permits for this shipment.

Work is progressing well now that the South African student is on board. We expect to be able to make Israeli parasitoid releases in South Africa in spring (Sept-Oct).

I.D. Description of Project Impact:

During this third year of the project, data on pest population dynamics and parasitism rate were collected in South Africa and in Israel. We have also completed some laboratory experiments toward Objectives 2 and 3 of the project. While these are important for the project, they are not of an applied nature.

I.E. Strengthening of Developing Country Institutions:

Investments in equipment and in facilities, including field facilities, are an ongoing process. They proceed reasonably well.

I.F. Future Work:

The experimental work in Israel should be completed by November 2004. The work in South Africa, however, is about one year behind schedule. This setback is due to the last minute withdrawal of the South African trainee during the first year of the study. We may need to request a one year extension (with no budget increase) of the project to complete planned work and allow Mr. Nofemela to complete his PhD program.

Section II

II.A. Managerial Issues: None

II.B. Budget: There were no major changes in budget items during this reporting period.

II.C. Special Concerns: We may need to ask for a one year, no-cost-increase extension of the project.

II.D. Collaboration, Travel, Training and Publications:
Collaboration - Collaboration level is satisfactory. The principle investigator, the co-principle investigator and Mr. Nofemela keep in contact through email, fax and telephone communications. These contacts allow the coordination of fieldwork and experimental procedures. It also necessary for Drs. Coll and Kfir to follow Mr. Nofemela's progress and provide him with guidance, while serving as his PhD advisors.

Travel – No travel was made by the PI and co-PI during this report period. More intense visits are planned for the next period when Mr. Nofemela is to start his research work.

Training - Mr. Nofemela arrived here in February. In addition to his formal PhD training, Mr. Nofemela also benefits much from the academic environment in Rehovot. He had the opportunity to interact with other faculty members, graduate students and staff in the department and familiarized himself with cole cropping system in Israel.

Publications - None

II.E. Request for US Embassy (Tel Aviv) AID or BOSTID Actions: None