VG95009
Pest & beneficial ecology in tomatoes

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VG95009

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Pest and Beneficial Ecology in Tomatoes

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Industry Summary

A lack of knowledge of pest and beneficial insect ecology was one of six key issues identified at a Tomato Pest Management Workshop in 1994 (Kay and Walton 1994). Such knowledge provides the basis of IPM programs.

This project, which had four main components, was developed to address the issue:

- Insects and spiders were sampled from unsprayed autumn and spring tomato crops at Bowen and Bundaberg to develop a comprehensive list of the arthropod fauna.
- The seasonal history of heliothis, *Helicoverpa* spp., was studied at Bundaberg.
- The occurrence of tomato leafminer (TLM), *Phthorimaea operculella*, was studied at Bundaberg, and new insecticides were tested.
- Wasp egg parasitoids of heliothis were studied.

The main results of these studies were:

- Two hundred and twenty-two species of insects and 58 species of spiders were collected from tomatoes at Bundaberg and 153 species of insects and 28 species of spiders at Bowen. All the major common pests were collected at each site. Many minor pests were recorded. These insects may become more important as insecticide use is minimised in IPM programs. Common predators were collected at both sites, and parasites were reared from pest insects. Many of the insects found were of little to no economic importance.
- Pheromone traps and egg collections detected the seasonal pattern of occurrence of heliothis at Bundaberg. *H. armigera* was dominant in January and February, and present in high numbers in March-April. Few *H. punctigera* were present. By mid May *H. armigera* numbers fell to low levels. In mid August through September *H. punctigera* reappeared, probably through immigration, and it occurred in high numbers until December. *H. armigera* also reappeared in late August , and its numbers gradually increased until it became the dominant species by late November-December. Diapause studies showed that up to 88% of *H. armigera* pupating in April-May entered diapause. Moths emerged from these overwintering pupae during September.
- Most TLM were found in the bottom third of trellised plants. Numbers were higher in spring crops than in autumn crops. Sampling of moths and larvae indicated that three to four overlapping generations of TLM developed in a tomato crop. Abamectin and spinosad showed promise in insecticide trials against larvae on potted plants.
- Parasitism rates of heliothis eggs in unsprayed tomato crops often reached high levels (60-90%). Several parasitoids were responsible. The surviving heliothis caused severe damage. In a large commercial trial, releases of *Trichogramma* wasps increased egg parasitism rates from 7-23% to 29-57%, a promising result.

There now is greater understanding of the ecology of insects, particularly the major pests, in tomato areas. More research is needed to gain further understanding. Further research and development will improve IPM in tomatoes, helped by this greater understanding.

Kay, I. R. and Walton, M. P. (1994). *Workshop Report: Tomato Pest Management.* Cooperative Research Centre for Tropical Pest Management, Brisbane, Australia. 65 pp.

Technical Summary

The arthropod fauna of tomatoes at Bowen and Bundaberg was surveyed, and the seasonal occurrence of two major pests and parasitism of *Helicoverpa* spp. eggs studied at Bundaberg to increase knowledge of insects associated with tomatoes.

Suction, sticky, pitfall and whole plant traps, sweep nets and hand collecting methods were used to systematically survey the arthropod fauna of autumn and spring crops in 1996. Two hundred and twenty-two species of insects and 58 species of spiders were collected from tomatoes at Bundaberg and 153 species of insects and 28 species of spiders at Bowen. The results indicate a greater diversity of arthropods at Bundaberg than at Bowen, and provide information on the species present at each location in each season, and on the suitability of different sampling methods for different species.

The seasonal incidence of *Helicoverpa* spp. at Bundaberg was determined by rearing adults from timed collections of eggs, and with pheromone traps. *H. armigera* was dominant in January and February, and present in high numbers in March-April. Few *H. punctigera* were present. By mid May *H. armigera* numbers fell to low levels. In mid August through September *H. punctigera* reappeared and it occurred in high numbers until December. *H. armigera* also reappeared in late August , and its numbers gradually increased until it became the dominant species by late November-December. The incidence and duration of pupal diapause in *H. armigera* was studied. Retention of pupal eyespots indicated that 30-86%, 38-88%, and 13-43% of pupae developing in 1996, 1997 and 1998 respectively entered diapause, but the figures for 1998 are considered dubious. Adult emergence from diapause pupae in field cages occurred from mid August to November, peaking in September.

Samples of *Phthorimaea operculella* larvae showed that 55-86%, 14-44%, and 1-13% were present in the bottom, middle and upper thirds of trellised plants respectively. Pheromone trapping and larval sampling of two spring and two autumn crops from 1996 to 1998 indicated that three to four overlapping generations of *P. operculella* developed in a crop, although data were difficult to interpret. *P. operculella* populations were higher in spring crops than in autumn crops. In a small host acceptance experiment no *P. operculella* larvae established on capsicum leaves compared to 80% larval establishment on tomato leaves, which suggests that capsicums are not a suitable host for *P. operculella*. In two small insecticide trials on potted tomatoes only abamectin caused significant mortality of *P. operculella* larvae in mines. Abamectin, spinosad and sulprofos killed neonate larvae.

Parasitism of *Helicoverpa* spp. eggs, principally by *Trichogramma* spp. and *Trichogrammatoidea* spp., reached levels of 48-92% in unsprayed tomato crops in 1995-1997. Generally *Trichogramma* spp. dominated early but *Trichogrammatoidea* spp. were dominant late in each crop. *Telenomus* sp. were uncommon. Twice weekly releases of *T.* nr *brassicae* at 300 000 wasps per ha into a 3 ha commercial block of tomatoes raised the parasitism level in field laid *Helicoverpa* spp. eggs to 29-57% compared to 7-23% in a control block. There was no difference in the rate of parasitism of eggs on leaves or on flowers.

These studies have increased our knowledge of the ecology of pest and beneficial insects in tomatoes.

1.0 Introduction

The Tomato Pest Management Workshop (Kay and Walton 1994) reviewed the status of tomato integrated pest management (IPM) at that time, determined priorities for future research, development and extension, and developed action plans to address the identified issues. Six key issues for the tomato industry were identified.

The lack of knowledge of pest and beneficial insect ecology was one of these key issues. The project reported on here was developed to address this issue, particularly in respect to the major pests *Helicoverpa* spp. (heliothis or tomato grub) and *Phthorimaea operculella* (potato tuber moth or tomato leafminer), and the important group of beneficial egg parasitoids in the family Trichogrammatidae. IPM programs, essential in the management of pests, are based on such knowledge but little such knowledge specific to tomatoes in Queensland was available.

The two major fresh market tomato production areas in Queensland are at Bowen and Bundaberg. Bowen (20°01'S, 148 °15'E) has a dry tropical climate with a marked summer wet season. The growing season, which takes advantage of the mild winter climate, extends from late February (first seedlings planted) to late November (last fruit harvested). Bundaberg (24°52'S, 152°21'E) has a mild tropical to sub-tropical climate. Tomatoes are grown all year round with peaks of production in autumn and spring. Seedlings are planted in the field from early January to mid April for the autumn crop, with harvesting from late March to mid August. The spring crop is planted from July to September and harvested from October to December.

A knowledge of the insect fauna, particularly the pests and beneficials, of a crop is essential in formulating IPM programs for that crop. Lists of major pests of tomatoes and descriptions of the damage they do are available (Smith 1977, Swaine *et al.* 1991, Fullelove 1992) but no comprehensive faunal survey in the crop has been done. Such surveys have been conducted in other crops. Bishop and Holtkamp (1982) surveyed the arthropod fauna of lucerne in New South Wales. In cotton, Bishop and Blood (1977) listed beneficial arthropods in south-east Queensland, and Room (1979) surveyed parasites and predators of *Helicoverpa* spp. in New South Wales. Cantrell *et al.* (1983) comprehensively surveyed beneficial arthropods in potato crops in south-east Queensland, while Kay and Brown (1991) listed insects associated with kenaf in north Queensland. In tomatoes, Osmelak and Fletcher (1988) trapped auchenorrhynchous insects near crops in Victoria.

Helicoverpa spp. are major pests of tomatoes. The larvae cause serious damage by feeding on flowers and fruit, but they also will feed on leaves and tunnel in the stem (Swaine *et al.* 1991, Fullelove 1992). In tomatoes in Queensland there has been research on insecticidal control of *Helicoverpa* spp. (Smith 1978, Hargreaves and Cooper 1979, Kay 1983 and 1993). Kay (1989) recorded the seasonal incidence of *Helicoverpa* spp. on tomatoes at Bowen, and Hamilton and Macdonald (1990) developed treatment thresholds for *Helicoverpa* spp. in processing tomatoes.

Zalucki *et al.* (1986) reviewed the literature on *Helicoverpa* spp. in Australia, covering taxonomy and identification, distribution, host plants, reproduction and host plant choice, immature development and diapause, immature survival, movements of adults and immatures, population biology and dynamics, and population management.

Much further work on the biology, ecology and management of *Helicoverpa* spp. has been undertaken since then. The following references are a sample of those written, for a full literature review is beyond the scope of this report. Zalucki *et al.* (1994) investigated *Helicoverpa* spp. in inland Australia while Maelzer *et al.* (1996), Davis *et al.* (1997), Gregg *et al.* (1995), and Rochester and Zalucki (1998) have investigated movement, migration and forecasting. Murray (1991) and Murray and Zalucki (1994) studied diapause and pupal mortality. Research methods have been reviewed (Zalucki 1991). Adamson *et al.* (1997) estimated the economic impact of *Helicoverpa* spp. on Australian agriculture, and the thrust of new management approaches are summarised in White *et al.* (1995).

P. operculella also is a serious pest of tomatoes. The larvae mine in the leaves and the fruit (Swaine *et al.* 1991, Fullelove 1992). Rothschild (1986) and Trivedi and Rajogopal (1992) reviewed the distribution, biology, ecology and management of *P. operculella*, particularly in relation to potatoes. Das and Raman (1994) listed host plants, while Cameron *et al.* (1997) discussed the importance of weed hosts in maintaining populations of *P. operculella*. Hargreaves and Cooper (1979) reported on several effective insecticides against *P. operculella* in tomatoes, but Kay (1993) found no insecticides effective against the pest. Hall (1996) reported on the implementation of a pilot IPM program, aimed primarily against *P. operculella* in the Bundaberg district. Baynes (1996) investigated the effect of various levels of tomato crop destruction on the subsequent emergence of *P. operculella*, and Ford (1998) examined the suitability of various weeds as host plants for *P. operculella*. Grbin (1999) investigated the feasibility of a production break strategy for *P. operculella* in areas in Queensland, and in doing so investigated its biology, and its occurrence on weed hosts, and developed a population simulation model.

The use of *Trichogramma* spp. as egg parasitoids as a management tool for *Helicoverpa* spp. has a long history (eg Twine and Lloyd 1982). The current status of *Trichogramma* spp. was discussed at a workshop in 1994 (Seymour *et al.* 1994), and at meetings in 1995 (Scholz 1995). Scholz (1994) reported on release trials of *Trichogramma* spp. into sweet corn and tomatoes, on the effect of pesticides on *Trichogramma* sp. and *Trichogrammatoidea* sp., and on the comparative efficacy of six species of egg parasitoids.

IPM programs have been and are being developed for insects pests in tomatoes. The most notable is that in California (Anon. 1990), while Berlinger (1992) proposed an IPM model for processing tomatoes in Israel. IPM programs for *Helicoverpa* spp. in processing tomatoes have and are being developed in Victoria (Smith *et al.* 1993, Smith *et al.* 1994, Smith *et al.* 1995, Bentley and Smith 1997). The development and progress of IPM in tomatoes in Queensland has been discussed by Hall (1996) and Kay and Hall (1998).

This project covered four areas of research to increase knowledge of the biology and ecology of pest and beneficial insects in tomatoes in Queensland.

1. A comprehensive survey of the arthropod fauna of tomato crops was conducted in both major growing areas.

2. The occurrence and abundance of *Helicoverpa* spp. was studied at Bundaberg. Similar studies (with the exception of detailed diapause studies) had been done previously at Bowen (Kay 1989).

3. Studies of the occurrence of *Trichogramma* spp. and *Trichogrammatoidea* spp. in tomatoes, and the effectiveness of commercial releases of *Trichogramma* sp. were done at Bundaberg.

4. Studies on the occurrence of *P. operculella* in tomatoes were done at Bundaberg. These studies were intended to complement and not duplicate studies being done in other QFVG/HRDC projects on *P. operculella* management in tomatoes ie VG95002 - A production break strategy for tomato leafminer in Queensland; and VG95006 – Monitoring, management and reduction of tomato leafminer in Bowen. The status of capsicum as an alternative host for *P. operculella* was assessed. Capsicums frequently are included in host lists (eg Das and Raman 1994) but rarely are infested in the tomato growing districts. Several insecticides were tested for their efficacy against *P. operculella*.

The results of these studies are presented in this report.

2.0 Materials and Methods

2.1 Survey of the arthropod fauna

The arthropod fauna of crops of tomatoes grown without insecticide treatments was sampled at Bundaberg and Bowen during 1996. An autumn and a spring crop, representing the main growing seasons at both locations, were sampled.

At Bundaberg each crop consisted of a block, 90m by nine rows, of tomatoes, var. Tornado, grown as a trellised crop on plastic mulch with trickle irrigation. Rows were 1.5m apart and plants were spaced 0.5m apart along the rows. Standard fertiliser and irrigation practices were used, and the plants were sprayed regularly with chlorothalonil and mancozeb and occasionally with copper hydroxide for disease control. The crops were not treated with insecticides except as detailed below. The autumn crop was planted in early March and the final sample was taken in early June. This crop was sprayed once with a *Bacillus thuringiensis* product in early May to reduce the numbers of *Helicoverpa* spp. and *Spodoptera litura* larvae which were causing excessive damage to the plants. *B. thuringiensis* was used as it affects only lepidoptera larvae and so should have caused minimal disruption to other arthropods in the crop. The crop was sprayed with dicofol in mid May to control two-spotted mite, *Tetranychus urticae*. Dicofol is a specific miticide which should not have affected insects. The spring crop was grown from early September to early December. Both trial blocks were bordered on one long side by a windbreak of mixed tree species. Bare fallow ground and plantings of tomatoes were nearby.

Autumn (late March to late June) and spring (late July to late October) crops of variety Target were grown and sampled at Bowen. Both crops were planted in blocks of eight rows by 62m, and were grown as ground crops on plastic mulch with trickle irrigation. Rows were 1.5m apart with 0.75m plant spacing. Standard fertiliser and irrigation practices were used and the crops were sprayed regularly with mancozeb for disease control. No insecticides were used. The spring crop was sprayed twice with dicofol in mid October to control an infestation of tomato russet mite, *Aculops lycopersici*, which was severely damaging the plants. The autumn crop was surrounded by fallow ground, a block of mango trees, and a block of dolichos, while the spring crop had sweet corn and tomatoes nearby.

At each location in each season the crops were separated into 12 plots each of 10m by three rows. The two outside rows of the crop were left as guards as was the centre row at Bundaberg, and there were guard areas at the ends of the blocks. On each sampling occasion two plots were selected at random and sampled. Plots were sampled only once, and then were excluded from further consideration. Sampling was carried out each fortnight from early flowering until the end of the crop ie on five or six occasions (Table 1).

The following sampling procedures were used.

1. Suction trap. A M^{c}Culloch Super Airstream IV Blower/Vac was used as a suction sampler. A fine mesh bag was placed over the 120mm diameter opening of the machine's vacuum tube to collect the sampled arthropods. A four metre length of row

in each plot was thoroughly vacuumed. Excess plant material was removed from the bag, then the remaining contents were placed in a container to be sorted later.

Table 1
The first and last sampling dates for the two crops at Bundaberg and Bowen, 1996

	Autumn crop	Spring crop
Bundaberg	26 March to 7 June	7 October to 6 December
Bowen	22 April to 21 June	22 August to 30 October

2. Pitfall trap. Each trap consisted of a clear plastic container, 100mm deep and with a top diameter of 115mm (a takeaway food container) carefully buried in the soil through a hole cut in the plastic mulch so that the soil surface was level with the top of the container. Approximately 100 – 150ml of a 1:1 mix of ethanediol + water was placed in the trap to collect and preserve captured arthropods. A circular (290mm diameter) flat metal tray supported on four thin wire legs was placed approximately 100mm above the trap to act as a protective roof. Two pitfall traps were placed in each plot, left in place for three days, then removed and the collecting liquid and arthropods put in a container to be sorted later.

3. Sticky trap. Each trap consisted of a 270mm by 120mm metal plate, one side of which was covered by Royal Blue Vinyl Contact. This in turn was wrapped tightly in plastic cling-wrap coated in Tanglefoot. One trap per plot was placed in a row on a stake at the height of the top of the crop and left for three days before being removed. Trapped arthropods were picked carefully from the Tanglefoot, washed in kerosene and stored in 70% alcohol.

4. Whole plant bag trap. The principle of this sampling method was to enclose fully 1m of row (ie a complete plant) and then kill and collect all arthropods on it. One plant per plot was bagged. One edge of a section of white cotton material was placed on the ground beneath the foliage along 1m of each side of the row ie there were two pieces of material, one on each side. These edges were clipped together, and the material rolled out from the centre to provide a material 'floor'. A wire frame that went over the row was placed on this floor. This all was done as gently as possible to minimise disturbance to the plant. The bag then was left for several hours to allow equilibrium to re-establish in the row. (We attempted to leave the bags in this position overnight, but this proved impractical because of wind, rain and dew problems, and for logistical reasons at Bowen.) The material on each side of the row then was carefully and rapidly gathered up over the wire frame and all the edges clamped with bulldog clips so that the whole plant was enclosed in the material bag. The interior of the bag was thoroughly sprayed with a synthetic pyrethroid aerosol spray and after a period of time the bag and plant were shaken to dislodge all specimens, the bag was opened, and all arthropods were collected and placed in a container to be sorted later. This bagging technique was quite successful on the trellised crops at Bundaberg but it did not work as well on the ground grown crops at Bowen.

5. Sweep net. Several metres of row in each plot were swept, excess plant material removed, and the collected material placed in a container to be sorted later.

6. Hand. Insects were collected by hand or with an aspirator. Lepidoptera larvae were collected and reared on plant material or on a navy-bean based artificial diet (Twine 1971) to the adult stage for species identification, and to obtain parasitoids. Eggs also were collected and held for parasitoid emergence. Hand collections were made as part of the structured sampling, but casual collections also were made.

All collected specimens were sorted, mounted, and labelled and identified in as much detail as possible. Mr J. Donaldson and Dr M. Elson-Harris identified the insects and mites and Dr J. Green identified the spiders.

2.2 *Helicoverpa* studies

2.2.1 Pheromone traps

Pheromone traps were used to monitor the occurrence of *Helicoverpa* species at Bundaberg Research Station from late October 1995 to early December 1998.

A single trap for each species was erected along one long side of an area of land of approximately 300m by 150m used for growing small plots of a variety of crops (eg tomatoes, sweet corn, capsicums, peanuts, sweet potatoes, pumpkins, and forage sorghum and legumes for green mulch). The two traps were separated by about 100m. The traps used were Agrisense green funnel traps which were suspended from a star picket so that they hung 1.5m above the ground. One trap was charged with an Agrisense *H. armigera* lure and the other with an Agrisense *H. punctigera* lure. The lures were replaced with fresh lures every four weeks. A Shelltox Ministrip, which contains dichlorvos, was placed in the bucket of each trap to kill trapped moths. Ministrips were replaced with new ones every eight weeks. The traps were cleared every seven days and the numbers of moths counted and recorded. Other insects in the traps were noted.

2.2.2 Egg collections

Helicoverpa species eggs were collected from tomato crops in the Bundaberg district from October 1995 to November 1998 to determine their abundance and to determine the species present.

Eggs were collected from two or three crops throughout the district, usually at fortnightly intervals. At times in the season when suitable crops were unavailable (usually in late December to mid January) or when other factors precluded collections then the interval between collections varied. Crops that had not been treated with insecticides for as long a period as possible were selected for sampling and this period ranged from two to seven days. Collections were timed so that numbers of eggs collected per unit time could be used as a measure of abundance. Such catch per unit effort methods of assessing populations are well recognised and useful providing the efficiency of the search does not change (Southwood 1978). To ensure this all sampling was done in the morning, eggs were collected from leaves only using the

egg-punch technique described by Hoffman *et al.* (1970), and very young or old crops were not sampled to standardise crop stage as much as practicable. The principal collector participated in all collections and usually was accompanied by a second person. Two people filled the role of second collector during the course of the project. Their timed data were not included until it was confirmed that their collecting efficiency was similar to that of the principal collector. Care was taken to collect eggs from a wide area in each crop to ensure that a proper estimate of abundance and species composition was obtained. The time spent sampling individual crops varied depending on the abundance of eggs and the time records were pooled within sampling dates. Eggs were returned to the laboratory, removed from the leaf discs, and the resultant larvae reared on the artificial navy bean-based diet (Twine 1971). Adults were dissected to determine the species (Common 1953). The species composition of adults was assumed to be the same as the eggs collected as there is no evidence of differential mortality in the rearing procedure which allowed a measure of abundance (number of eggs collected per person per hour) to be calculated for each species.

2.2.3 Diapause studies

The incidence and duration of pupal diapause in *H. armigera* in the Bundaberg district was investigated in a preliminary way in 1996, and more comprehensively in 1997 and 1998.

In each year *H. armigera* eggs were collected from tomatoes on a number of occasions during autumn and early winter. These eggs and the subsequent larvae, which were reared on the navy bean-based diet (Twine 1971), were held under near ambient conditions of light and temperature in an outdoors area where they were shaded from direct sunlight. (The temperatures in this area were recorded on several occasions each year using a thermohygrograph and compared with daily maximum and minimum temperatures recorded in a Stevenson screen at the Bureau of Sugar Experiment Stations weather station approximately 400m away. The two sets of temperatures always were very close.) In most collections final instar larvae were separated into two groups as two methods were used to estimate diapause. Sometimes there were insufficient larvae to use both methods and one only was used.

Larvae in one group were allowed to pupate in the diet and the date of pupation was recorded. Each pupa then was removed from the diet and placed in a clear plastic container, 75mm diameter by 80mm high with a screw top lid, about three quarters filled with vermiculite. These containers were held in cardboard boxes in the outdoor area under near ambient conditions. The presence or absence of eyespots, the retention of which indicates diapause in *Helicoverpa* species (Shumakov and Yakhimovich 1955, Cullen and Browning 1978), was assessed 10-15 days after pupation to determine the incidence of diapause. The containers were examined thrice weekly (Monday, Wednesday, Friday) and dates of moth emergence were recorded to determine the length of the pupal period for both non-diapause and diapause pupae. Dissection was used to confirm that the moths were *H. armigera* (Common 1953). Pupae that failed to emerge were speciated by measuring the distance between the cremaster spines (Kirkpatrick 1961). The rare *H. punctigera* found were excluded from the data.

Forty mature larvae from the second group in each collection were placed in individual cages on bare, loose soil in the field and allowed to pupate naturally. Most larvae tunneled into the soil, and presumably pupated, within a day. Those that did not tunnel in after several days were removed from the experiment. Each individual cage was made from a clear plastic cup, 70mm diameter by 80mm high, with the bottom cut off. The base was pushed 10-15mm into the soil and the top was covered with a square of bridal tuille held in place with an elastic band. The 40 individual small cages were enclosed in a 1m by 1m by 1m cage made of heavy open mesh material supported on a metal frame. The edges of the mesh were buried in the soil and there were sleeves in two sides for access. While these cages undoubtedly caused some shading, it would be no more than that in a vegetated area. The pupae therefore experienced natural conditions of soil temperature, moisture and light. The cages were examined thrice weekly (Monday, Wednesday, Friday) and dates of moth emergence were recorded. Moths were removed and the species confirmed by dissection. Many moths emerged in the individual cages, and those that did not were retained by the outer cage. This method allowed the duration of the pupal stage for diapause and non-diapause pupae to be determined but it could not provide accurate data on the proportion of the population entering diapause.

In 1996 three collections of late instar (fourth and fifth) larvae were made from sweet corn to confirm that *H. armigera* reared naturally in the field for the majority of their lives behaved similarly to those collected as eggs and reared under our experimental conditions. These larvae were placed onto diet and then treated as described above.

2.3 *Phthorimaea operculella* studies

2.3.1 Occurrence in crops

The location of *P. operculella* infestations on tomato plants was studied in a spring-summer tomato crop in 1995-1996. The tomatoes were trellised and grown with standard agronomic practices. The crop was sprayed with fungicides and copper hydroxide for disease control, but no insecticides were applied. On six occasions during the crop's life four plants were selected at random and their height measured. Each plant then was cut into three sections, the top, middle, and bottom thirds, and each section was placed in a separate bag and returned to the laboratory. In the laboratory the plant sections were examined carefully and the number of *P. operculella* larval mines and larvae counted and recorded.

P. operculella infestations were monitored in four unsprayed crops of tomatoes from 1996 to 1998. Each crop consisted of a trellised block, 9 rows by 90m, of a commercial variety grown using standard agronomic practices. The crops were sprayed with fungicides and copper hydroxide for disease control, but received no insecticide sprays. In each crop two pheromone traps were placed in the centre row just before or just after the crop was planted. Each trap was hung from the top of a trellis stake about 25m in from the end of the row, and so the two traps were separated along the row by about 40m. The traps were vertical water traps, a design commonly used in Queensland tomato growing areas, baited with Agrisense *P. operculella* pheromone lures. Lures were not replaced during the life of a crop as trials had shown no difference in trap catches with lures 0, 2, 4, 8 and 12 weeks old (Kay unpub.

data). The traps were emptied weekly and the numbers of moths counted. In the two 1996 crops a leaf from the bottom third of each of 40 randomly selected plants was collected each week. The number of mines in the leaves was counted, as were the numbers of larvae in the small, medium and large size classes. The 1997 and 1998 crops were sampled similarly, except that when the plants were young and small 40 whole plants were examined for mines in the field. As the plants grew larger then 40 leaves were sampled. The head capsules of larvae were measured under a microscope and the larvae separated into the four instars on the basis of these measurements.

2.3.2 Parasitism

On a number of occasions throughout the project *P. operculella* larvae were collected from unsprayed crops and placed on potatoes in a container in the laboratory. Numbers of *P. operculella* moths and parasitoids that emerged were counted and the parasitoids identified.

2.3.3 Are capsicums a host?

Capsicum plants (var Giant Bell) and tomato plants (var Floradade) were grown in pots in a planthouse. When the plants were large enough they were infested with *P. operculella* larvae. Five neonate (<16 hours old) larvae from a laboratory colony were placed on the upper surface of tagged leaves of each of two capsicum plants and two tomato plants (as controls) on each of four consecutive days ie eight plants of each type were treated. On each day one infested capsicum plant and one infested tomato plant were placed in a planthouse (with uncontrolled temperatures and natural daylength) and one of each was placed in a constant temperature (CT) room at 24-26 °C and 12:12 L:D photoperiod. On the fourth day four neonate larvae were placed on the growing points of each of two capsicum plants as well, and these plants were placed in the CT room. All plants were examined after seven days and the number of larval mines and the number of live larvae recovered were recorded.

2.3.4 Insecticides

Two trials were done using similar methods. There were six treatments and four replicates in Trial 1 and five treatments and four replicates in Trial 2

Ten neonate (<12 hours old) *P. operculella* larvae from a laboratory colony were placed on the leaves of each of a number of small potted tomato plants, variety Floradade. These plants were held in a constant temperature room at 24°C and a 13:11 L:D photoperiod for two days before spraying to provide plants with 2 day old larvae in mines.

On the day of spraying a 2-day plant and an uninfested plant were sprayed in each replicate of each treatment. Two replicates were sprayed on each of two separate days. Plants in the control treatment were sprayed with water only. Treatments were applied in the equivalent of 1000L of water per ha with a motorised Echo sprayer fitted with a boom and four Albuz APT hollow cone nozzles operated at 690 kPa.

Several hours after spraying when the plants had dried 10 neonate larvae were placed onto the leaves of the previously uninfested plants to test the insecticides against

larvae that had to move on and mine into treated leaves. These were termed 0 day old larvae.

After treatment plants were returned to the constant temperature room. After seven days the plants were closely examined and the numbers of live larvae were counted. It was assumed that larvae not found alive had died. Leaves were checked for cadavers and some were found but counts of cadavers were not considered a reliable indicator of efficacy as they were small, difficult to find and see and were easily dislodged.

Analyses of variance were carried out on the square root (x + 0.5) transformed data using Genstat.

2.4 *Trichogramma* studies

2.4.1 Assessing natural infestations

The parasitism rates of naturally laid *Helicoverpa* eggs by naturally occurring parasitoids was assessed in four crops of tomatoes from 1995 to 1997 at Bundaberg Research Station. Each planting consisted of nine rows by 90m of trellised tomatoes grown with standard agronomic practices, and which received regular sprays of mancozeb and chlorothalonil and occasional sprays of copper hydroxide for disease control. No insecticides were applied to the crops.

In each crop *Helicoverpa* species eggs were collected from leaves at regular intervals (fortnightly for the 1995 crop and approximately weekly for the other crops) from early flowering until the end of the crop using the egg punch method of Hoffman *et al.* (1970). Eggs were collected throughout the block to obtain a representative sample.

The leaf discs with eggs were returned to the laboratory where the eggs were examined under a stereomicroscope to confirm their developmental stage. Only "brown" eggs (ie those with a brown ring or showing overall brown colouration) were kept to determine parasitism rates. Newly laid white eggs and obviously parasitised black eggs were discarded. Most parasitism occurs in the first two days, so brown eggs give a good indication of the level of parasitism (B. Scholz pers. comm.). The leaf discs with a single egg were placed into wells in multi-well trays, which were then wrapped in cling plastic and placed in an incubator at approximately 25°C. They were examined after some days to determine hatching and the percentage parasitism. Parasitoids were identified to genus.

In 1995 eggs also were collected from a nearby plot of tomatoes of the same age that were sprayed twice weekly with standard insecticides to allow comparison between egg parasitism rates in sprayed and unsprayed tomatoes.

2.3.2 Assessing commercial releases

Two commercial releases of *Trichogramma* were assessed.

In the first, a single release of *Trichogramma* nr *brassicae* was made in an old crop of tomatoes in November 1995. The crop had been treated with insecticides during its life and up until shortly before the release. The *Trichogramma* were released in *Sitotroga* eggs broadcast onto the plants, and emergence was expected within 24 hours of release. The release rate is not known. *Helicoverpa* egg collections were made one day pre-release and one, two, three and five days post-release using the methods described in 2.3.1. Percentage parasitism and the identification of the parasitoids were determined.

The second commercial release assessed was a large trial conducted in association with Mr R Llewellyn of BioProtection and SP Exports. Commercially reared *Trichogramma* nr *brassicae* were released twice weekly at approximately 300 000 wasps per hectare into a three hectare block of unsprayed tomatoes near Bundaberg from 22 August to 7 October 1996. (A single release was made in an adjoining block on 16 August.) Fifteen releases were made, starting at early flowering. The *Trichogramma*, as parasitised *Sitotroga* eggs about to emerge and mixed with semolina, were spread over the top of the tomato rows by a tractor-mounted device. *Helicoverpa* spp. eggs were collected from four large sections within the release block, to ensure a representative sample was obtained, and held to determine the parasitism rate and the species of parasitoid responsible. Approximately 100 eggs were collected on each sample date. Collection and holding methods were the same as those described in 2.3.1. Egg collections also were made from a check block of unsprayed tomatoes of similar age located on the same farm approximately 1km from the release block and separated from it by a patch of trees and scrub and other blocks of tomatoes. Egg collections from the release and check blocks were continued until standard insecticide (methomyl) sprays were applied to the check block in mid September and the release block in late September.

BioProtection assessed the efficacy of releases by placing sentinel cards of *Helicoverpa* eggs in the field, recovering them after several days and determining the percentage of cards with parasitised eggs.

On one occasion, 19 September 1996, 25-30 eggs were collected from leaves and from flowers in each of the four sampling areas in the release block to test if *T.* nr *brassicae* parasitised eggs at the same rate on each of the plant structures. A t-test was used to test if the mean rates of parasitism were the same (Analytical Software).

3.0 Results

3.1 Survey of the arthropod fauna

Insects and mites collected in the sampling program in 1996 are given in Table 2. Data on location, cropping season, and collection method are presented. Insects were identified to species if possible. In cases where specimens were identified to genus then species were separated if more than one was collected, if possible. However, the entry "unidentified species" may refer to one or more species. Numbers of each species were not recorded.

Spider identifications together with similar collection data are presented in Table 3. Numbers of each species were recorded and are presented in the Table 3.

(Tables 2 and 3 are positioned at the end of the Results section.)

3.2 *Helicoverpa* studies

3.2.1 Pheromone traps

The numbers of *H. armigera* and *H. punctigera* caught in the pheromone traps each week in 1995-96, 1997, and 1998 are shown in Figures 1a, b, and c respectively. A similar, but not identical pattern of *Helicoverpa* spp. occurrence and abundance was recorded in each year.

H. punctigera were rarely caught from January to September in each year. They appeared in the traps in September in 1996 and 1997 and in low numbers in 1998, in which year they arrived in numbers in mid October. In each year they only were trapped from about September to December.

H. armigera were trapped during the whole year with peaks in catches in the period from mid February – late April, and from late August to mid December. Catches of *H. armigera* generally were low in the winter months of May, June and July.

Very few other insects were caught in the traps. *Spodoptera litura* (F.) moths were recorded occasionally.

3.2.2 Egg collections

The numbers of eggs of each *Helicoverpa* species collected per person per hour from tomato crops in 1995-96, 1997, and 1998 are shown in Figures 2a, b, and c respectively. Similar patterns of occurrence were recorded in each year but the relative abundance of the two species differed from year to year.

H. punctigera eggs were collected from about September through to late February – early March each year. Numbers were highest from September to November each

year, and they were particularly high in 1997. *H. punctigera* eggs were not found from about April to August.

H. armigera eggs were collected all year although generally numbers were low from May to September. In each year numbers increased in about September and remained reasonably high, with the occasional drop, until March. Large numbers of *H. armigera* eggs were recorded from late March through April each year.

Figure 1a
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research during 1995-1996.

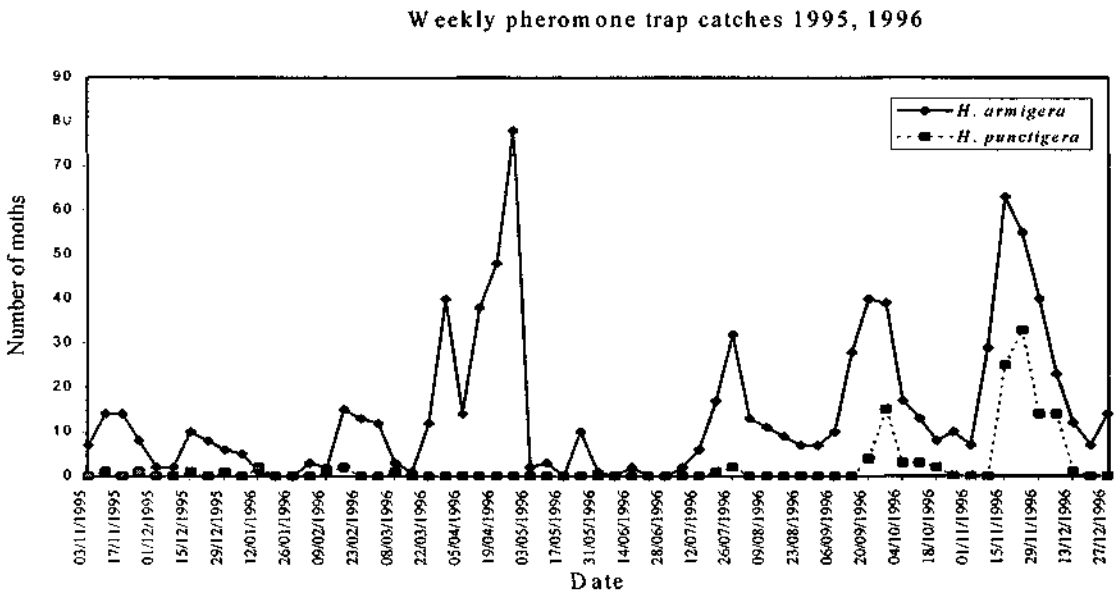


Figure 1b
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research during 1997.

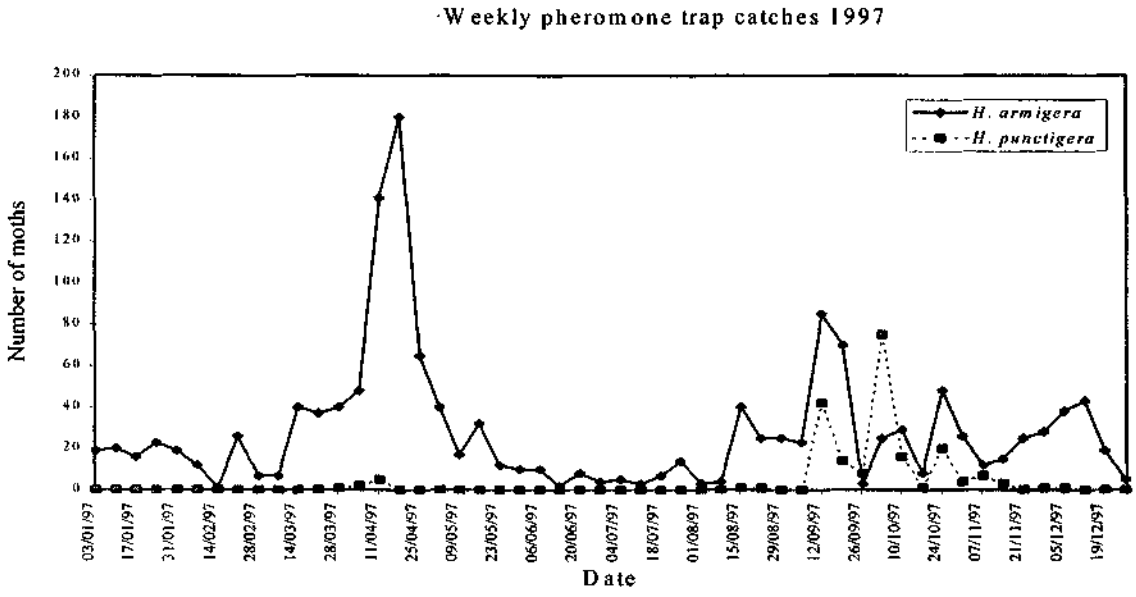


Figure 1c
Weekly pheromone trap catches of *Helicoverpa* spp. moths at Bundaberg Research during 1998.

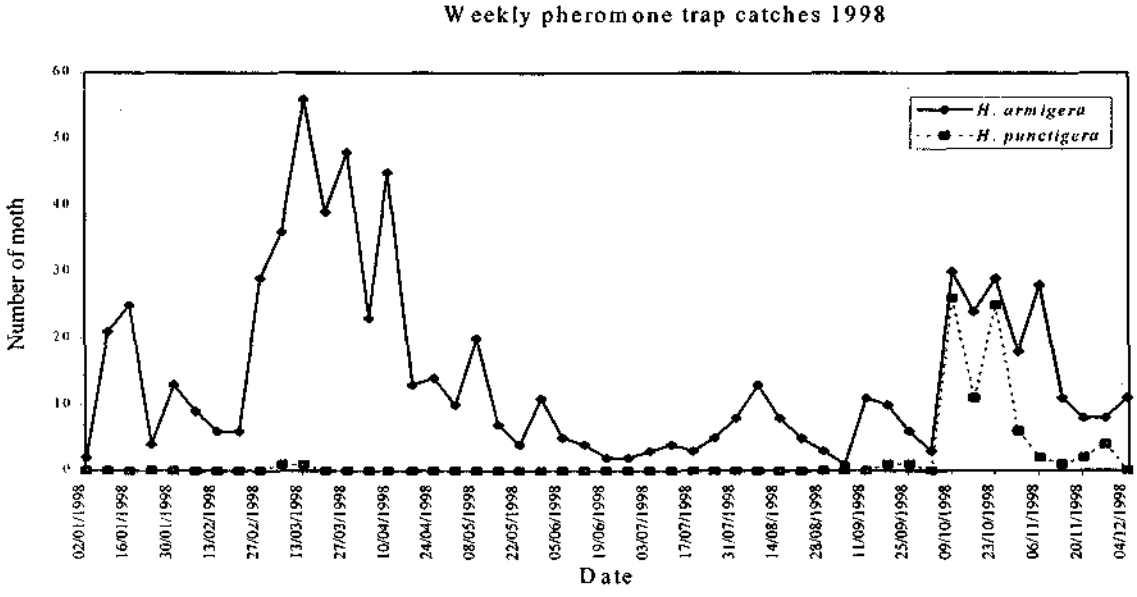


Figure 2a
The abundance of *Helicoverpa* spp. eggs in 1995-1996.

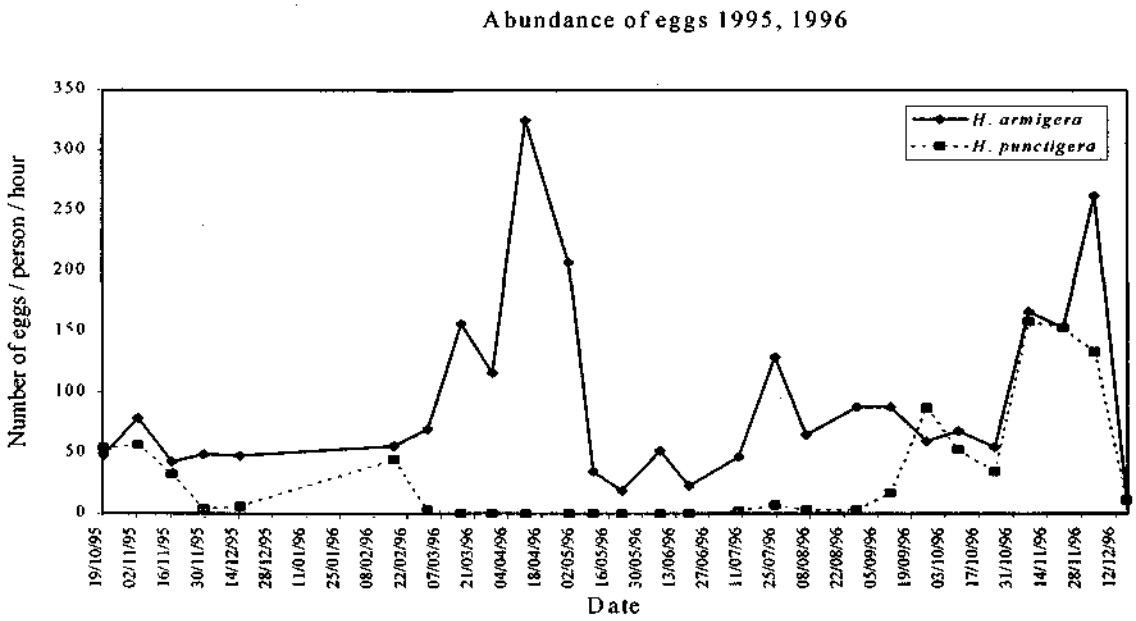


Figure 2b
The abundance of *Helicoverpa* spp. eggs in 1997.

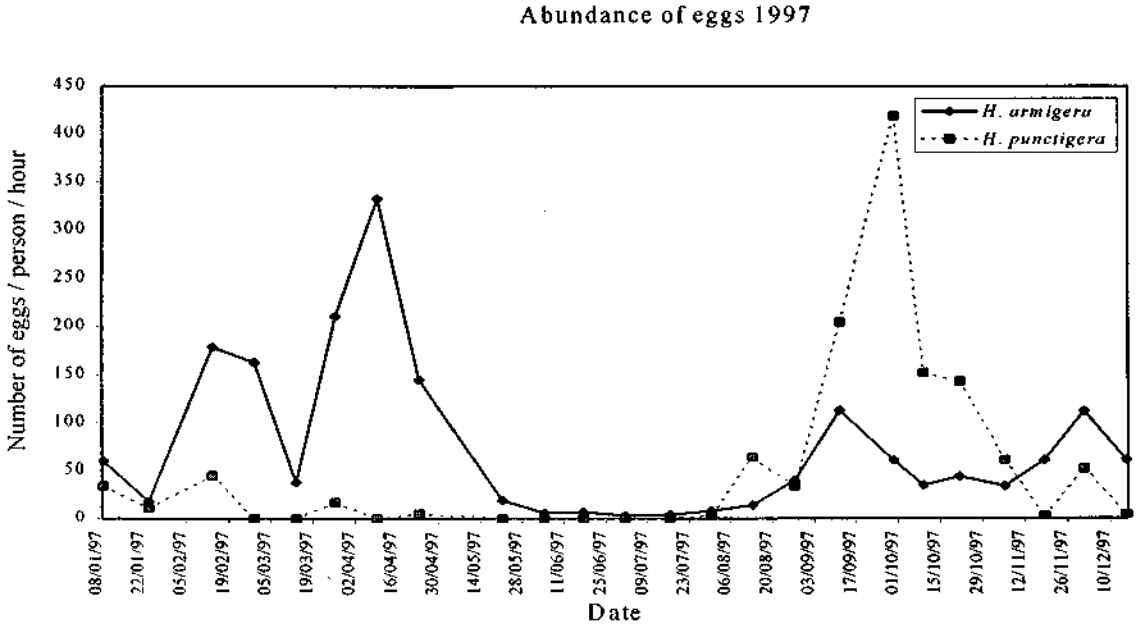
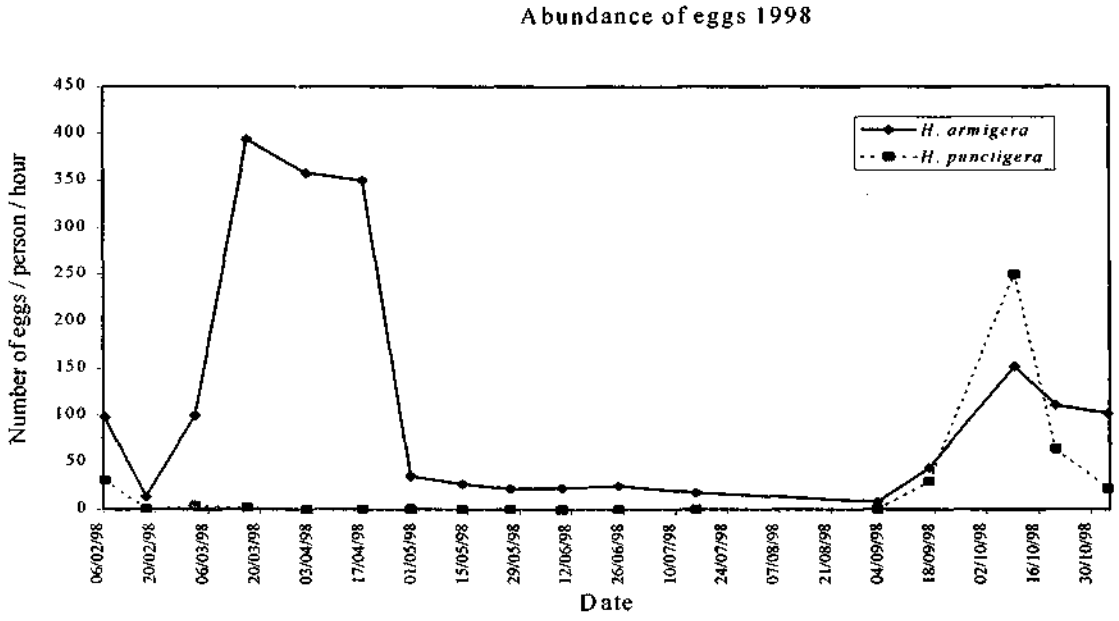


Figure 2c
The abundance of *Helicoverpa* spp. eggs in 1998.



3.2.3 Diapause

Tables 4, 5, and 6 show the percentage of pupae in diapause as determined by eyespot retention, and the duration of the pupal stages for non-diapause and diapause pupae for both assessment methods for each collection date for 1996, 1997 and 1998 respectively.

The preliminary investigations in 1996 (Table 4) indicated that a proportion of pupae developing as eggs and larvae during March-May entered pupal diapause. In the field moths emerged from diapause pupae from late August to November, with most emerging in mid to late September.

In 1997 the eyespot retention studies showed that a considerable proportion of pupae developing from eggs collected from mid March to early May entered diapause (Table 5). However the 1998 eyespot retention results (Table 6) indicated a much lower percentage of pupae entered diapause in that year. (This difference will be commented on in the Discussion.)

The field studies do not give accurate information on the proportion of non-diapause and diapause pupae as mortality factors are not necessarily the same because of the different lengths of time the two types of pupae spend in he soil. However some indication of the proportion in diapause can be gained from the number of moths emerging after winter (ie from diapause) compared to the number put into the cage. These results in 1998 indicated a higher percentage in diapause than indicated from the eyespot retention studies. (See Discussion.)

In the field studies moths emerged from diapausing pupae in from mid August to November, with peaks of emergence in mid-late September in 1996 and 1998, and late August – mid September in 1997.

Table 4

The incidence of pupal diapause as measured by eyespot retention and the duration of the pupal periods, and the duration of the pupal period for non-diapause and diapause larvae in the field in 1996. n is the number of pupae.

Date of egg collection or larval collection	Eyespot retention			Field		
	% in diapause (n)	Duration of pupal stage (days) ± SD (n)		Date of pupation (number put into cage)	Duration of pupal stage (days) ± SD (n)	
		non-diapause	diapause		non-diapause	diapause
Tomato						
1 March	0 (18)	21 ± 3 (14)	-	-	-	-
16 March	11 (9)	26 ± 7 (8)	171 ± 0 (1)	-	-	-
29 March	58 (24)	29 ± 4 (4)	140 ± 14 (10)	-	-	-
29 April	30 (23)	44 ± 7 (13)	96 ± 13 (7)	25 May (47)	46 ± 3 (5)	103 ± 15 (9)
14 May	86 (7)	-	85 ± 5 (2)	19 June (24)	43 ± 4 (3)	91 ± 10 (17)
28 May	-	-	-	10 July (9)	40 ± 0 (1)	53 ± 2 (4)
6 June	38 (8)	37 ± 3 (4)	51 ± 1 (2)	-	-	
21 June	0 (9)	35 ± 2 (8)	-	-	-	
Sweet corn						
15 March	2 (46)	18 ± 2 (39)	186 ± 0 (1)	19 March (20)	14 ± 3 (7)	-
2 April	13 (32)	22 ± 4 (19)	173 ± 3 (3)	3 April (41)	19 ± 4 (14)	184 ± 14 (11)
15 April	50 (16)	30 ±3 (5)	142 ± 11 (7)	19 April (33)	27 ± 3 (3)	171 ± 27 (15)

Table 5

The incidence of pupal diapause as measured by eyespot retention and the duration of the pupal periods, and the duration of the pupal period for non-diapause and diapause larvae in the field in 1997. n is the number of pupae.

Date of egg collection	Eyespot retention			Field		
	% in diapause (n)	Duration of pupal stage (days) ± SD (n)		Date of pupation	Duration of pupal stage (days) ± SD (n)	
		non-diapause	diapause		non-diapause	diapause
14 March	53 (15)	29 ± 2 (7)	171 ± 15 (8)	-	-	-
19 March	39 (46)	missing	175 ± 19 (14)	11 April	23 ± 1 (24)	166 ± 19 (14)
26 March	58 (120)	31 ± 2 (45)	161 ± 11 (11)	18 April	24 ± 2 (17)	153 ± 11 (9)
2 April	46 (54)	33 ± 4 (24)	161 ± 16 (23)	25 April	26 ± 2 (15)	151 ± 13 (14)
9 April	38 (56)	40 ± 6 (25)	138 ±19 (16)	6 May	32 ± 3 (24)	126 ± (12)
16 April	73 (67)	43 ± 6 (10)	133 ± 10 (33)	13 May	36 ± 9 (23)	112 ± 24 (14)
23 April	83 (35)	49 ± 0 (2)	127 ± 7 (19)	21 May	39 ± 4 (7)	111 ± 20 (21)
1 May	88 (24)	51 ± 0 (1)	106 ± 10 (12)	30 May	42 ± 5 (3)	99 ± 18 (19)

Table 6
The incidence of pupal diapause as measured by eyespot retention and the duration of the pupal periods, and the duration of the pupal period for non-diapause and diapause larvae in the field in 1998. n is the number of pupae.

Date of egg collection	Eyespot retention			Field		
	% in diapause (n)	Duration of pupal stage (days) ± SD (n)		Date of pupation	Duration of pupal stage (days) ± SD (n)	
		non-diapause	diapause		non-diapause	diapause
26 Feb	0 (98)	15 ± 2 (87)	-	14 March	14 ± 4 (32)	-
5 March	2 (83)	16 ± 2 (64)	184 ± 3 (2)	21 March	13 ± 1 (20)	-
11 March	3 (35)	19 ± 3 (29)	164 ± 0 (1)	31 March	15 ± 0 (1)	163 ± 13 (3)
18 March	8 (87)	21 ± 4 (72)	183 ± 38 (7)	4 April	35 ± 17 (9)	176 ± 11 (22)
26 March	26 (46)	23 ± 3 (26)	143 ± 25 (12)	15 April	25 ± 3 (7)	158 ± 15 (23)
1 April	15 (61)	27 ± 3 (37)	137 ± 19 (9)	21 April	25 ± 2 (12)	148 ± 20 (27)
8 April	13 (76)	31 ± 4 (50)	134 ± 29 (9)	28 April	31 ± 3 (22)	146 ± 16 (11)
16 April	20 (110)	38 ± 4 (63)	115 ± 24 (19)	8 May	36 ± 4 (2)	132 ± 10 (27)
23 April	35 (48)	44 ± 4 (17)	105 ± 25 (14)	19 May	57 ± 0 (1)	111 ± 10 (35)
29 April	43 (21)	46 ± 2 (9)	90 ± 7 (5)	-	-	-

3.3 *Phthorimaea operculella* studies

3.3.1 Occurrence in crops

The mean number, and the number as the percentage of the total, of *P. operculella* larval mines and larvae recorded in the three height sections of tomato plants are shown in Table 7.

The data show that very few mines or larvae were found in the top third of the plants. Between 10 and 23% of mines and 14–44% of larvae were found in the middle third of plants, while 77-84% of mines and 55-86% of larvae were in the bottom third of the plants.

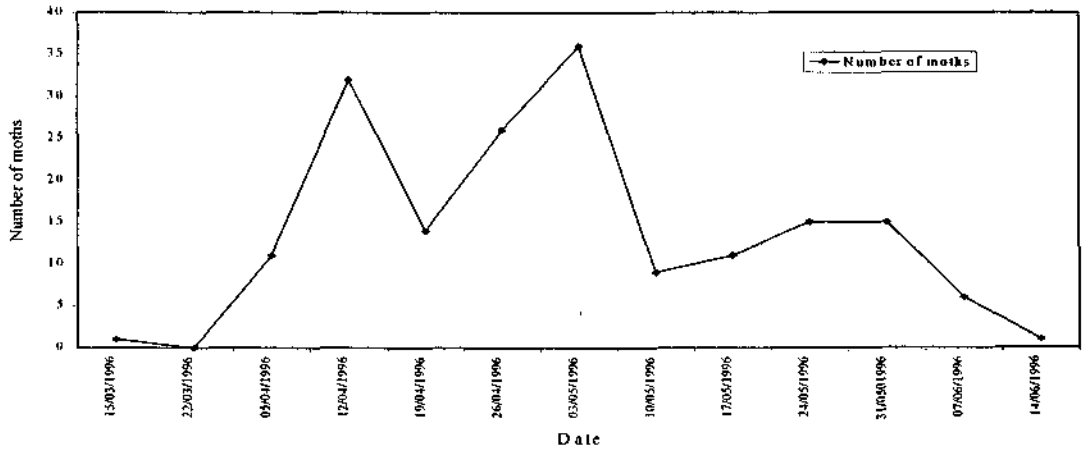
The pheromone trap catches (total of two traps) in the autumn 1996 crop are shown in Figure 3. Numbers were low, but the presence of the three peaks suggests that three generations of moths developed during the life of the crop. A fourth generation may

have emerged from the crop residue. Very few to no mines or larvae were found in the weekly leaf samples, so no details of these samples are reported here.

Table 7
The mean number, and the number as the percentage of the total, of *P. operculella* larval mines and larvae recorded in the three height sections of tomato plants in 1995-1996.

Day	Pl.H t.cm	Top section				Middle section				Bottom section			
		Mines		Larvae		Mines		Larvae		Mines		Larvae	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
24 Nov	75	2.3	8	0.3	3	3	10	2	19	26	82	8	77
29 Nov	90	0.3	0	0.3	1	16	23	9	44	55	77	11	55
6 Dec	100	0.8	1	0	0	12	17	3	14	58	82	17	86
14 Dec	110	0	0	0	0	13	20	4	24	50	80	13	76
20 Dec	110	0	0	0	0	12	16	3	32	66	84	6	68
2 Jan	123	1	1	0.3	13	14	21	0.5	25	50	77	1.3	62

Figure 3
Number of *P. operculella* moths caught each week in two pheromone traps in the 1996 autumn crop.



Pheromone trap catches in the spring 1996 crops are shown in Figure 4, and the results of the larval sampling are presented in Figure 5. Moth numbers were very high throughout the crop's life and generational peaks are difficult to determine. Similarly, larval numbers were high, and the results difficult to interpret.

Figure 4
Number of *P. operculella* moths caught each week in two pheromone traps in the 1996 spring crop

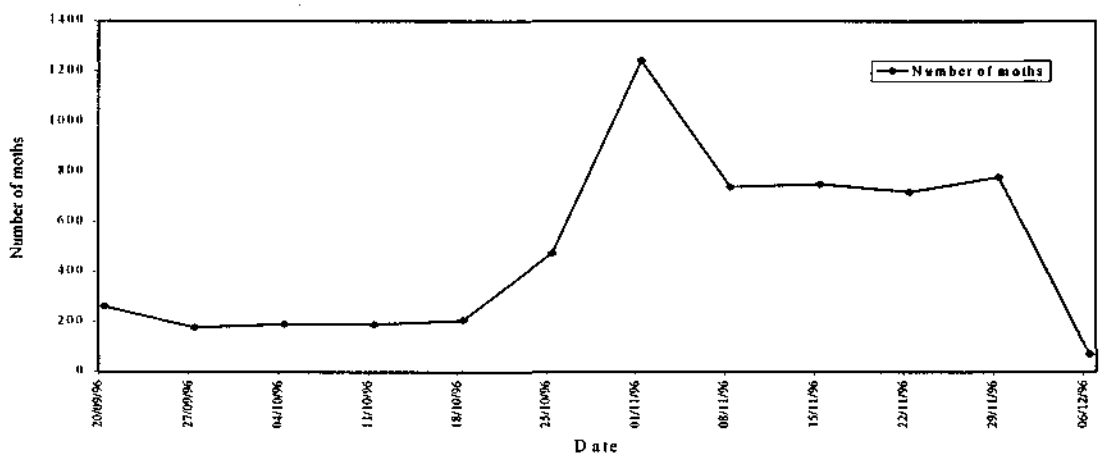
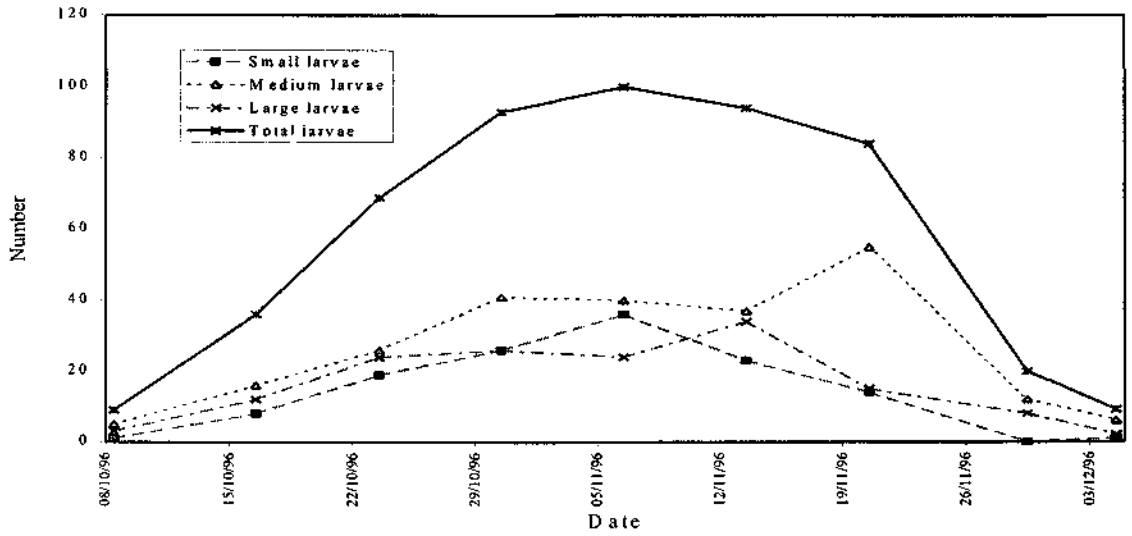


Figure 5
Numbers of *P. operculella* larvae in 40 leaves and their size composition in the 1996 spring crop.



Pheromone trap catches in the spring 1997 crops are shown in Figure 6, and the results of the larval sampling are presented in Figure 7. Moth numbers were very high and two clear peaks in numbers are apparent, and these may represent two generations that have developed in the crop. The larval counts indicate that three generations developed in the crop but that generations overlapped considerably.

Figure 6
Number of *P. operculella* moths caught each week in two pheromone traps in the 1997 spring crop.

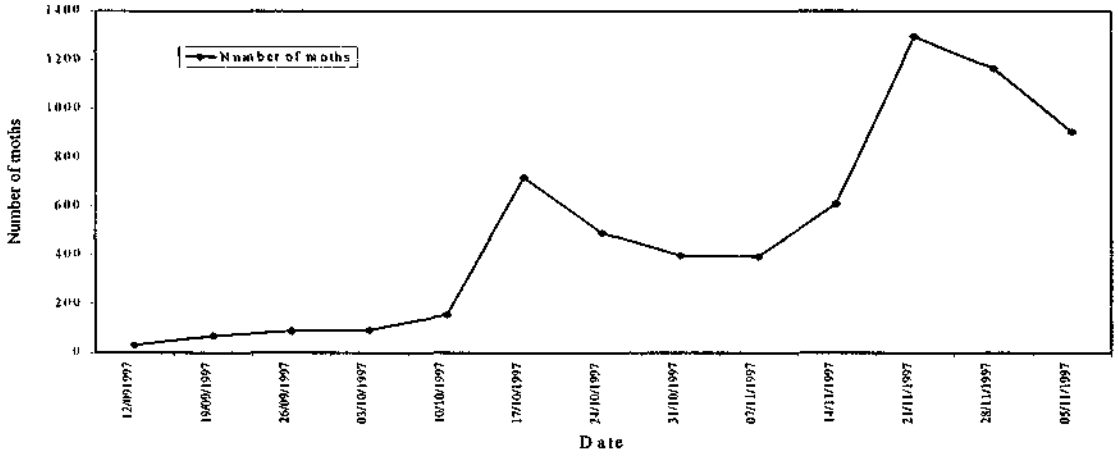
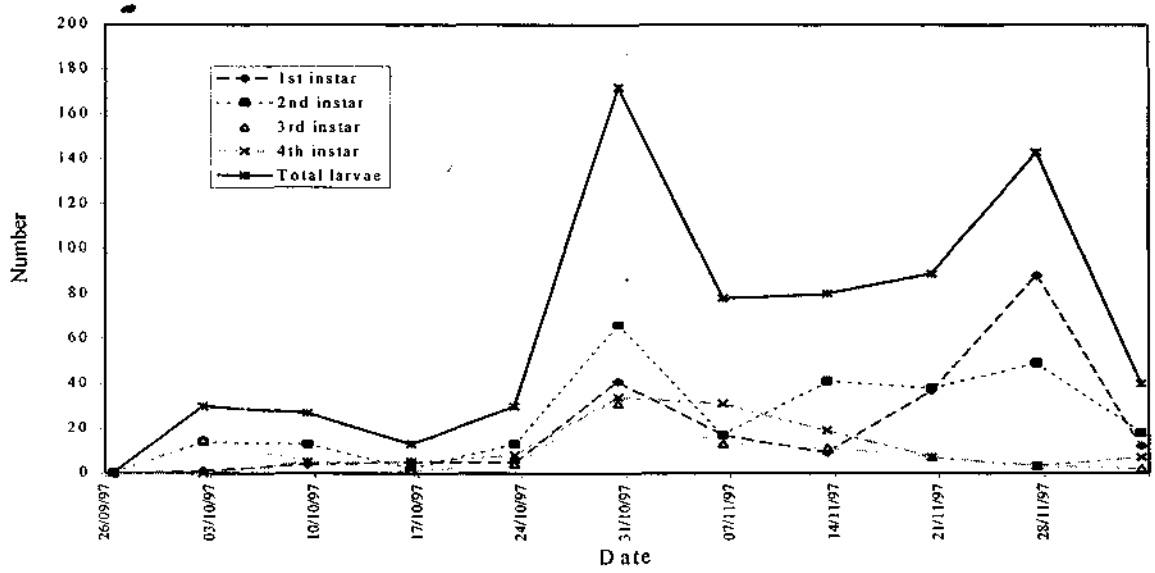


Figure 7
Numbers of *P. operculella* larvae in 40 leaves and their instar composition in the 1997 spring crop.



Pheromone trap catches in the autumn 1998 crops are shown in Figure 8, and the results of the larval sampling are presented in Figure 9. Moth numbers were quite low for much of the crop life, although moderate numbers were recorded in one week. Generations are hard to distinguish. Larvae were not found for five weeks and then it appears that three to four overlapping generations developed in the crop.

Figure 8
Number of *P. operculella* moths caught each week in two pheromone traps in the 1998 autumn crop.

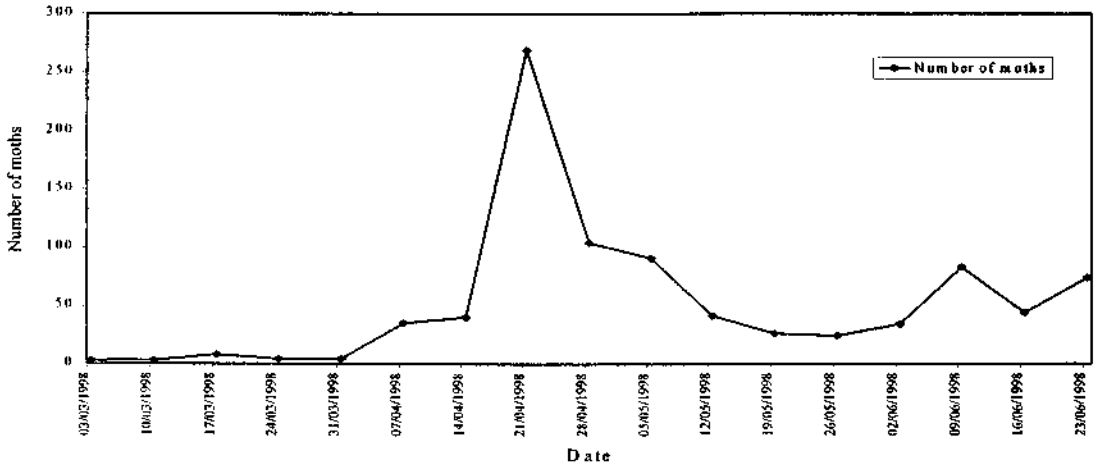
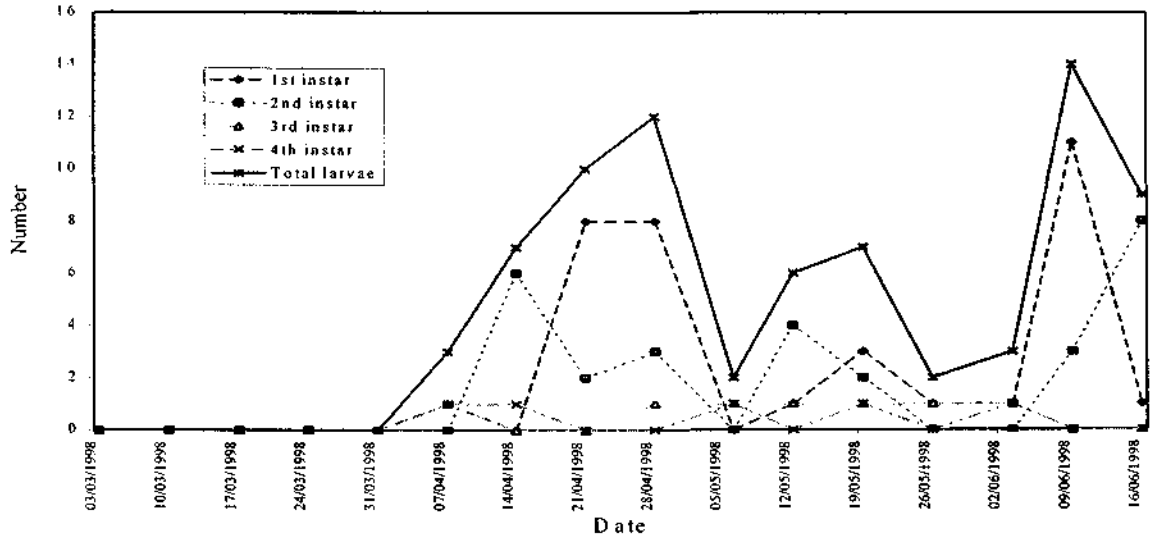


Figure 9
Numbers of *P. operculella* larvae in 40 leaves and their instar composition in the 1998 autumn crop.



3.3.2 Parasitism

No parasitoids were reared from weekly collections of larvae from 23 November 1995 to 2 January 1996, while 361 moths emerged. Nine *Apanteles subandinus* Blanchard

were reared and 469 moths emerged from larvae collected weekly from 8 October 1996 to 4 December 1996. Five *A. subandinus* and 53 moths were reared from a larval collection taken on 14 November 1997.

3.3.3 Are capsicums a host?

The numbers of larval mines and live larvae recorded are shown in Table 8. No evidence of leaf mining by *P. operculella* was detected on the capsicum leaves, and no larvae were recovered. In contrast, medium to large mines were obvious on 90% of infested tomato leaves, and 67.5% of the larvae were recovered which indicates that the infestation technique worked and that the larvae used in the experiment were healthy. Several tomato plants in the CT room deteriorated and datum leaves died. Mines, but not live larvae, were found in these leaves.

Table 8
The number of larval mines on capsicum and tomato plants and the number of live *P. operculella* larvae recorded seven days after infestation.

Day	Planthouse				CT Room			
	Tomato		Capsicum		Tomato		Capsicum	
	Mines	Larvae	Mines	Larvae	Mines	Larvae	Mines	Larvae
1	5	5	0	0	3	2	0	0
2	5	5	0	0	5	3	0	0
3	3	1	0	0	5	1	0	0
4	5	5	0	0	5	5	0	0
4	Growing points						0	0
4	Growing points						0	0

There was no evidence of larval tunnelling or other damage to the growing points of the capsicums and no larvae were recovered.

3.3.4 Insecticides

The results of the two trials are shown in Table 9.

3.4 *Trichogramma* studies

3.4.1 Assessing natural infestations

The percentage of *Helicoverpa* species eggs parasitised in the unsprayed and sprayed tomato crops in 1995 are given in Table 10, and the percentage of *Helicoverpa* species eggs parasitised in the crops sampled in 1996 and 1997 are given in Table 11.

Table 9

Numbers of live *P. operculella* larvae per plant seven days after spraying. Plants were infested with 10 larvae each immediately after spraying (0 day larvae) or two days before spraying (2 day larvae).

Treatment (g ai / ha)	Mean number of live larvae *	
	0 day larvae	2 day larvae
Trial 1		
check (water only)	8.99 a #	8.72 a
imidacloprid (59.5)	8.49 a	8.99 a
ROY 2390 (300)	7.49 a	7.97 a
spinosad (96)	2.24 b	6.38 a
abamectin (8.1)	1.74 bc	5.18 a
sulprofos (720)	0.77 c	3.62 a
Trial 2		
check (water only)	9.49 a	8.48 a
spinosad (96)	2.21 b	5.95 a
sulprofos (720)	1.49 b	6.42 a
abamectin (8.1)	0.98 b	2.66 b
abamectin (10.8)	0.77 b	2.20 b

* Back-transformed means following square root (x + 0.5) transformation before analysis.

For each trial in each column means followed by the same letter are not significantly different at the 5% level.

Table 10

The percentage of *Helicoverpa* species eggs parasitised in the unsprayed and sprayed tomato crops in 1995. *Trich.* = *Trichogramma; T'oid.* = *Trichogrammatoidea; Telen.* =*Telenomus.* n = number of eggs.

Date 1995	Percentage of *Helicoverpa* eggs parasitised							
	Unsprayed				Sprayed			
	Trich.	*T'oid.*	*Telen.*	Total (n)	*Trich.*	*T'oid.*	*Telen.*	Total
19 Oct.	0	0	0	0 (33)	1.7	0	0	1.7 (59)
2 Nov.	0	0	1.4	1.4 (70)	0	0	0	0 (49)
16 Nov.	0	0	0	0 (55)	0	0	0	0 (17)
29 Nov.	2.3	18.2	0	20.5 (44)	0	4.2	0	4.2 (24)
14 Dec.	0	47.8	0	47.8 (38)	3.7	11.1	0	14.8 (54)

Egg parasitism reached moderate (48%) to high (87-92%) levels in the unsprayed crops sampled. The sprayed crop sampled in 1995 had a lower level of parasitism than the unsprayed crop. Three genera of parasitoids emerged from parasitised eggs. Species of *Trichogramma* and *Trichogrammatoidea* are difficult to separate and so species have not been separated here. All the *Trichogramma* were a dark species (Scholz 1994) and probably two species of *Trichogrammatoidea* were reared. These probably were *T. robusta* Nagaraja and *T. bactrae* Nagaraja. In the 1996 and 1997 crops *Trichogramma* were initially the dominant parasitoids, but they were replaced by *Trichogrammatoidea* spp. late in the crop life. *Telenomus* sp. were not common.

Table 11
The percentage of *Helicoverpa* species eggs parasitised in the unsprayed and sprayed tomato crops in 1996 and 1997. n = number of eggs.

Date	Percentage of *Helicoverpa* eggs parasitised			
	Trichogramma	*Trichogramm-atoidea*	*Telenomus*	Total (n)
Autumn 1996				
21 March	9.4	0	0	9.4 (53)
29 March	18.2	6.5	0	24.7 (77)
4 April	-	-	-	-
12 April	27.6	11.5	0	39.1 (87)
19 April	31.5	21.8	0	53.3 (92)
26 April	42.0	39.5	0	81.5 (81)
3 May	15.4	76.9	0	92.3 (13)
Spring 1996				
4 October	2.3	2.3	0	4.6 (43)
10 October	23.3	0	0	23.3 (30)
17 October	3.0	0	0	3.0 (65)
25 October	9.5	0	0	9.5 (42)
1 November	29.1	4.6	1.2	34.9 (86)
7 November	40.6	33.3	0	73.9 (96)
14 November	40.6	19.8	0	60.4 (96)
21 November	16.7	64.6	0	81.3 (96)
28 November	4.2	78.1	0	82.3 (96)
5 December	7.3	80.2	0	87.5 (96)
Spring 1997				
8 October	6.2	2.1	0	8.3 (96)
15 October	36.1	20.6	0	56.7 (96)
22 October	52.4	21.4	1.0	74.8 (103)
29 October	30.2	39.6	4.2	74.0 (96)
5 November	12.5	51.4	5.5	69.4 (72)
12 November	2.9	61.8	2.9	67.6 (34)
19 November	0	65.6	0	65.6 (93)
26 November	6.7	50.0	3.3	60.0 (30)

3.4.2 Assessing commercial releases

The results of the first monitored commercial release are shown in Table 12. No *Trichogramma* were reared from *Helicoverpa* eggs before or after the release. *Trichogrammatoidea* were reared at low percentages.

Table 12
The percentage of *Helicoverpa* spp. eggs parasitised before and after a commercial release of *Trichogramma* sp. in 1995. n = number of eggs.

Day of egg collection	Percentage of *Helicoverpa* spp. eggs parasitised		
	Trichogramma	*Trichogrammatoidea*	Total (n)
1 d pre-release	0	15.9	15.9 (44)
1 d post-release	0	22.6	22.6 (84)
2 d post-release	0	7.8	7.8 (77)
3 d post-release	0	9.1	9.1 (77)
5 d post-release	0	0	0 (48)

Figures 10 a and b show the results of the large commercial release trial. Parasitoids reared from collected eggs were identified with confidence to genus, and as accurately as possible to species using information supplied by B. Scholz and R. Llewellyn. *Trichogramma australicum* Girault was the main natural parasitoid present while *Trichogramma carverae* Oatman and Pinto and *T. robusta*, *T. bactrae* and *Telenomus* sp. also were recorded. *T.* nr *brassicae* was the main species found in the release block after releases started and a few were recovered in the check block. Parasitism rates reached nearly 60% in the release block compared to 23% in the check block but they fell rapidly once insecticides were used.

The parasitism rate of eggs on flowers (18.8 ± 6.5%, mean ± SD) did not differ significantly from that of eggs on leaves (15.6 ± 5.4%) ($t = 0.77$, 6 df, $p = 0.47$). All the parasitoids were *T.* nr *brassicae*.

Figure 10 a
Percentage parasitism of *Helicoverpa* spp. eggs in the release block. Fifteen releases of *Trichogramma* nr *brassicae* were made between mid August and early October.

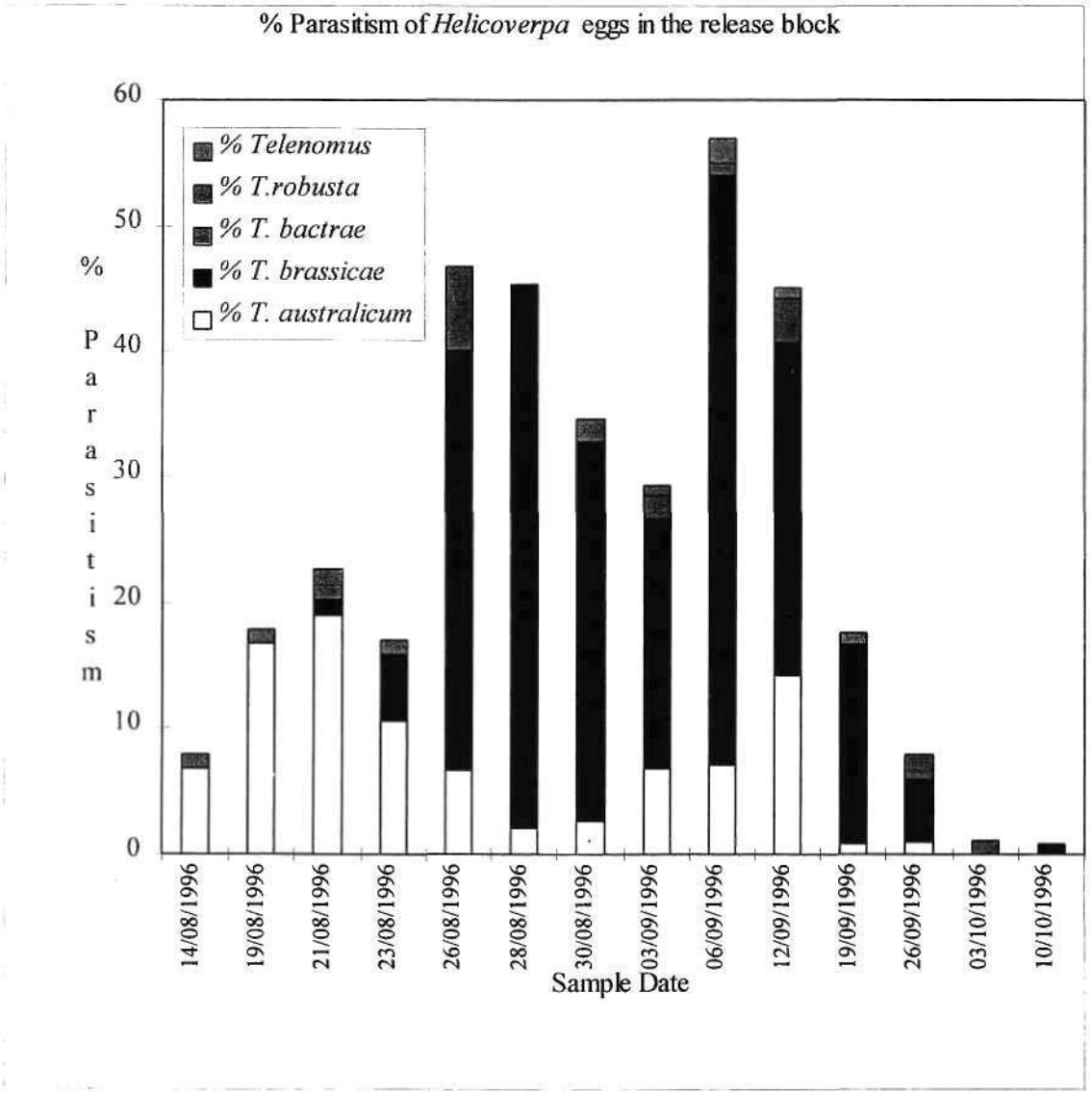


Figure 10 b
Percentage parasitism of *Helicoverpa* spp. eggs in the check block.

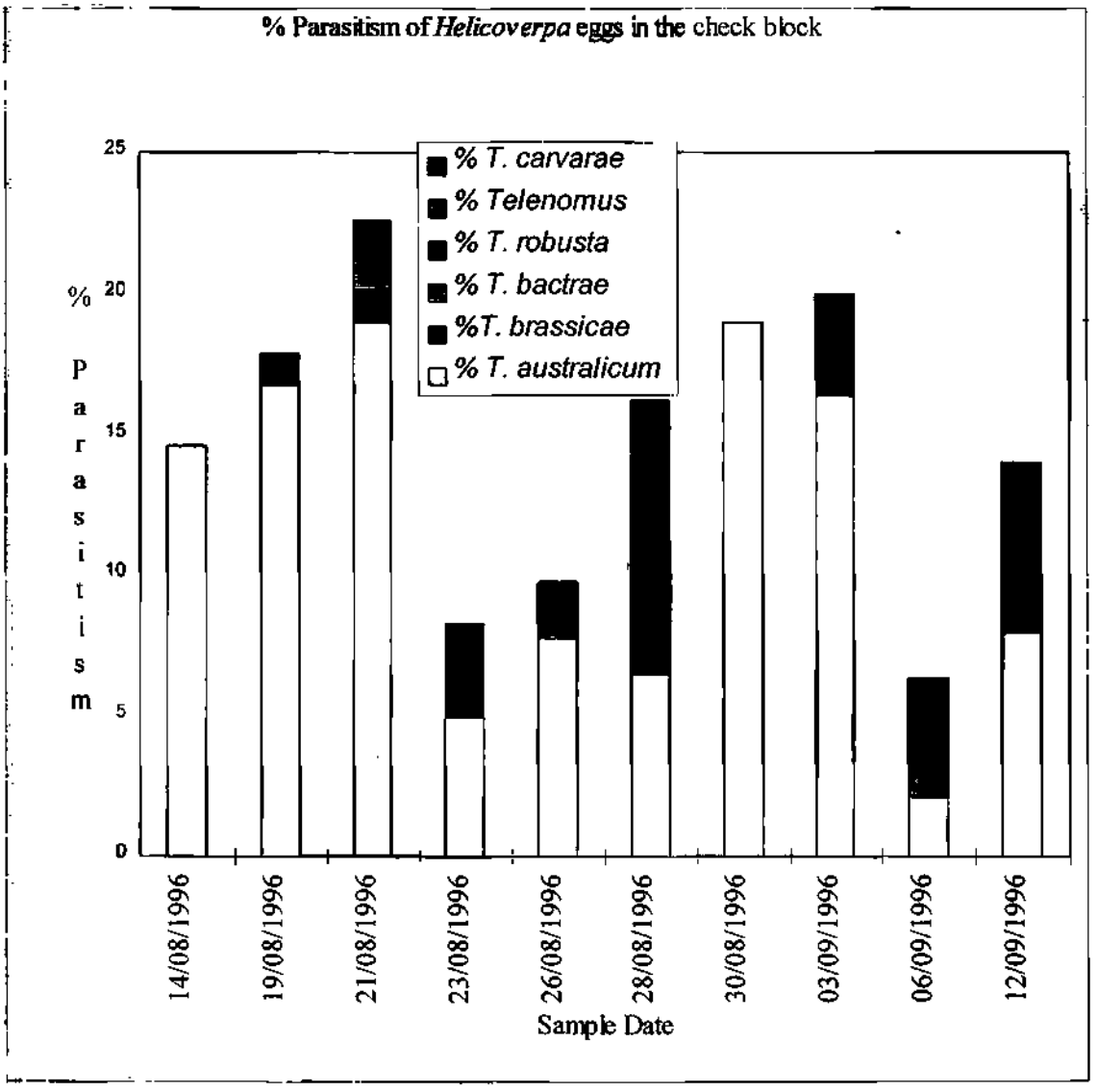


Table 2

Insects and mites collected from tomatoes in 1996. Collection methods are: 1 Suction trap; 2 Pitfall trap; 3 Sticky trap; 4 Whole plant bag trap; 5 Sweep net; 6 Hand; 7 Reared. "Unidentified species" may refer to one or multiple species.

Identification	Bundaberg		Bowen		Notes
	Autumn	Spring	Autumn	Spring	
INSECTS					
BLATODEA					
Blatellidae					
Ectoneura sp.	1, 3, 6	4			
COLEOPTERA					
Anthicidae					
Anthicus excavatus Champion			1, 2, 4		
Anthicus sp.	1, 2, 4	2, 4, 5	1, 3, 4, 6	2	
Anthribidae					
Araecerus sp.	2, 3, 4, 6	1, 4			
Apionidae					
Apion sp.			5		
Rhinorhynchidius sp.			4		
Cantharidae					
unidentified species	2				
Carabidae					
unidentified species	2	4		2	
Chrysomelidae					
Acanthoscelides macrophthalmus (Schaeffer)			5		
Aphthona scutellatus Baly			4		
Aulacophora hilaris (Boisduval)		5			
Monolepta australis (Jacoby)	5	6			

Rhyparida sp.	4				
Coccinellidae					
Coccinella transversalis Fabricius		4, 6	3, 6		
Coelophora inaequalis (Fabricius)			1, 6		
Epilachna 28-punctata pardalis (Boisduval)	6	1, 2, 6, 7	1		larvae feeding on leaves
Halmus ovalis (Blackburn)	6				
Scymus (Pullus) mitior Blackburn	4				
unidentified species			1, 4	5	
Corylophidae					
unidentified species	1, 2, 4	1, 2, 4, 5	1, 2, 3, 4, 5	1, 2, 4	
Cucujidae					
Cryptamorpha dejardinisi (Guerin)	1, 3, 4, 6	1,2, 4, 5			
Curculionidae					
Hypocryphalus mangiferae (Stebbing)			4		
Hypothenemus sp.		5			
Lixus mastersi Pascoe			5		
Lixus sp.	3				
Xyleborus perforans (Wollaston)	2				
unidentified species (Scolytinae)			1, 2, 3, 4, 5	2	
Dermestidae					
Orphinus sp.			1, 4	2	
Elateridae					
Conoderus sp.	3, 6	2, 4	2, 4, 6		
unidentified species	3		2	2	
Lanthridiidae					
Corticaria sp.	1, 3, 4, 5	1, 2, 4, 5	1, 3, 4		
Mordellidae					
Mordella sp.			3		
unidentified species	3		3		

Mycetophagidae					
Litargus sp.	1, 2, 3, 4	1, 2, 4, 5			
Typhaea stercorea (Linnaeus)	4	2, 4	2, 3, 4	2, 4, 6	
Nitidulidae					
Brachypeplus sp.	2	2, 4			
Carpophilus sp.	1, 2, 4	2, 4, 5		4, 6	
Lasiodactylus sp.		2			
Urophorus humeralis (Fabricius)	2, 3	2, 4, 5			
unidentified species			4		
Scarabaeidae					
Aphodius sp.	3				
Ataenius sp.		2	2	2	
Dasygnathus dejeani Macleay		2			
Trichiorhyssemus sp.			2, 3, 4	2, 4	
Staphylinidae					
unidentified species	2, 3, 4	1, 2, 4, 5	1, 2, 3, 4	2	
Tenebrionidae					
Gonocephalum sp.		6	4, 6	2, 6	
unidentified species	4				
CHILOPODA					
unidentified species	2				
COLLEMBOLA					
Entomobryidae					
unidentified species	1, 2, 3, 4	1, 2, 4	2, 3, 4	2	
DERMAPTERA					
Forficulidae					

Elaunon bipartitus Kirkby	1, 2, 4, 6	4			
Labiduridae					
Labidura sp.	2	2			
Nala lividipes (Dufour)			2	2	
DIPTERA					
Asteiidae					
Asteia sp.	1, 2, 4	5			
Cecidomyiidae					
unidentified species	1, 2, 3, 4, 5,	1, 2, 4	2, 3, 4		
Ceratopogonidae					
Alluaudomyia sp.		1			
Dasyhelea sp.	5				
Forcipomyia sp.	1, 4, 5		5		
Lasiohelea sp.	4				
unidentified species	1, 3, 4, 5, 6		1		
Chironomidae					
unidentified species	1, 3, 4, 5	1, 2, 4, 5	1, 3, 5		
Chloropidae					
unidentified species	1, 3, 4	4	1, 3, 4, 5		
Oscinellinae unidentified species	1, 5		1, 5		
Culicidae					
Aedes ? vigilax (Skuse)			1		
Aedes sp.	1		1, 3		
Dolichopodidae					
Amblylopsilopus sp.			5		
Mesorhaga sp.			5, 6		
Sympycnus sp.	1		6		
Drosophilidae					

Dettopsomyia nigrovittata (Malloch)	1				
Drosophila sp.	3, 4	4			
Drosophila (Drosophila) busckii Coquillett	4, 7	1			reared from larvae in fruit
Drosophila (Drosophila) sp.				2	
Drosophila (Hirtodrosophila) mixtura Bock		4			
Drosophila (Scaptodrosophila) ? bryani Malloch	1, 4	1			
Drosophila (Scaptodrosophila) enigma Malloch		4			
Drosophila (Scaptodrosophila) ? subnitida Malloch		1			
Drosophila (Sophophora) sp.	1, 4, 5, 6	1, 2, 4, 5	1	1, 6	
Scaptomyza australis Malloch	1, 4	1, 4, 5			
unidentified species	3, 5	2	3		
Empididae					
Drapetis sp.	1, 2, 4, 5	4	1, 4, 5		
Ephydridae					
Hydrellia sp.	4, 5		3		
Scatella sp.			1	1, 5	
unidentified species	3, 5	5			
Lauxaniidae					
Homoneura sp.	1, 5		1, 5		
Lonchaeidae					
Lamprolonchaea brouniana (Bezzi)	5	2, 4, 5		5	
Milichiidae					
unidentified species	3	1, 4	4		
Muscidae					
Atherigona orientalis Schiner	1, 4, 6, 7	1, 2, 4, 5, 7	2, 3, 5, 6, 7	1, 5, 7	reared from damaged fruit
Mycetophilidae					

Orfelia sp.		2			
unidentified species	1, 2, 4, 6	1	3, 5	1	
Otitidae					
Physiphora aenea (Fabricius)	5	4			
Phoridae					
Megaselia *scalaris* Loew	3				
Megaselia sp.	1, 2	1, 2, 4			
unidentified species	3	2	2, 3	2	
Psychodidae					
Brunetta sp.	1, 4	4			
Psychoda sp.	3, 4		1	2	
unidentified species	1, 2, 3, 4		1, 2, 3, 4		
Pyrgotidae					
unidentified species	4, 5, 6				
Sarcophagidae					
Heteromychia australis (Johnson & Tiegs)			5		
Scatopsidae					
Scatopse sp.		2			
unidentified species	3				
Sciaridae					
unidentified species	2, 3, 4	1, 2, 4	1, 2, 3	2	
Sepsidae					
Parapalaeosepsis plebeia (Meijere)	5, 6	1, 2, 4, 5	1		
Sphaeroceridae					
unidentified species	3, 4				
Stratiomyidae					
Hermetia illucens (Linnaeus)		2			
Odontomyia decipens (Guerin)		2			
Neoexaireta spinigera (Wiedemann)		2			

Syrphidae					
Eumerus sp.		5			
Simosyrphus grandicornis (Macquart)			5, 6		
Tachinidae					
Carcelia illota (Curran)	7	7			reared from *Helicoverpa* sp. larva, *Chrysodeixis* sp. larva
Chaetophthalmus dorsalis (Malloch)	7	7			reared from *Helicoverpa* sp. larva
Goniophthalmus australis (Baranov)	2, 5, 7	7	7		reared from *Helicoverpa* sp., *Spodoptera* sp larvae
Palpostoma sp.		4			
Peribaea sp.		4	7		reared from *Helicoverpa* sp. larva
Phasia sp.			5		
HEMIPTERA					
Aleyrodidae					
Trialeuroides vaporariorum (Westwood)	1, 4, 5	1, 4, 5			
unidentified species	3		3	1	
Anthocoridae					
Blaptostethus sp.	1				
Xylocoris sp.	4	2	2, 4		
unidentified species	1, 3, 4	1, 4	5		
Aphididae					
Aphis gossypii Glover	1, 2, 4, 5, 6	4	1, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	
Macrosiphum miscanthi (Takahashi)		6			
Myzus persicae (Sulzer)	1, 2, 4, 6	1, 4, 6		1, 2, 4, 5, 6	
Rhopalosiphum sp.		6			
unidentified species	1, 2, 3, 4, 5	1	1, 2, 3, 4, 5	2, 4	
Berytidae					

Metacanthus pertenerus vittatus Gross			5		
Cicadellidae					
Austroagallia torrida Evans		1, 2, 4	1		
Austroasca viridigrisea (Paoli)	1, 4, 5	1, 4, 5	1, 4, 5, 6		
Austroasca sp.	3		3, 5		
Balclutha sp.		6			
Cicadulina bimaculata (Evans)	1, 5		1, 3		
Myrmecophryne sp.		4	3		
Orosius argentatus (Evans)		1, 4, 6	5		
unidentified species	2, 3, 4, 5, 6	1, 4, 6	5	2, 5, 6	
Cicadidae					
Pauropsalta sp.		2			
Cixiidae					
Oliarus felis Kirkaldy			5	5	
Oliarus lubra Kirkaldy	3	7		2	reared from nymphs on roots of tomato plant
Coreidae					
Mictis caja Stal		5			
Cydnidae					
Cydnus ovulatus Dallas				2	
Cydnus sp.			2, 6		
unidentified species			4	4	
Delphacidae					
Cemus koebelei (Kirkaldy)	1, 4		1, 2, 3, 4		
Cemus sp.			1, 5		
Peregrinus maidus (Ashmead)			1	2, 5	
Perkinsiella saccharicida Kirkaldy	3, 4		3, 4, 5		
Phacalastor sp.			3		
Sogatella longifurcifera (Esaki & Ishihara)	3		1		

Sogatella sp.	5				
Toya sp.	5		3, 4, 5	1	
Diaspididae					
Odonaspis ruthae Kotinsky	3				
Flatidae					
Colgar sp.			1		
Siphanta sp.			3		
Lygaeidae					
Arocatus rusticus (Stal)	2				
Dieuches maculicollis (Walker)	4	4			
Geocoris lubra (Kirkaldy)		4	4		
Graptostethus varipictus Slater	4				
Horridipamera nietneri (Dohn)	4, 6		1		
Nysius clevelandensis Evans	1, 3, 4, 5	2, 4, 5	1, 4, 5		
Nysius vinitor Bergroth	1, 2, 3, 4, 5	1, 2, 4	1, 5	5	
Oxycarenus luctuosus (Montrouzier)				4, 6	
Pachygrontha austrina Kirkaldy			5		
Pamerapa thoracica (Distant)			6	2	
Plinthisus sp.			3	1, 4	
Spilostethus hospes (Fabricius)		4, 5			
Stylogeocoris sp.	1, 4				
Machaerotidae					
Pectinariophyes stalii (Spanberg)		6			
Miridae					
Campylomma liebknechti (Girault)	1, 3, 4, 5, 6	1, 2, 4, 5	1, 3, 4, 5		
Creontiades sp.	6	1, 4	5		
Deraeocoris signatus (Distant)	1, 3, 4, 5	1, 4, 6	1	1, 3, 6	
Nesidiocoris tenuis (Reuter)	1, 4, 5, 6	1, 5	1, 4, 5, 6		
Taylorilygus pallidulus (Blanchard)		6			

Tytthus mundulus (Breddin)	3		1, 3, 5, 6		
unidentified species	1, 3, 4, 5, 6	1, 2, 4			
Nabidae					
Nabis kinbergii Reuter	4	1, 2, 4, 5			
Pemphigidae					
unidentified species		4	1		
Pentatomidae					
Cermatulus nasalis (Westwood)		2			
Plautia affinis Dallas	4, 6	1, 2, 4	6	4, 5, 6	
Nezara viridula (Linnaeus)	1, 4, 6	4, 6	6	1, 5, 6	
Oechalia schellenbergii (Guerin-Meneville)		5, 6			
Psyllidae					
Mycopsylla fici (Tryon)		6			
unidentified species	3, 4, 5, 6	1, 4	1, 3, 5	4	
Reduviidae					
Coranus trabeatus Horvath		6			
Empicoris rubromaculatus Blackburn	1, 4	4	1		
Pristhesancus plagipennis Walker	6				
unidentified species	1, 2		1		
Triozidae					
unidentified species	6	1			
HYMENOPTERA					
Apidae					
Apis mellifera Linnaeus	5	4, 5	5	5	
Trigona sp.	5	6			
Aphelinidae					
unidentified species	3		3		

Braconidae					
Apanteles subandinus (Blanchard)	7	7			reared from *P. operculella* larva
Cotesia sp.		5, 6	4		
Diaeretiella rapae (M'Intosh)		7	1	1, 2, 4, 7	reared from aphid mummy
Microplitis sp.	7	5, 7	1, 5, 7	1, 5, 7	reared from *Helicoverpa* sp. larva
Microplitis sp.	7	7			reared from *Chrysodeixis* sp. larva
unidentified species Rogandinae			5		
Chalcidae					
Dirhinus sp.			1		
Epitranus sp.	4				
Colletidae					
unidentified species			5		
Encyrtidae					
Copidosoma ? floridanum (Ashmead)	1, 2, 4, 7	2, 4, 7		7	reared from *Chrysodeixis* sp. larva
Copidosoma sp.	3, 6				
unidentified species	3, 5	5			
Eulophidae					
Elachertus sp.	1, 4				
? Renaniana sp.	4				
unidentified species	4		3	2	
Eupelmidae					
Anastus sp.		1			
Evaniidae					
unidentified species	2				
Formicidae					
Cerapachys sp.				2	
Iridomyrmex bicknelli Emery	4				
Iridomyrmex purpurens sanguinea Forel				2, 6	
Iridomyrmex sp.	2, 4	2, 4	2, 6	2	

Paratrechina sp.	2	2	4		
Pheidole sp.	3		1, 2, 4, 5	1, 2, 4	
Rhytidoponera metallica (F. Smith)		2			
Rhytidoponera sp.	2, 4	2			
Solenopsis sp.				2	
Stigmacros sp.	4				
Technomyrmex sp.		4			
Tetramorium sp.	1, 2, 4, 5	2, 4			
unidentified species	3, 4, 6	2, 5	1		
Ichneumonidae					
Echthromorpha agrestoria insidiator (Smith)	6				
Heteropelma scaposum (Morley)	7	5	5, 7	7	reared from *Helicoverpa* sp. larva
Lissopimpla excelsa (Costa)	6	5			
Netelia sp.		4, 6			
Mymaridae					
Polynema ? joulei Girault	5				
unidentified species	5				
Pteromalidae					
Acroclisoides sp.	1, 4				
Canberrana sp.	1				
Pachycrepoides vindemmiae (Rondani)	1				
Trichomalopsis sp.	1, 4				
Scelionidae					
Anteromorpha australica Dodd	2		1		
Baryconus sp.	4				
Telenomus sp.	1		1		
Trissolcus basalis (Wollaston)	1, 2, 4				
unidentified species	3				
Scoliidae					

Campsomeris tasmaniensis Saussure		2			
Trichogrammatidae					
Trichogramma sp.	2				
Trichogramma spp.	7	7	7	7	reared from *Helicoverpa* spp. eggs
Trichogrammatoidea spp.	7	7	7	7	reared from *Helicoverpa* spp. eggs
LEPIDOPTERA					
Gelechiidae					
Phthorimaea operculella (Zeller)	1, 3, 4, 5, 7	1, 4, 5, 7	1, 4, 5, 7	1, 2, 4, 5, 7	reared from larva in leaves and fruit
Noctuidae					
Agrotis ipsilon aneituma Walker	7				reared from egg
Chrysodeixis argentifera (Guenee)	7	4, 7		5	reared from larva
Chrysodeixis eriosoma (Doubleday)	4, 7	6, 7		7	reared from larva
Helicoverpa armigera (Hubner)	1, 4, 5, 7	1, 4, 5, 7	1, 4, 5, 7	1, 4, 5, 7	
Helicoverpa punctigera (Wallengren)	1, 4, 5, 7	1, 4, 5, 7	1, 4, 5, 7	1, 4, 5, 7	uncommon in spring
Spodoptera litura (Fabricius)	4, 7	4, 7	7	7	reared from larva
Pyralidae					
Hymenia recurvalis (Fabricius)			1, 5	6	
MANTODEA					
unidentified species	4				nymph
NEUROPTERA					
Chrysopidae					
Chrysopa sp.	4	6			
unidentified species	2			2	nymphs
Hemerobiidae					
Micromus tasmaniae (Walker)	1	4, 6			
Myrmeleontidae					

Myrmeceon sp	4				
Nymphidae					
Nymphes myrmeleonides Leach		5			
ORTHOPTERA					
Acrididae					
unidentified species		1, 4, 5	4		nymphs
Gryllidae					
Lepidogryllus sp.		2			
Teleogryllus commodus/oceanicus (Walker/LeGuillou)				2	
unidentified species	3, 4	1	1, 2, 4		
Pyrgomorphidae					
Atractomorpha similis Bolivar			1, 4, 5, 6	4, 6	
PSOCOPTERA					
Ectopsocidae					
unidentified species	1, 2, 3, 4, 5	1, 4, 5	1, 2, 3	2, 4	
Hemipsocidae					
unidentified species	1, 2, 3, 4				
Lachesillidae					
unidentified species	4	1, 4			
Liposcelidae					
unidentified species	3		3		
Pachytroctidae					
unidentified species	1, 2, 3, 4		2, 3		
Psilpsocidae					
unidentified species	1		4		

THYSANOPTERA					
Merothripidae					
unidentified species	3				
Phlaeothripidae					
Karnyothrips melaleuca (Bagnall)	2				
unidentified species	1, 5, 6	4	1, 3, 4		
Thripidae					
Arorathrips mexicanus (Crawford)	3		1, 3, 4	4	
Arorathrips sp.			1		
Chirothrips ah Girault			3		
Frankliniella occidentalis (Pergrande)	3				a single individual
Frankliniella schultzei (Trybom)	3, 4		1, 3, 5	4, 6	
Neohydatothrips samayunkur Kudo			3		
Thrips tabaci Lindeman	3, 4, 5	1, 2, 4			
Thrips sp.	2				
unidentified species	3	1, 4	3		
MITES					
Suborder Acaridida					
unidentified species	4				
Suborder Actinedida					
Eriophyidae					
Aculops lycopersici (Massee)	6	6	6	6	
Tetranychidae					
Tetranychus urticae Koch	6	6			
Suborder Gamasida					
unidentified species	2, 3				
Suborder Oribatida					
unidentified species			2, 3		

Table 3

Spiders collected from tomatoes in 1996. Collection methods are: 1 Suction trap; 2 Pitfall trap; 3 Sticky trap; 4 Whole plant bag trap; 5 Sweep net; 6 Hand.

Identification	Bundaberg		Bowen		Total numbers collected	
	Autumn	Spring	Autumn	Spring	Bundaberg	Bowen
Amaurobiidae						
Badumna sp.	1				10	
Species a	1, 4				2	
Araneidae						
Araneus sp.a	1, 4	4			5	
Araneus sp. b	4	4			2	1
Celaenia sp.				1		1
Eriophora transmarina (Keyserling)	1	4			2	
unidentified	1				3	
unidentified juvenile	4	1			4	
Clubionidae						
Clubiona sp. a	1, 4, 5		4		28	1
Clubiona sp. b	1, 4	1	1, 5	2, 6	17	4
Clubiona sp. c	1, 4				8	
Clubiona sp. d	4	1			5	
unidentified	4	4	1, 3, 4	2	2	5
Corinnidae						
Corinnomma sp.			1			1
Supunna sp.	3				1	
Dictynidae						
unidentified		4			2	
Gnaphosidae						
Species a	1, 2, 4	4		4	7	1

Species b		1, 4			2	
unidentified juvenile	4			2	1	1
Heteropodidae						
Heteropoda sp.	4				1	
Linyphiidae						
Erigone sp.	1, 4	2, 4			11	
Species a	1, 2, 4	4		2	12	3
Species b	1, 2, 4	4			10	
Species c	1, 2	2			7	
Species d		1, 2, 4		2	27	2
Species e		1, 2, 4			6	
Species f		4			4	
unidentified juveniles	1, 2, 4	2	5		10	1
Lycosidae						
Lycosa sp. a	1, 2, 4, 5	2, 4	4, 5		15	4
Lycosa sp. b	2		2, 4	2	2	9
Lycosa sp. c		2	2	2	10	14
Lycosa sp. d		4		2	1	1
Lycosa sp. e		2			1	
unidentified			3			1
unidentified juvenile	1				1	
Mimetidae						
Australomimetus sp.			4			1
Miturgidae						
unidentified species		2			1	
Oxyopidae						
Oxyopes sp. a	1, 4				3	
Oxyopes sp. b	1, 4		1, 4, 5	2	4	15
Oxyopes sp. c	1	1, 4	1, 5		6	11

Oxyopes sp.d			1, 4, 5	1, 4	2	24
Pisauridae						
Dolomedes sp.	1, 2, 3, 4	1, 4			19	
Salticidae						
Bianor maculatus (Keyserling)	1			2	1	1
? *Cytaca* sp.	1				1	
Frigga sp.		5			1	
Helpis sp.	4				1	
Lycidas sp.	5		1		1	1
Myrmarachne sp. a	1, 2, 3, 4	4			13	
Myrmarachne sp. b	1, 4				1	
Myrmarachne sp. c	2				1	
Plexippus sp.				2		1
unidentified	3		3		1	1
unidentified juvenile	4				1	
Tetragnathidae						
Deliochus sp.	4				1	
Leucauge dromedaria (Thorell)	1, 3, 5		4		3	1
Phonognatha sp.	1				2	
Tetragnatha sp. a	4	5	5		2	1
Theridiidae						
Achaearanea sp. a	1, 4, 5	1, 4, 5	4	4, 6	42	7
Achaearanea sp. b	4	4	4	4, 6	14	4
Achaearanea sp. c	1	1			2	
Argyrodes antipodiana O. P. Cambridge	1				2	
Steotoda sp.	4				1	
Theridion sp.a	1, 4	1, 4		2, 4, 6	21	3
Theridion sp. b	1, 4				10	
Theridion sp. c	4	4			4	

Theridion sp. d	1				2	
unidentified	1	1		2	2	
Thomisidae						
Diaea sp. a	1, 3, 4	4, 5	1, 4, 5	5	15	14
Diaea sp. b	4	4			4	
Tibellus sp.				6		1

4.0 Discussion

4.1 Survey of the arthropod fauna

Approximately 222 species in 100 families in 14 Orders of insects were collected in tomatoes at Bundaberg, and approximately 153 species in 79 families in 11 Orders were collected at Bowen. (The category "unidentified species" in each family was counted as one species for this purpose.)

A wide variety of insects were found in tomato crops. Some of these probably were transients through the crop and so are of little importance for pest management. Others are feeders on decaying organic matter or on fungi and, while they are important in the tomato ecosystem as decomposers and as prey for others, they are of little economic significance. The drosophilid flies and some of the small beetles (eg *Cryptamorpha dejardinisi*) are examples. Some of the insects feed on the tomato plant and so are pests while others are parasitoids or predators. The survey collected all of the major pests of tomatoes with the exception of *Bactrocera tryoni* (Queensland fruit fly) (see Hargreaves and Kay 1994; Smith 1958, Smith 1977), and many recognised important beneficial insects.

Despite this intensive sampling it is unlikely that this list contains all the insects that will occur in tomatoes. Some insects are sporadic in occurrence and they may be present in other years. The sampling techniques used, although varied, may not have collected some species. For example, *B. tryoni* was not collected in this survey.

Both chlorothalonil and mancozeb were applied to the tomato crops for disease management. Both of these are fungicides and little adverse effect on the arthropod fauna was expected from their use. Livingstone *et al.* (1978) showed chlorothalonil had little effect on predators. However Yardim and Edwards (1998) suggested that weekly applications of chlorothalonil in tomatoes resulted in small reductions in the populations of coccinellids, anthocorids, and spiders. Croft (1990) reviewed work on the toxicity of pesticides to a number of natural enemy species and reported that mancozeb was moderately harmful to a trichogrammatid, a neuropteran, and a syrphid. Broadley and Thomas (1995) suggest that mancozeb has low toxicity to to a range of beneficial arthropods including wasps, coccinellids, and a neuropteran. It is not known if the fungicides had any adverse effect on arthropods in the surveyed crops but it is likely that any such adverse effect would have been small.

The data indicate that a greater diversity of insects occur in tomatoes at Bundaberg than at Bowen. While this may be the case, some caution should be exercised when interpreting these data. Different teams of people conducted the sampling at each location and while the methods used were essentially the same some variations in sampling efficiency and effectiveness may have occurred. The crop architecture differed between the two locations with the Bundaberg crops trellised and the Bowen crops grown on the ground, and this difference may have affected the efficiency of some of the sampling techniques. In particular, the whole plant bag traps were difficult to use on the ground crops at Bowen so their efficiency probably was much lower there than when they were used at Bundaberg on trellised crops. However this difference in crop architecture may have a real influence on the species richness and diversity in tomatoes between the two locations, with the trellised crops providing a

greater range of habitats for insects to use. The differing climates may have been important in determining the species present at each location.

Further discussion on the insects collected will be made under Order headings.

Coleoptera. Among the known pests, the red-shouldered leaf beetle, *Monolepta australis*, was recorded in both autumn and spring crops at Bundaberg but it was not recorded at Bowen. *M. australis* is a sporadic pest and it is known to occur in the Dry Tropics region (eg Kay and Brown 1991). *Epilachna 28-punctata*, the twentysix-spotted potato ladybird, is a minor pest. The record of *Gonocephalum* sp. is interesting. A lot of extension literature on tomatoes lists *G. carpentariae* (Blackburn), the northern false wireworm, as the species whose larvae and adults cause occasional damage to tomatoes, particularly at Bowen (eg Swaine *et al.* 1991). The *Gonocephalum* adults collected in this survey could not be identified to species but they were not *G. carpentariae* (J. Donaldson pers. comm.). It would be instructive to do more intensive sampling of this insect at both Bowen and Bundaberg to determine the species present and those responsible for causing damage.

Beetles in the families Anthicidae, Anthribidae, Corylophidae and Mycetophagidae probably were associated with leaf litter and were general scavengers or were feeding on fungi (Lawrence and Britton 1991). *C. desjardinisi*, which was common at Bundaberg but was not found at Bowen, feeds on moulds and decaying vegetable matter (late K. Houston pers. comm.). Nititulids were common in rotting fruit.

There were few predatory beetles. Carabids were scarce with only a few specimens of an unidentified species collected. Several species of predatory coccinellid were collected but a greater range of species have been reported in studies on other crops (Bishop and Blood 1977, Cantrell *et al.* 1983). The role of the staphylinids, all very small specimens, is not known. The red and blue beetle, *Dicranolaius bellus* (Guerin-Meneville) was a notable absentee from the range of predatory beetles found. This beetle is considered a common and important predator in cotton crops in Australia (eg Pyke and Brown 1996) but it was not recorded in tomatoes in this survey and it has not been noted in the crop at other times.

Dermaptera. Adults and nymphs of the predatory earwig *Labidura* sp. were collected frequently in pitfall traps at Bundaberg but they were absent from collections at Bowen. In contrast, the pest species *Nala lividipes* was taken at Bowen but not at Bundaberg.

Diptera. Many of the flies recorded probably are of little importance in tomatoes. Some were probably transients (eg the families Cecidomyidae, Ceratopogonidae, Chironomidae, and Culicidae). Others probably were breeding in decaying vegetation and rotting fruit, and some definitely were doing this. The muscid *Atherigona orientalis* was common in both seasons in both locations. Although it is a secondary pest whose eggs and larvae are found in damaged, rotting fruit, it is a pest of quarantine significance. Vinegar flies, family Drosophilidae, were common at both locations, and their apparent scarcity at Bowen may be more a factor of lack of rigour in sorting and curating them than of their absence.

The metallic green tomato fly, *Lamprolonchaea brouniana*, a minor pest, was collected at both locations but was more common at Bundaberg.

Predatory dipterans collected included the empidid *Drapetis* sp., several species of Dolichopodidae which appeared more common in Bowen in the autumn crop, and several species of Syrphidae. These predatory flies may have been more common than is reflected in the survey as most of the sampling methods were inefficient in collecting them. They really required specific targeting with a sweep net.

Several tachinid parasitoids were reared from collected lepidopteran larvae. They apparently were more common at Bundaberg than at Bowen, but this may be an artefact of a difference in the frequency and size of larval collections between the two locations. As well, lepidopteran infestations, particularly of *Helicoverpa* spp., in the crop were lower at Bowen than at Bundaberg, especially in the spring planting.

Fruit flies in the family Tephritidae, particularly Queensland fruit fly, *B. tryoni*, are accepted as important pests of tomatoes and they are of special quarantine significance (eg Swaine *et al.* 1991, Hargreaves and Kay 1994). No members of the family were collected in this survey. Although fruit were collected with the aim of rearing out fruit flies, none were reared. Severe damage by lepidopteran larvae, in particular *Helicoverpa* spp., meant that very few sound fruit were produced by the plants in these crops, and it is likely that the crops and the damaged fruit were unattractive to fruit flies.

Hemiptera. Greenhouse whiteflies, *Trialeuroides vaporariorum*, were collected in low numbers in the Bundaberg crop. Since this survey, silverleaf whitefly, *Bemisia tabaci* biotype B, also has been found on tomatoes at both Bowen and Bundaberg.

Aphids were common at both locations with *Aphis gossypii* and *Myzus persicae* the most common species. *M. persicae* was not found in the autumn crop at Bowen but it was common in the spring crop. The potato aphid, *Macrosiphum euphorbiae*, was not recorded.

A number of Auchenorrhyncha, particularly in the families Cicadellidae, Cixiidae and Delphacidae were collected. The vegetable leafhopper, *Austroasca viridigrisea*, was common. *Orosius argentatus*, the vector of the tomato big bud causal agent, was collected in low numbers in the spring crop at Bundaberg but not in the autumn. Delphacids were remarkably seasonal, common in autumn but rare in spring. Osmelak and Fletcher (1988) sampled auchenorrhynchous insects in processing tomatoes in Victoria over five years using light and suction traps. They recorded more species than were collected in this survey, and while some species are common to both surveys there are many differences. They point out that there was considerable variation in the activity levels of each species from year to year, so a one year survey such as ours may not record all species.

Several plant feeding mirids were quite common. The tomato mirid, *Nesidiocoris tenuis*, was common in the autumn crop at both locations and it was present in the spring crop at Bundaberg. The presence of nymphs indicated breeding. Smith (1958) reported that feeding by *N. tenuis* caused swellings on young stems.

The plant feeding pentatomids *Nezara viridula* and *Plautis affinis* were common in both seasons at both locations. They are capable of causing considerable damage to tomato crops.

Several species from the family Anthocoridae were collected in both seasons at Bundaberg and in the autumn crop at Bowen. Yardim and Edwards (1998) considered anthocorids as important predators in tomatoes in Ohio, and van den Berg and Cock (1993) reported anthocorid bugs and ants as the predominant predators of heliothis eggs in cotton in Kenya.

Other predatory bugs recorded in this survey included *Geocoris lubra*, *Campylomma liebknechti* which is also a plant feeder and was common, *Deraeocoris signatus* (quite common), *Tytthus mundulus* (common at Bowen in the spring crop), two pentatomids, and several species of Reduviidae. Damsel bugs, *Nabis kinbergii*, were quite common at Bundaberg, particularly in the spring crop, but were not found at Bowen. All of these insects are reported as predators in other crops eg cotton by Bishop and Blood (1977) and Pyke and Brown (1996); potatoes by Cantrell *et al.* (1983).

Hymenoptera. A number of species of ants were recorded at each location. van den Berg and Cock (1993) regarded ants as important predators in cotton in Kenya, but their role in cotton in Australia is poorly understood (Pyke and Brown 1996). Their role and importance as predators in tomatoes in Queensland is not known, but during this survey they were observed attacking large *Helicoverpa* spp. and *Chrysodeixis* spp. larvae that had fallen to the ground.

Compared to the many parasitic wasps collected from potato crops in the Lockyer Valley by Cantrell *et al.* (1983) relatively few were taken in this survey in tomatoes. As well, identification of some of the microhymenoptera has proved difficult.

Wasps were reared from some hosts and these associations are given in Table 2. *Microplitis* sp. and *Heteropelma scaposum* were reared from larvae of *Helicoverpa* spp. and several other known *Helicoverpa* parasitoids in the family Ichneumonidae (Room 1979, Pyke and Brown 1996) were collected. Parasitism of *Chrysodeixis* spp. larvae by *Copidosoma ?floridanum* was quite high at both locations. Although the three introduced parasitoids of *Phthorimaea operculella* (ie *Apanteles subandinus*, *Orgilus lepidus*, and *Copidosoma desantisi*) have been reared from *P. operculella* larvae in tomatoes, potatoes, eggplant and weeds at Bundaberg (P. Horne pers. comm., P. Timson-Farrell pers. comm., Kay unpub. data) only *A. subandinus* was reared from larvae in this survey, and no adults were collected by any of the other sampling methods. *P. operculella* larval samples for parasitoid collections were not taken at Bowen and apparently nothing is known of the parasitoids in that area.

Trichogrammatids are common parasitoids of *Helicoverpa* spp. eggs at both locations. While it is known that several species of each of the genera *Trichogramma* and *Trichogrammatoidea* occur at each location we did not attempt to determine the species in this survey. Identification of trichogrammatids to species is difficult particularly with dried specimens (B. Scholz pers. comm.).

Lepidoptera. Beet webworm, *Hymenia recurvalis*, was the only lepidopteran recorded that was not reared from an immature stage on tomatoes. It is not a pest of tomatoes although adults frequently are seen around crops.

All the other species are known common pests of tomatoes (Smith 1958, Smith 1977, Hargreaves and Kay 1994). *Agrotis* spp., cutworms, are sporadic pests so their absence at Bowen during this survey does not mean that they do not occur there. Kay (1989) reported the seasonal history of *Helicoverpa* spp. at Bowen, and that at Bundaberg is given elsewhere in this report. *Sceliodes cordalis*, eggfruit caterpillar, is known to attack tomatoes but it was not recorded in this survey.

Thysanoptera. Tomato thrips, *Frankliniella schultzei*, were recorded at both locations, but not in the spring crop at Bundaberg indicating a seasonal pattern of occurrence there. Onion thrips, *Thrips tabaci*, were common at Bundaberg but were not found at Bowen. The record of a single individual of western flower thrips, *Frankliniella occidentalis*, at Bundaberg is strange. An infestation of western flower thrips occurred in a flower nursery at Bundaberg in early 1996 but there have been no other records of the insect in the district since.

Few mites were collected during this survey. The two common pest species, tomato russet mite (*Aculops lycopersici*) and two-spotted mite (*Tetranychus urticae*), were recorded and they occurred in large numbers. The paucity of other species may have been due simply to their absence, or to the possible inefficiency of the sampling methods in collecting them.

Fifty-eight species of spiders in 16 families were collected at Bundaberg, and 28 species in 12 families were collected at Bowen. The spider collection data indicate that a much greater diversity of spiders occurred at Bundaberg than at Bowen but, as with the insects, some caution should be exercised in interpreting these data, particularly because of the difficulties with the whole plant bag traps at Bowen. However there are some clear differences in the species present in each location and in the numbers collected and it is likely that these differences are real.

The spiders collected had a variety of prey capture techniques including hunting on the ground (eg Gnaphosidae, Lycosidae, and Pisauridae), hunting on foliage (eg Clubionidae, Oxyopidae, Salticidae, Thomisidae), and web building (eg Araneidae, Linyphiidae, Tetragnathidae and Theriidae) (Green 1996). This diversity would be important for their effectiveness as predators in the crop. The web building spiders were much more numerous at Bundaberg than at Bowen, possibly because the trellised plants provided a better habitat for them than did the plants on the ground. Spiders in the families Clubionidae, Linyphiidae and Theriidae were most numerous at Bundaberg while members of Oxyopidae and Lycosidae were the most numerous spiders at Bowen.

Bishop (1980) sampled the spider fauna in cotton fields at two locations in south-east Queensland and recorded a total of 25 species in 10 families. Three species, a clubionid and two theridiids, made up 80-86% of the specimens collected. The spider fauna in tomatoes appears comparable with or a little richer than that in cotton. The two crops are reasonably close in physical structure so the habitats provided by each are not too dissimilar. Green (1996) recorded over 150 species from 21 families in

citrus orchards in south-east Queensland. Spider habitats in a citrus orchard are varied and diverse in comparison to those in a tomato or cotton crop and this is reflected in the greater number of species found in the orchards.

Spiders are regarded as generalist predators. Nyffeler *et al.* (1994) reviewed the feeding patterns of 10 families which are the most abundant spider predators in agroecosystems. Common prey included flies, aphids, small hemipterans, wasps, small beetles, springtails (Collembola), ants, and other spiders, but few lepidopteran insects. They concluded that " there is evidence that spiders may play an important role as mortality agents of certain crop pests of small body size such as aphids (Aphididae), leafhoppers (Cicadellidae), planthoppers (Delphacidae), and fleahoppers (Miridae) in fields where little or no insecticide is used." Riechert and Lawrence (1997) reported that spiders significantly limited increases in numbers of phytophagous homopterans, coleopterans and dipterans in a field in Tennessee. Various spiders are credited with predating on *Helicoverpa* spp. in cotton (Room 1979, Pyke and Brown 1996). The exact role and importance of spiders in tomato fields in Queensland is not known but numerous small insects of the types described by Nyfeller *et al.* (1994) and psocids are found in unsprayed tomatoes and they probably provide the bulk of the spiders' prey.

Many of the insects recorded in this survey are predators also and most of these probably are generalist predators. Some have been mentioned in the discussion already. Their exact role and their prey in tomatoes is not known. Even in Australian cotton where detailed research has been conducted for many years the role of predatory insects still is little known. Most emphasis usually is placed on the influence of the predators on the major pests which are *Helicoverpa* spp. in both cotton and tomatoes.

Bishop and Blood (1977) listed 19 species of predatory insects from south-east Queensland cotton. Room (1979) considered more than half of the 500 species of insects and spiders he found in Australian cotton fields were predacious to some extent. He suggested that at least 19 species of insects were predators of *Helicoverpa* spp. and provided evidence from radio-tracer studies and laboratory feeding studies that these insects fed on *Helicoverpa* spp.. The role of predators is promoted in extension type publications eg Pyke and Brown (1996). However Dillon *et al.* (1992) showed that predation is a relatively minor component of the mortality in *Helicoverpa* eggs in Australian cotton. Stanley and Gregg (1994) argue that little is really known about the effect of predators in Australian cotton, and they provide data that indicate that predator numbers are positively correlated with numbers of leafhoppers rather than with numbers of *Helicoverpa* eggs or larvae. They say that there is no conclusive evidence that the predator complexes can regulate *Helicoverpa* populations to economic thresholds, but they emphasise that does not mean that the predators are of no benefit in cotton pest management.

In the absence of any detailed research in tomatoes in Queensland on predators, their associations, interactions and role it is reasonable to argue that the cotton model would not be too dissimilar to that in tomatoes. Hence, rather than being a major factor in regulating populations of the major pests of tomatoes, *Helicoverpa* spp., the predators in tomato crops may be more closely associated with leafhoppers and other

small, soft-bodied insects. Their interactions with the other important pest, *P. operculella*, are unknown.

Use of a variety of sampling techniques ensured that the greatest possible range of arthropods was collected. Some species (eg *Campylomma liebknechti*) were taken with many of the techniques, while others (eg *Labidura* sp. and *Nala lividipes*) were collected by one method only. The best method to use to sample insects or spiders in any research on tomatoes would depend on the target species, and the information gathered in this study will aid in the selection of an appropriate technique. The suction trap and the whole plant bag trap collected a wide array of species of insects and spiders, and either would be a reasonable sampling tool for obtaining a broad view of the fauna in a crop. Pitfall traps are essential for sampling ground dwelling species.

4.2 *Helicoverpa* studies

Discussion on the heliothis studies is combined rather than separated into its component parts as the parts interact to explain the population dynamics of the insects.

A single pheromone trap was monitored for each species in this study rather than a grid of traps around the district. The use of single traps somewhat limits the value of the collection data compared with data collected from a grid. The location of the traps in relation to nearby crops may have influenced the catches. However it is considered that the results are useful in indicating the activity of *Helicoverpa* spp. and that they provide a reasonable indication of the situation in the district. More detailed monitoring was not warranted for the aims of the study. The purpose of the traps was to provide a measure of occurrence of the two species. Pheromone traps do not provide a good measure of the relative abundance of the two species and nor do they give a good prediction of egg densities on crops (Fitt *et al.* 1984). This latter point is demonstrated in this study as the relative abundance of eggs of the two species clearly differs from that indicated by the numbers of moths caught.

The egg collection method was an effective way to measure the occurrence and abundance of the two species on tomatoes. Care was taken to minimise any variation in collecting methods so that results were comparable between sampling dates, and from year to year. Particular care was taken to maximise the time between the previous insecticide spray on the crop and the collection of eggs as the higher level of insecticide resistance in *H. armigera* compared to *H. punctigera* could have biased collection data towards higher proportions of *H. armigera*. In all cases all eggs collected were younger than the time since the previous spray so they would not have been sprayed, and eggs were removed from the leaf discs before being placed on the diet so the neonates would not contact spray deposits on the leaf discs. There is a maximum number of eggs that can be collected per unit time due to handling time, and this value is around 400-450 eggs per hour. The method still provides a good indication of relative abundance.

Two techniques were used to study diapause in *H. armigera*. The eyespot retention studies showed that a proportion of *H. armigera* developing in March to May entered

diapause. The results indicate that the proportion fluctuated between years with a high percentage entering diapause in 1997 but a much lower percentage in 1998. The differences between the two years are cause for concern.

Diapause in *H. armigera* is induced mainly by the egg and larval stages experiencing reducing photoperiods down to a critical level, moderated by temperature (Komarova 1959, Roome 1979). Hence it could be expected that the proportion of the population entering diapause would be reasonably constant from year to year, as daylengths are the same. Table 13 shows that mean temperatures in the critical months were similar in 1997 and 1998, although the mean minimum in April 1997 was 3°C cooler than in 1998. This may have had some influence on the proportion of pupae developing during April entering diapause. There could be some variation as daily temperatures can be quite variable and their influence could be important.

Table 13
Mean monthly maximum and minimum temperatures (°C) measured at the Bureau of Sugar Experiment Station, Bundaberg, for 1996, 1997, and 1998.

Month	1996		1997		1998	
	Max	Min	Max	Min	Max	Min
January	30	22	29	19	28	22
February	31	20	30	21	32	22
March	29	19	28	19	29	19
April	28	17	27	15	28	18
May	25	15	25	14	24	14
June	24	11	22	10	23	11
July	22	8	23	10	23	11
August	23	10	23	9	24	13
September	26	12	26	14	25	16
October	26	15	26	16	27	16
November	28	18	29	20	27	17
December	30	20	31	22	29	20

However what is of particular concern is the great difference in diapause indicated by the eyespot method and the field cages in 1998. The field cage method does not give an accurate figure for the percentage of pupae in diapause as differences in mortality rates between diapause and non-diapause pupae cannot be estimated. However the number of moths emerging from diapause pupae compared to the initial number of larvae/pupae in the cage gives an estimate of the minimum level of diapause. For example, in 1998 collections on 1 April, 16 April, and 23 April resulted in 27, 27, and 35 moths emerging from diapause pupae respectively out of the initial 40 pupae in each cage. This indicates minimum diapause levels of 68%, 68%, and 88% compared to the levels of 15%, 20%, and 35% shown by the eyespot method (Table 6). Why this difference? The reasons are not known. High temperatures experienced soon after pupation can affect diapause induction in some *Heliothis* species (Phillips and Newsom 1966), and possibly pupae retained for eyespot examination in 1998 were exposed to high temperatures at a critical stage somehow. This discrepancy places some doubt on the validity of the eyespot technique in determining the proportion of

pupae entering diapause, particularly in 1998. It has been used successfully by Kay (1982) and Wilson *et al.* (1979). D. Murray (pers. comm.) has criticised its use to determine moth emergence dates. It would seem reasonable to accept the 1997 eyespot results, which show that up to 88% of pupae entered diapause, as they are supported by field results. It is likely that much higher levels of diapause occurred in 1998 than are indicated by the eyespot results.

The levels of diapause reported here are lower than the levels of 62–100% reported on the Darling Downs by Kay (1982) and the 87–100% reported in the Namoi Valley of New South Wales by Wilson *et al.* (1979). It is likely that the proportion of pupae entering diapause would fall from south to north.

Non-diapausing pupae developed more slowly the later in the year they pupated, due to the cooler temperatures they experienced, in both the eyespot and field cage methods. They emerged throughout the winter months, so explaining the presence of moths and eggs on tomatoes in the field during the winter. Diapausing insects spent considerable periods as pupae (see Tables 4, 5, 6). In general, those from earlier collections had a longer means pupal period than those from later collections, so that emergence from diapause tends to be coordinated.

H. armigera moths emerged from diapause around mid to late September. On the Darling Downs, Murray (1991) reported that *H. armigera* moths eclosed from diapause pupae in field cages in late September – early November. Duffield (1998) reported that most diapausing *H. armigera* emerged in the first two weeks of November in the Riverina area of New South Wales.

Can the observed patterns of occurrence and abundance of *Helicoverpa* species at Bundaberg be explained? The pheromone trap records and the egg collection data together produce a pattern of species occurrence. *H. punctigera* is absent from about April to late August-September. In 1997 and 1998 it was the dominant species in September-October and in 1996 it was equal in numbers to *H. armigera*. Numbers of *H. punctigera* decline in the early months of the year, and *H. armigera* then dominates. *H. armigera* is present all year. Both trap and egg collection data indicated low numbers in winter, increases in spring (August-September), and high numbers in summer, with a peak in abundance in late March-April. These patterns of abundance complement and conform to those reported in southern Queensland and New South Wales (Zalucki *et al.* 1986) and north Queensland (Kay 1989, Titmarsh *et al.* 1990).

It is generally accepted that *H. punctigera* migrates into eastern areas each spring from breeding areas in inland Australia (Gregg *et al.* 1995). This migration probably is the source of the *H. punctigera* that appear at Bundaberg in spring each year. For example, in 1997 westerly winds provided great conditions for migration of *H. punctigera* from south-west Queensland to Bundaberg on the nights of 5-9 September (W. Rochester pers. comm.). The pheromone trap data (Figure 1b) shows *H. punctigera* appearing in the traps cleared on 12 September. In 1998 *H. punctigera* (and *H. armigera*) arrived on the Darling Downs (D. Murray pers. comm.) and at Bundaberg in early October.

W. Rochester (http://pest.cpitt.uq.edu.au) has prepared a model to predict *Helicoverpa* generational times. Using the 1996 *H. punctigera* pheromone trap catches, with 27 September as the start date for moths, the model predicts the next generation of moths on 19 November. The peak catch in the trap occurred on 22 November (Figure 1a). The pheromone trap caught no more moths so predictions of future generations could not be assessed. In 1997 using 12 September as the start date the model predicts 11 November as the next generation date. There is a small peak then in the trap catch (Figure 1b) but the relationship is confused by earlier peaks, possibly from further migration events. The model and the egg collection data indicate that four generations of *H. punctigera* develop on tomatoes at Bundaberg during summer. The predicted generational dates and the corresponding dates shown by the collection data in Figure 4 are given in Table 14. The first peak of *H. punctigera* eggs is taken as the starting point in each year. The relationship between predicted and observed dates is quite good, although the extra observed peak of eggs in early October 1997 adds some confusion.

Table 14
Predicted and observed generation dates of *H. punctigera* eggs.

Dates in 1996/1997 season		Dates in 1997/1998 season	
Predicted	Observed	Predicted	Observed
26 Sept 1996	26 Sept 1996	13 August 1997	13 August 1997
19 Nov 1996	12-28 Nov 1996	26 Oct 1997	22 Oct 1997
31 Dec 1996	<8 Jan 1997	11 Dec 1997	3 Dec
7 Feb 1997	12 Feb 1997	20 Jan 1998	no coll.
19 March 1997	26 March	27 Feb 1998	28 Feb1998

The occurrence and abundance of *H. armigera*.can be explained also. The diapause studies demonstrated that quite a high percentage (up to 88%) of *H. armigera* developing during late March to May enter pupal diapause. This helps to explain the fall in numbers during autumn. However some continue to develop, albeit more slowly due to the lower temperatures, and *H. armigera* is recorded on crops and in traps during the winter months. *H. armigera* moths emerge from diapausing pupae in late August-late September into October, which explains the increase in pheromone trap catches and egg collections then. It is probable that some migration of *H. armigera* from western areas also occurs then, and this particularly was the case in October 1998.

H. armigera becomes the dominant species during summer, in keeping with its pattern elsewhere (Zalucki *et al.* 1986). Small peaks of moths and eggs were recorded in summer and autumn each year, with a very large peak in late March-early April in each year. Studies of potential migration showed that egg counts in tomatoes during summer and autumn are significantly higher following nights on which winds favour migration from cropping areas to the west (Rochester and Zalucki 1998, W. Rochester pers. comm.). For example, in 1997 there was high potential (in terms of wind patterns) for migration from Biloela and Dalby to Bundaberg on 24 and 25 March, and from Dalby, Goondiwindi and Narrabri on 6-8 April (W. Rochester pers. comm.). Pheromone catches and egg counts peaked at this time (Figures 1b, 2b). Similarly, in

1998 there was high potential for migration from the Darling Downs on the nights of 6-8 March (W. Rochester pers. comm.), and trap catches and egg numbers increased markedly just after this (Figures 1c, 2c).

Hence it appears that the *H. armigera* population at Bundaberg is made up of a local component supplemented by immigrants from cropping areas to the north- and south-west. These immigrants are likely to pay an important role in determining the insecticide resistance status of *H. armigera* in the Bundaberg district.

The generational time model using early spring peaks of moths or eggs as start dates did not give good predictions of generational peaks. Presumably this was because the combination of the local population and immigrants resulted in overlapping generations and unpredictable peaks in numbers.

These studies add to the knowledge of *Helicoverpa* species population dynamics. The knowledge will be useful in determining management strategies for these key pests.

4.3 *Phthorimaea operculella* studies

4.3.1 Occurrence in crops

The results of the vertical strata sampling of tomato plants clearly indicates that a large percentage of the larvae occur close to the ground. The *P. operculella* population in this trial was quite high. Very few larvae or mines were found in the top third of the plants. This result was expected as it generally is accepted that infestations are worst low on the plants, but it was necessary to document this formally. The result confirms that sampling for *P. operculella* larvae, whether for experimental purposes or as part of a crop monitoring program, should be concentrated in the lower section of trellised plants. Similarly, insecticide sprays against *P. operculella* should be targeted at the lower two thirds of the plants.

It is very obvious from the pheromone trapping and larval sampling that much higher populations of *P. operculella* occur in spring tomato crops than in autumn crops at Bundaberg. This seasonal difference was recorded in the two seasons in 1996 and in the 1997-1998 seasons, and it has been noted previously (Hall 1996).

Pheromone trap catches in the 1996 autumn crop show three peaks of moth catch, each separated by three to four weeks (ie about a generation time) (Figure 3). The first peak occurred about four weeks after the crop was planted, time for a generation to develop from initial migrants early in the crop life. Immigrant moths could not be separated from those that developed in the crop so interpretation of the data is difficult. It appears that three generations developed in the crop, with time available for a partial fourth generation.

The pheromone trap and larval collection data for the 1998 autumn crop also are difficult to interpret. Few moths were trapped in the first five weeks, but a large catch was recorded on 21 April, possibly due to an immigration event, although some fourth instar larvae had been recorded two weeks previously (Figure 8). There were three peaks in the total number of larvae, and three clear peaks in numbers of first instar

larvae (Figure 9; 21-28 April, 19 May, 9 June) can be seen following the adult peak on 21 April. The presence of fourth instar larvae on 7 and 14 April shows that a generation had developed by then. That presence, and the three peaks of first instars after that indicate that three to four generations developed in the crop. Larvae of all instars were present together indicating that generations were not distinct but overlapped considerably. This was obvious in all the crops where larval sampling was done and it would be expected as moths were constantly present.

The data from the 1996 spring crop (Figures 5 and 6) are difficult to interpret as moderate to very high numbers of moths were caught throughout the crop life, and larvae of all size groups were present concurrently.

The 1997 spring crop pheromone catches are shown in Figure 6. Moths were caught from planting on, and catches generally increased as the crop developed. The large number of moths caught indicate a large population. Two peaks in moth numbers are apparent, and they appear to represent generation peaks. The first peak in mid October probably represents a generation that developed within the crop from immigrants early in the crop's life. The generation time in spring is about four to five weeks. The second peak, in mid to late November, is a further generation time after the first and clearly indicates the following generation. Moths were always present in the crop and immigration may have occurred throughout the life of the crop so generations are not distinct. Three peaks of total larval numbers are obvious in Figure 7, in early October, late October, and late November, indicating that three generations of larvae developed in the crop. The times between peaks are about a generation time. The larval sampling shows that larvae of all instars were present for most of the crop life ie moths were constantly ovipositing and generations overlapped. It also shows that three generations of larvae could develop during the life of the crop. For example second instar larvae peaked in early October (from eggs laid early in the crop), in late October, and again in mid-late November. Similarly third instar numbers peaked in early October and in late October. The third peak, expected in late November was lost when mites killed the lower leaves in which the larvae were mining. The peaks in first instar numbers recorded in late October and late November correlate well with the peaks in moth numbers recorded in pheromone traps. They are about a week later, the approximate development period for eggs. It is probable that these late November larvae would develop to moths in normal crops. A miticide-treated crop would last for several weeks longer than this experimental planting, and *P. operculella* are known to emerge from crop residues for many weeks after plants are desiccated and slashed. This sampling gives a good picture of *P. operculella* population development in a spring crop, although the experimental conditions of no insecticides and miticides meant that some information was lost at the end of the crop's life.

Larvae of all ages (and presumably pupae in their sites) were present in leaves at the end of the crop life in all the crops monitored. Baynes (1996) found that large numbers of *P. operculella* moths emerged from an old crop of tomatoes for up to 34 days after the crop had been sprayed with a desiccant and slashed. Hence there is evidence that the immature *P. operculella* present at the end of the crop life will continue to develop to the adult stage when they can move to and infest new crops. This is further evidence for the importance of god crop hygiene and the rapid destruction of old crops as key components of the management system for *P. operculella* in tomatoes (Baynes 1996, Hall 1996, Kay and Hall 1998, Grbin 1999).

4.3.2 Parasitism

Very low levels of parasitism of *P. operculella* larvae were recorded in this study, and only *A. subandinus* was found. Franzmann (1980) reported high incidences of parasitism by *A. subandinus* of larvae in potatoes and tobacco in 1976. P. Timson-Farrell (pers. comm.) studied parasitism levels in unsprayed, "IPM", and high chemical use tomato crops in 1993-4. He recorded parasitoids (mainly *Orgilus lepidus* Muesebeck, but also *Copidosoma desantisi* Annecke and Mynhardt) only in the unsprayed crop where the overall parasitism level was 15%. However he also recorded high levels of parasitism in several larval collections from eggplant. Both *O. lepidus* and *A. subandinus* were recorded from *P. operculella* larval collections in potatoes in 1994 (P. Horne and Kay unpub. data). Grbin (1999) recorded low levels of parasitism of *P. operculella* in weeds by *A. subandinus*. Hence, while *P. operculella* parasitoids are present and active in other crops and in weeds, it seems that parasitism levels in tomatoes are comparatively low. It would be interesting to know why. It is unlikely that the use of fungicides and copper hydroxide on the experimental crops would have adversely affected the parasitoids as adult *O. lepidus* and *C. desantisi* are not killed by these chemicals (Kay unpub. data).

4.3.3 Are capsicums a host?

The results of the capsicum work are clear. The evidence strongly indicates that capsicum leaves and growing points are not suitable host material for *P. operculella.*

4.3.4 Insecticides

The results from Trial 1 showed that imidacloprid and ROY 2390 (an insect growth regulator from Bayer) were not effective against 0 day larvae that had to move over and tunnel into treated leaves, and nor were they effective against 2 day old larvae already in mines in the leaves.

Spinosad, abamectin and sulprofos all were reasonably effective against 0 day larvae in Trial 1. There were no significant differences ($P>0.05$) between any of the treatments for numbers of 2 day larvae, despite apparently large differences in the means as there were considerable variations between replicates in counts of live 2 day larvae in the sulprofos, abamectin and spinosad treatments.

In Trial 2 there were significantly fewer ($P<0.05$) live 0 day larvae in all four insecticide treatments compared to the check. Spinosad, sulprofos and abamectin will kill exposed neonate *P. operculella* larvae. However only abamectin (at both rates) had significantly fewer ($P<0.05$) live 2 day larvae than the check. (Again there was considerable variation in larval survival between replicates of abamectin at the lower rate.)

P. operculella eggs are laid in protected positions, often in cracks or crevices, on the underside of leaves, where leaves and fruit touch and overlap, and under the calyx on fruit. It is difficult for a spray to penetrate and contact these positions. The newly hatched larvae quickly tunnel into the plant and mine within it. Larvae feeding within

the plant tissue are protected from direct exposure to sprays. Hence for an insecticide to be effective it must be able to kill larvae in mines. Of the insecticides tested only abamectin showed evidence of doing this, although even it produced some variable results. Further testing of abamectin, particularly at the higher rate, against *P. operculella* in the field would be worthwhile.

This pot technique for rapidly testing candidate insecticides against *P. operculella* is useful. It is quick and inexpensive compared with a field trial. It allows the insecticide to be tested against the insect in the absence of complicating factors such as high pest pressure and inefficient spray coverage that can affect the outcome of field trials. The results do give a good indication of the insecticide's efficacy in the field (Kay unpub. data).

4.4 *Trichogramma* studies

4.4.1 Assessing natural infestations

Trichogrammatid parasitoids of *Helicoverpa* occur naturally in the Bundaberg district. Sampling in unsprayed crops showed that high levels of egg parasitism developed as the crops grew, and that parasitoids were present in crops quite early in the crop life, ie at early flowering. Despite this parasitoid activity many *Helicoverpa* eggs escape being parasitised and the resulting larvae cause considerable damage in the crops. All the unsprayed crops sampled in this study suffered high levels of damage by *Helicoverpa* spp. larvae and very few fruit were marketable. Naturally occurring parasitoids will not give effective control of *Helicoverpa* spp. in tomato crops.

Insecticides are known to affect parasitism by trichogrammatids. Scholz (1994) showed that the survival of adults of *Trichogramma carverae* and *Trichogrammatoidea bactrae* exposed to deposits on lettuce leaves of permethrin, endosulfan and methomyl was greatly reduced, and Waite (1981) reported that parasitism of *Helicoverpa* spp. eggs by *Trichogramma* sp. reached a maximum of 7% in a methomyl-treated cotton crop compared with 60% in an unsprayed crop. The comparison between the parasitism rates in the unsprayed crop and the sprayed crop in 1995 illustrates that spraying with insecticides adversely affects trichogrammatids in tomatoes, even though parasitism reached only moderate levels in the unsprayed crop. Similarly, parasitism by *T.* nr. *brassicae* fell from 45-57% to almost nothing once insecticides were used in the commercial release block in the release trial.

Sampling in the unsprayed crops in 1996 and 1997 showed that initially *Trichogramma* sp. was the main parasitoid present but that it was replaced by *Trichogrammatoidea* spp. as the crop matured. The reasons for this are not known but it appears as if the *Trichogramma* sp. was out-competed by the *Trichogrammatoidea* spp.. Perhaps *Trichogrammatoidea* spp. take longer to find and move into crops and were just later arrivals. Perhaps they are better able to search for host eggs on older crops or have a faster rate of development and greater fecundity allowing them to build to higher numbers as time progresses. Comparative studies of developmental rates, rates of increase, and parameters of host searching and parasitisation between members of the two genera would be interesting, and may help

to explain the observations. The potential for mass-rearing and release of *Trichogrammatoidea* spp. should be investigated.

4.4.2 Assessing commercial releases

The first small commercial release of *Trichogramma* was a disaster and it provides lessons on what should not be done. The aim of the grower in making the experimental release is unclear as he had no obvious intent to monitor its effectiveness. The parasitoids were released onto an old crop that had been sprayed frequently with conventional insecticides and so presumably had high levels of insecticide deposits on the leaves. These deposits may have adversely affected the survival of the newly emerged *Trichogramma* adults. The conditions under which the *Trichogramma* were stored and handled before release are not known, but possibly were not ideal, and the time of emergence was not recorded although it was expected to be soon after release. The emergence time is important. If *Trichogramma* wasps emerge before release they may be damaged by the release method. If they do not emerge for a long time after release they are subjected, as parasitised *Sitotroga* eggs, to the rigours of the weather and to predators. The grower did not know the release rate but it probably was quite low. No *Trichogramma* sp. were reared from *Helicoverpa* spp. eggs in collections up to five days after the release indicating that no parasitism resulting from the release occurred. It would be unfortunate if the potential of *Trichogramma* releases as a management tool for *Helicoverpa* spp. was judged from releases such as this, but unfortunately there is considerable risk that will occur.

The large commercial release trial conducted by BioProtection and SP Exports and monitored as part of this project was carried out with much more rigour and purpose, and it allowed a much better appraisal of the potential of *Trichogramma* releases to be made. Because of the involvement of the company rearing the *Trichogramma*, BioProtection, the *Trichogramma* were handled correctly before release, the timing was good, and comprehensive assessments of effectiveness made.

Before releases started parasitism rates in both blocks were similar (8-23%) with *T. australicum* the dominant species. As releases proceeded parasitism rates increased in the release block to about 45%, dropped for unknown reasons to 29%, and then increased again to 45-57%. Most of this parasitism was due to the released species, *T.* nr. *brassicae* while *T. australicum* contributed 2-14% and there was a small contribution from *Trichogrammatoidea* spp. and *Telenomus* sp..In the check block parasitism rates ranged from 7% to 23%, mainly due to *T. australicum*, and to *T. bactrae* on several occasions. A few *T.* nr. *brassicae* were reared from eggs in the check block, indicating that the parasitoids are capable of moving over some distance. As expected parasitism rates dropped in both blocks once standard insecticides were applied.

BioProtection used sentinel egg cards to monitor the effectiveness of the releases. These cards are small strips of paper on which a number (approximately 10) *Helicoverpa* sp. eggs are attached. The cards are stapled to tomato leaves in the field, left for several days, and then recovered and held in vials to determine if parasitoids emerge. Using this technique they reported 80-90% parasitism resulting from the releases (R. Llewellyn pers. comm.), considerably higher than the 45-57% rates in

field collected eggs. Both techniques (ie egg cards and field collected eggs) are valid and both have advantages and disadvantages. The cards allow sampling and assessment to be made when field eggs are scarce. They measure parasitism over a set time frame. They may over-estimate effective parasitism as the emergence of any parasitoids from any eggs on a card is counted as a success (ie one egg parasitised while the other nine are unparasitised is a success) and there is no measure of the actual number of eggs parasitised. The use of the field-collected egg technique allows parasitism to be assessed in the natural egg population, in eggs laid in real-life positions on the plant. It may under-estimate the rate of parasitism as further parasitisation may have occurred at later stages of egg development than the brown egg stage collected, although Scholz (pers. comm.) says that most parasitisation occurs quite early in the life of the egg. The use of field-collected eggs is difficult when numbers are low. Both techniques are useful. The cards are particularly useful in experimental assessments but field-collected eggs should be used to confirm the effectiveness of releases. The method used to assess parasitism rates should be stated when rates are quoted.

The results of the trial indicate that releases of *T.* nr. *brassicae* were successful in increasing *Helicoverpa* egg parasitism rates. However a parasitism rate of 60% would not be high enough to give acceptable control if pest population levels were high. It would be very useful if pest numbers were low to medium when it might reduce the pest numbers to below an economic threshold. Previous release trials on tomatoes have given ambivalent results (Scholz 1994), but successes have been demonstrated on a variety of tree crops (Llewellyn 1995).

Parasitism rates were the same in eggs laid on leaves and in eggs laid on flowers in the single assessment made. *Helicoverpa* larvae hatching from eggs laid on flowers are likely to feed on the flowers and cause immediate damage to the flowers resulting in loss of yield. Those on leaves may feed on the leaves, which is not of great importance, before moving to a flower or fruit. Hence it is most important that eggs on flowers are destroyed and it is important to know that the parasitoids are effective on the eggs on flowers. Eggs usually are collected from leaves when using the field-collected egg method of assessing parasitism rates. The results of this sample indicate that assessing parasitism rates of eggs on leaves gives a similar, valid measurement of parasitism of eggs on flowers. Possibly the comparison should be repeated several times to confirm the result.

The use of *Trichogramma* releases to manage *Helicoverpa* spp. in tomatoes shows promise. However further research and development of *Trichogramma* technology (species used, release methods, release rates) is needed. Releases may be useful in early crop stages and when there is low to medium pest pressure, but they are unlikely to be effective when pest pressure is high. Their use will require excellent management skills.

5.0 Technology Transfer

The main thrust of the project was to acquire information on the biology and ecology of tomato insects. Such information provides the foundation on which IPM programs are built. Often it is not directly applicable to a grower, although, for example, knowledge of which species of *Helicoverpa* is present may help in deciding which insecticide to apply.

A number of activities have been done to ensure growers and the industry are aware of the project, its aims, and the information acquired in it. These have included:

1. A large display of posters, insects, and plants describing the project and its aims was erected and manned at AgroTrend in May 1996 at Bundaberg. AgroTrend is an annual two day agricultural exhibition which attracts large numbers of growers, industry people, and the general public. The display also was exhibited as part of the Bundaberg Fruit and Vegetable Growers display at the Bundaberg Show in June 1996.
2. A poster depicting results from the project was presented at the First National Tomato Conference, Surfers Paradise, 4-7 February 1997.
3. An article, "A new look at tomato pests and predators" that described the project, its purpose and progress was published in Queensland Fruit and Vegetable News on 5 June 1997, p21.
4. Articles on the purpose and progress of the project were included in a publication on activities at Bundaberg Research Station in 1997. This 57 page booklet, "Bundaberg Research Station Review 1992-1996" was distributed to all producers in the district and more widely, and has been presented to many visitors to the Station.
5. Progress reports on the project have been presented at twice yearly meetings of the Coastal Burnett Vegetable Advisory Group during the course of the project. This group consists of QDPI staff at Bundaberg, the QHI Vegetable Program Manager, and representatives of each of the local growers organisations and their representatives to QFVG.
6. Articles based on results from the project have been published in the Bundaberg Fruit and Vegetable Growers newsletter. These articles are: "Heliothis and insecticide resistance – any worries?", *Bundaberg Region Horticultural Newsletter*, Number 32, p4, 1998: "Heliothis – when and why", *Bundaberg Region Horticultural Newsletter*, Number 23, p4, 1998; "Clean up those old tomato blocks – control leafminer", *Bundaberg Region Horticultural Newsletter*, Number 10, p4, 1996.
7. A paper based on the project activities was presented at the Sixth Australasian Applied Research Conference, Brisbane, 29 September – 2 October 1998 . The paper was: Kay, I.R. and Hall, J.L. (1998). Tomato IPM at Bundaberg. pp. 78-84. *In* :Zalucki, M.P., Drew, R.A.I. and White, G.G. (Eds.) *Pest Management – Future Challenges* – Proceedings of the Sixth Australasian Applied Entomological Research Conference, Brisbane, Australia, 29 September – 2 October 1998.
8. Progress reports have been written for inclusion in the Queensland Fruit and Vegetable Growers Research Reports.
9. Talks on the project have been given to groups of visitors to the Research Station. These have included grower groups and school groups.

6.0 Recommendations

The biology and ecology of pest and beneficial insects of tomatoes is an immense topic. This study illustrates its size by showing that the crop is home to large numbers of insects and spiders species, and by adding just a little more information to the body of knowledge on *Helicoverpa* spp., key agricultural pests, and on *P. operculella*. The study has identified numerous gaps, both large and small, in our knowledge of the biology and ecology of pest and beneficial insects in tomatoes. Filling these gaps will provide topics for numerous research, development and extension projects, and will greatly help the development of pest management in tomatoes.

The faunal survey illustrated the need for good taxonomic support to underpin such work. Good taxonomy and systematics is the base on which all entomological research should be based. Shauff and DeSalle (1998) argued strongly that systematics is of vital importance to biological control. It is of vital importance to insect pest management in general.

The faunal survey gave a broad overview of the fauna in the crop. Many more specific, detailed studies could be done to understand the insects in the crop.

The *Helicoverpa* studies provided a greater insight into the pests' occurrence at Bundaberg. *Helicoverpa* spp. are such widespread, major pests that they must be considered with a broad view. Despite this, work specific to tomatoes is necessary.

P. operculella still has had little work done on it in tomatoes. Much, much more work is needed.

Recommendations from this project include:

1. Organisations providing research (eg QDPI), industry organisations, and funding bodies should recognise the importance of insect systematics to pest management, and they should support, encourage and foster this branch of entomology.

2. Projects relating to the faunal survey that need to be researched include: (a) determining the interactions between the predators found and their prey. What do they prey on, and are they useful in regulating pest numbers? This is needed particularly with respect to *Helicoverpa* spp. and *P. operculella*; (b) Further studies on parasite – host interactions are needed; (c) Numerous smaller questions should be investigated eg which species of *Gonocephalum* occur in crops and cause damage, and how important are ants?

3. The tomato industry (and other vegetable industries) must actively maintain strong links with other industries affected by *Helicoverpa* spp., in particular the cotton and grain industries, and they should strive to manage the pests cooperatively.

4. Life-table studies of *Helicoverpa* spp. in tomatoes should be done to provide a better understanding of the ecology of the insects in the crop.

5. Further research on *P. operculella* should include studies on the effect of predators on *P. operculella* populations, whether parasitoids of *P. operculella* occur at

Bowen, why parasitism levels appear to be low in tomatoes, and whether these levels can be increased.

6. Further research and development of *Trichogramma* technology (eg species used, release systems, application rates) should be supported.

7. Any further work requires support. The industry, the research and development organisations and the funding bodies must ensure that sufficient resources are provided.

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